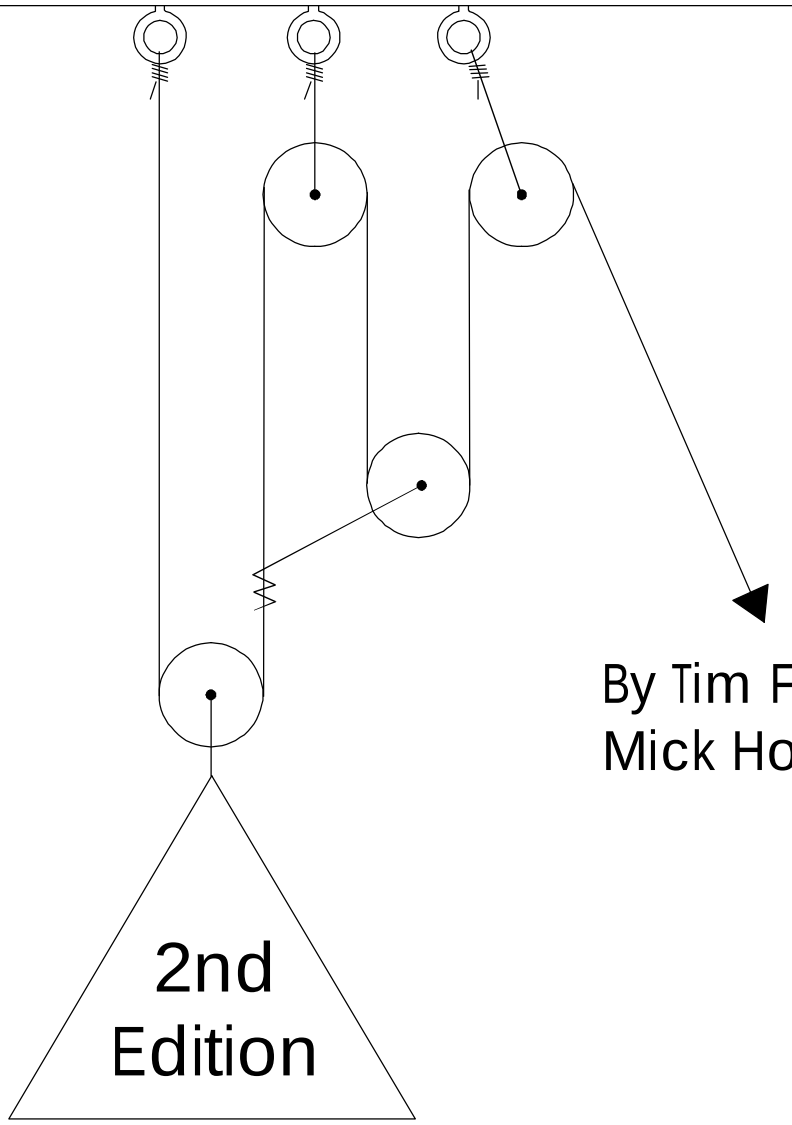
How to Calculate the Mechanical Advantage of hauling systems



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Mick Holton

2nd
Edition

Special thanks to Reed Thorne, Ropes that Rescue, Sedona, Arizona, U.S.A.

Types of Hauling Systems

There are three types of hauling systems:

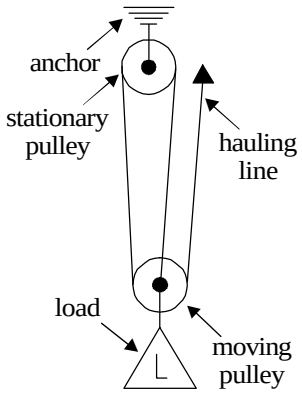


Figure 1

1. Simple Hauling Systems

A simple hauling system is when all moving pulleys are attached to the load.

2. Compound Hauling Systems

A compound hauling system is a simple hauling system that is pulling on the end of another simple hauling system.

In this example (Figure 2) the two separate systems are joined using a prussic hitch.

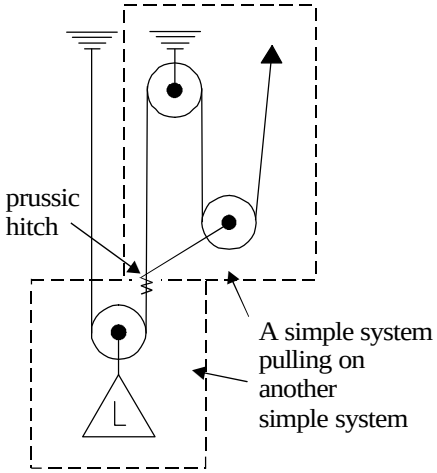


Figure 2

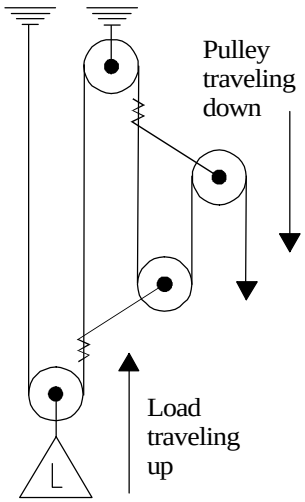


Figure 3

3. Complex Hauling Systems

A complex hauling system is created when you have a moving pulley that is traveling in the opposite direction to the load.

There are two methods that can be used to calculate the mechanical advantage of a hauling system. One is called “Counting the Lines” method and the other is called “Adding the Tensions” method.

1. Counting the Lines Method

1.1 Simple Hauling Systems

To calculate the mechanical advantage of a simple mechanical advantage hauling system using the counting the lines method all you have to do is:

✚	Starting at the hauling line, count the number lines that are attached directly to the load or attached to the pulley that is attached to the load. This will tell you the mechanical advantage of the system.

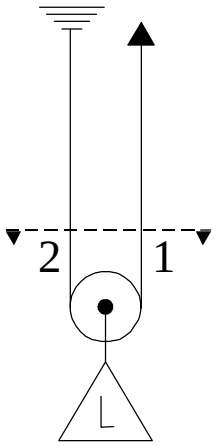


Figure 4

Cover the top half of the hauling system and count the number of lines attached to the load pulley. In this example (figure 4) the mechanical advantage is 2:1

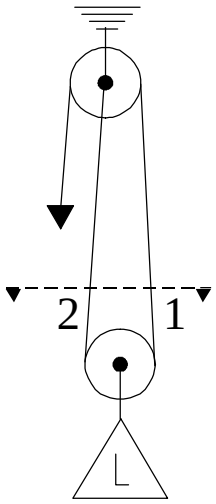
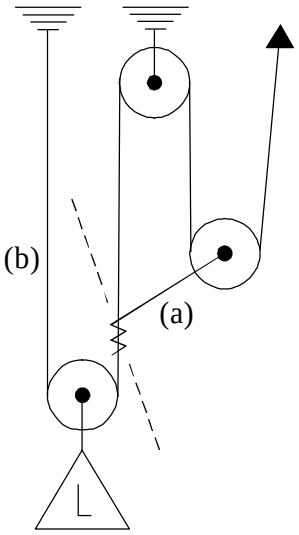


Figure 5

In this example (figure 5) the hauling line is not attached directly to the load. If you cover the top section of the hauling system you can see that only two lines are attached directly to the load pulley. The mechanical advantage of this system is still 2:1

1.2 Compound Hauling Systems

You can use the “Counting the Lines” method to calculate the mechanical advantage of compound or multiplying systems.



✚	See the example in figure 6 Draw a line at the point of attachment of the prussic hitch. This helps by keeping the two systems separate. See figure 6(a) and 6(b) Starting at the hauling line calculate the mechanical advantage as follows:

Figure 6

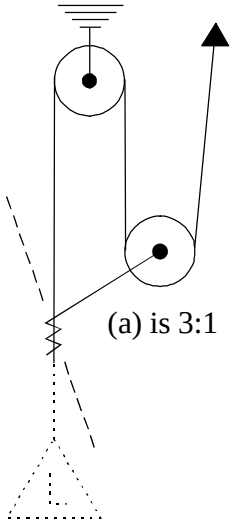


Figure 6 (a)

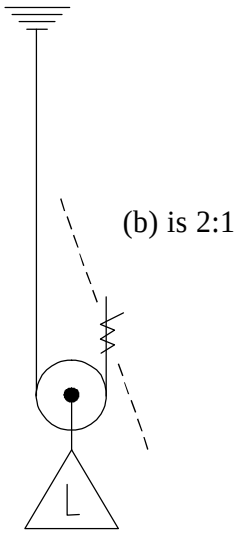


Figure 6 (b)

M.A. = (a) x (b)
= (3:1) x (2:1)
= 6:1

The mechanical advantage of the hauling system in figure 3 is 6:1

2. Adding the Tensions Method

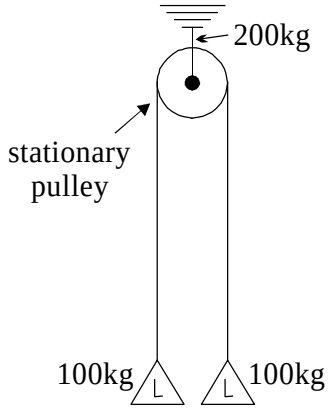


Figure 7

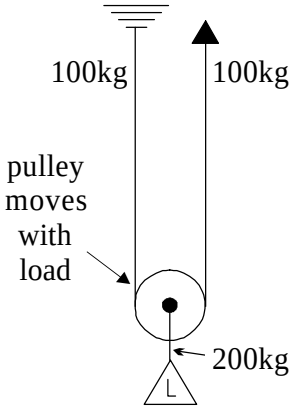
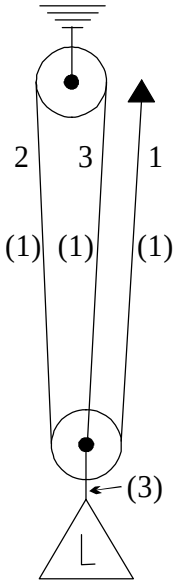


Figure 8

✚	To better understand the "Adding the Tensions" Method you will need to learn a basic principle. If a force is being applied to one side of a pulley the same force will be applied on the other side of the pulley. In simple terms if there is a 100kg load on one side of a pulley there must be another 100kg load on the other side of the pulley and there will be a 200kg load on pulley anchor. See figures 7 and 8.

2.1 Simple Hauling Systems

To calculate the mechanical advantage of a simple hauling system using the adding the tensions method, all you have to do is:



MA = 3:1

Figure 9

Look at the amount of tension on each part of the simple hauling system in figure 9. Each part is numbered 1, 2 and 3. The amount of tension is indicated by the use of brackets.

If you apply one unit of tension to the hauling line, numbered 1, there will also be one unit of tension on lines 2 and 3. This is due to the basic principle that we learned earlier.

All three lines are attached to the load pulley, therefore there is a total of three units of tension on the load.

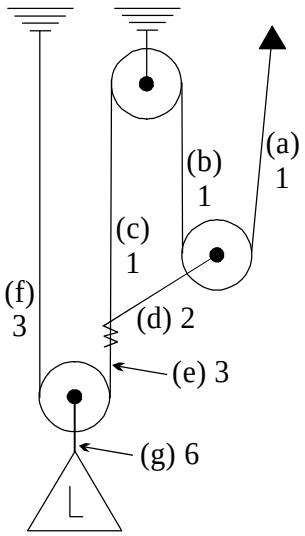
The mechanical advantage is 3:1

✚	When using the adding the tensions method you must add the tensions of all the lines that are attached to the load or the pulley that is attached to the load.

2.2 Compound Hauling Systems

To calculate the mechanical advantage of a compound or multiplying hauling system using the adding the tensions method, all you have to do is:

- Always start at the hauling line and look at the amount of tension you are applying to that part of the system. Remembering the basic principle that you learned earlier, you can now work out how many units of tension are on each part of the system.
- Using the example below (figure 10), if you apply one unit of tension to the hauling line at point (a) there will be one unit of tension at point (b) and one unit of tension at point (c).
- **Stop when you reach a prussic hitch.**
- There is one unit of tension on either side of the pulley attached to the prussic loop, therefore there must be two units of tension on the prussic loop (d).
- There is one unit of tension at point (c) and two units of tension on the prussic loop (d) therefore there are three units of tension just below the prussic loop (e).
- Remembering the basic principle again, if there are three units of tension at point (e) there must be three units of tension on the other side of the pulley at point (f).
- We now add the tensions being applied to the load pulley, (e)+(f)=(g) or 3+3 = 6. You started by applying a force of 1 to the hauling line and ended up with a force of 6 at the load pulley, therefore the mechanical advantage is 6:1.



MA = 6:1

Figure 10

IN SUMMARY

(a) is the haul line with 1 unit of force applied. (a), (b) & (c) are all subjected to the same force up until the prussic knot.

(d) is the prussic loop attaching a pulley to the main line. The force at (d) = force at (a) + force at (b)

(e) is a part of the main line, just under the prussic that is now subjected to an increased force. The force at (e) = force at (c) + force at (d)

(g) is the attachment to the load and is subjected to an even greater force. The force at (g) = force at (e) + force at (f)

The final force at (g) = 6 units when we apply a single unit of force at (a) therefore we have a 6:1 M.A.

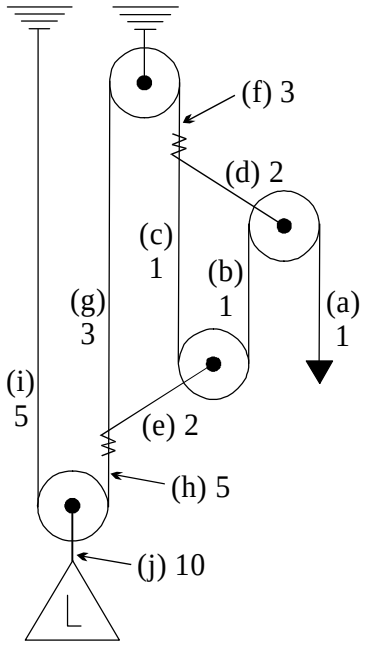
+	When using the adding the tensions method you must add the tensions of all the lines that are attached to the load or the pulley that is attached to the load. Do not include the tensions that are in the lines that are not attached to the load or load pulley.

You cannot use the “Counting the Lines” method to calculate the mechanical advantage of complex hauling systems but it is an easy calculation when using the “Adding the tensions” method.

2.3 Complex Hauling Systems

To calculate the mechanical advantage of a complex hauling system using the adding the lines method, all you have to do is:

- Always start at the hauling line and look at the amount of tension you are applying to that part of the system. Remembering the basic principle that you learned earlier, you can now work out how many units of tension are on each part of the system.
- Using the example below (figure 11), if you apply one unit of tension to the hauling line at point (a) there will be one unit of tension at point (b) and one unit of tension at point (c).
- **Stop when you reach a prussic hitch.**
- There is one unit of tension on either side of the pulley attached to prussic loop (d) therefore there must be two units of tension on the prussic loop. There is also one unit of tension on either side of the pulley attached to prussic loop (e) therefore there must be two units of tension on the prussic loop.
- There is one unit of tension at point (c) and two units of tension on prussic loop (d) therefore there are three units of tension just above the prussic loop at point (f).
- There is now 3 units of tension on the line a point (f) therefore there must also be 3 units of tension on the other side of the pulley at point (g).
- There are 3 units of tension at point (g) and 2 units of tension on prussic loop (e) so we add those tensions giving us 5 units of tension at point (h) below the prussic hitch.
- There are 5 units of tension at point (h) so there must be 5 units of tension on the other side of the pulley at point (i).
- You now add the tensions being applied to the load pulley, (i)+(h)=(j) or 5+5 = 10. You started by applying a force of 1 to the hauling line and ended up with a force of 10 at the load pulley, therefore the mechanical advantage is 10:1

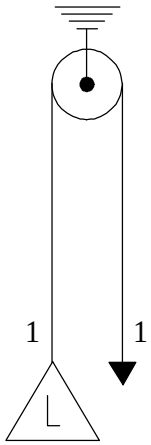


MA = 10:1

Figure 11

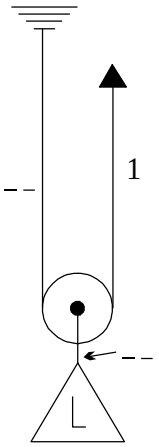
+ When using the adding the tensions method you must add the tensions of all the lines that are attached to the load or the pulley that is attached to the load.
Do not include the tensions that are in the lines that are not attached to the load or load pulley.

Test yourself with the following simple mechanical advantage hauling system examples. Fill in the blanks.



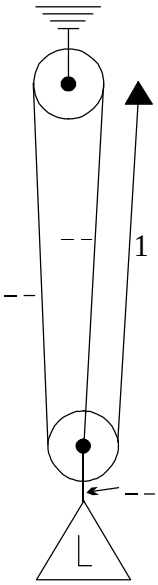
MA = _____

Figure 12



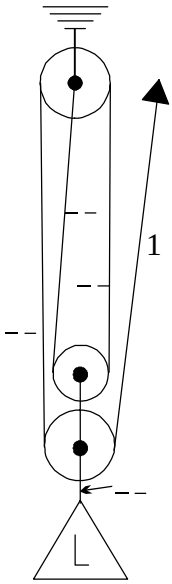
MA = _____

Figure 13



MA = _____

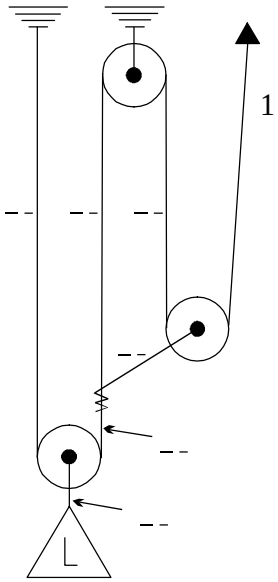
Figure 14



MA = _____

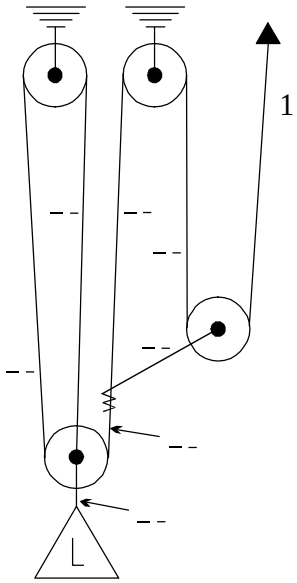
Figure 15

Test yourself with the following compound mechanical advantage hauling system examples. Fill in the blanks.



MA = _____

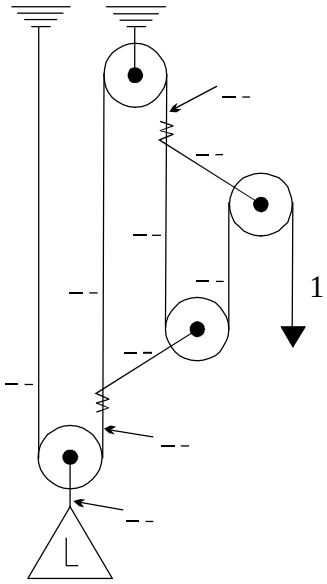
Figure 16



MA = _____

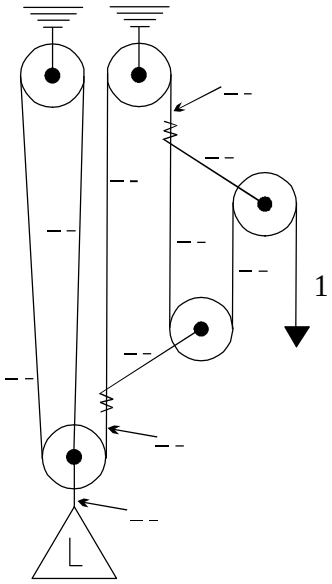
Figure 17

Test yourself with the following complex mechanical advantage hauling system examples. Fill in the blanks. Remember that you cannot use the "counting the lines" method to calculate the M.A. of these two system examples.



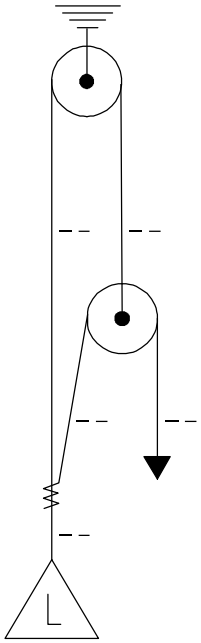
MA = _____

Figure 18



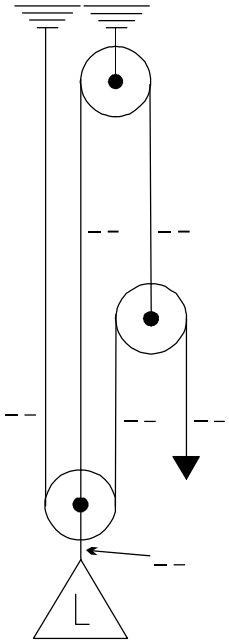
MA = _____

Figure 19



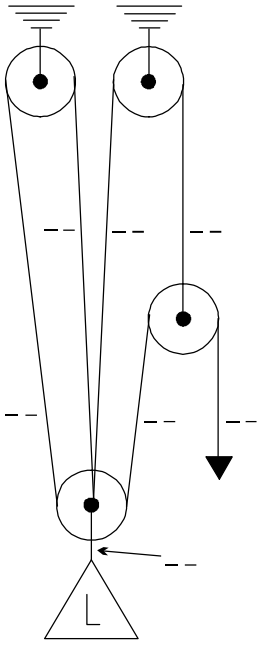
MA = _____

Figure 20



MA = _____

Figure 21



MA = _____

Figure 22

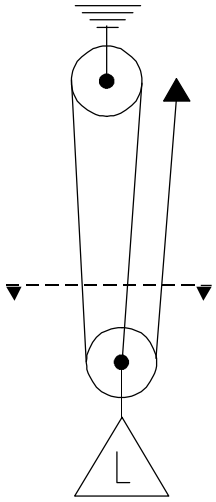
The hauling system in figure 20 is known as a Single Spanish Burton.

The hauling systems in figures 21 and 22 are known as Double Spanish Burtons, however they have different mechanical advantage ratios. Can you calculate them?

The Difference Between Advantage & Disadvantage

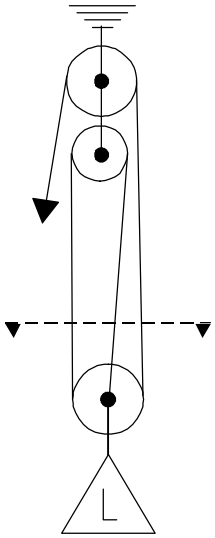
A hauling system is reeved to disadvantage when the hauling line goes through a pulley that does not add to the mechanical advantage of the system, it only adds friction.
This pulley is usually referred to as a redirection pulley. Figure 23 is a 3:1 system reeved to advantage whilst figure 24 is a 3:1 system reeved to disadvantage.

The term disadvantage means there is extra friction in the system, not necessary to achieve the mechanical advantage of the system you have built. Don't be put off using redirection pulleys, the term reeved to "disadvantage" is a technical term only. You can use redirection pulleys whenever they will make the job of the hauling party easier. There can be advantages to reeving a system to disadvantage.



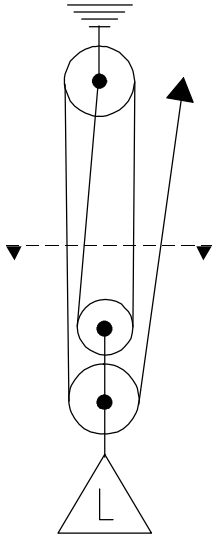
Mechanical Advantage 3:1 Reeved to Advantage

Figure 23



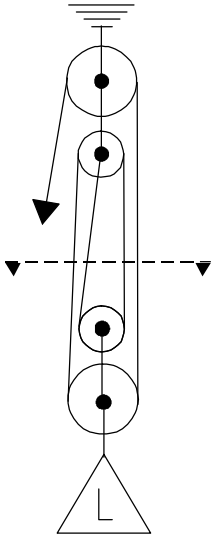
Mechanical Advantage 3:1 Reeved to Disadvantage

Figure 24



Mechanical Advantage 4:1 Reeved to Advantage

Figure 25



Mechanical Advantage 4:1 Reeved to Disadvantage

Figure 26

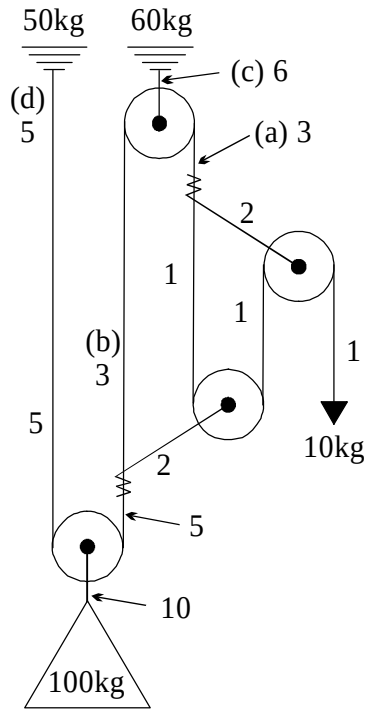
The Adding the Tensions Method can also be used to calculate the forces that are being applied to the anchors of a hauling system

To calculate the mechanical advantage of a hauling system you add the tensions that are being applied to the load, but we can also add the tensions that are being applied to the anchor or multiple anchors. Adding the tensions that are being applied to the anchors is not necessary to calculate the mechanical advantage of a hauling system but it will assist with the anchor selection process.

You need to remember that when a hauling operation is underway, the forces will increase because of friction. Friction will be present at many locations throughout the hauling system including:

- Friction between the load and the surface that the load may be contacting
- Friction between the rope and any surface that the rope may contact, this includes edge friction
- Friction that exists at every pulley as it is impossible to produce a friction free pulley
- Unwanted friction can also be generated if our hauling system twists, causing the rope to come in contact with itself. This needs to be avoided.

Below is an example showing the calculation of anchor tensions:



MA = 10:1

Figure 27

Figure 27 is an example of a hauling system with a mechanical advantage of 10:1, this has already been calculated using the adding the tensions method.

Now you can add the tensions that are being applied to the anchors.

The tension at point (a) is 3 and the tension at point (b) will also be 3 so we add those tensions to get a tension at the anchor (c) of 6.

The tension at anchor (d) will be 5 because that part of the hauling system simple terminates at that anchor and does not use another pulley.

If the load weighed 100kg, a force of 10kg would have to be applied at the hauling line to support the load. Anchor (c) would be subjected to a force of 60kg and anchor (d) would be subjected to a force of 50kg.

If you used a single anchor point by joining (c) and (d) the single anchor would be subjected to a force of 110kg.

Don't forget that once the hauling operation commences the forces will increase due to added friction.

Answers Page

Figure 12 MA = 1:1

Figure 13 MA = 2:1

Figure 14 MA = 3:1

Figure 15 MA = 4:1

Figure 16 MA = 6:1

Figure 17 MA = 9:1

Figure 18 MA = 10:1

Figure 19 MA = 15:1

Figure 20 MA = 3:1

Figure 21 MA = 4:1

Figure 22 MA = 5:1