6. Block and Tackle*

A block and tackle is a combination of pulleys and ropes often used for lifting. Pulleys grouped together in a single frame make up what is called a pulley block. The tackle refers to the rope.

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<th>Learning Objectives:</th>
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<td>1. Notice that masses moving at constant speed must be in equilibrium, Newton’s 1st law holds.</td>
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<td>2. Learn to solve problems involving ropes and pulleys.</td>
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<td>3. Practice working as part of a group to rig a complicated pulley system, which would be difficult for one person to do alone.</td>
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<td>4. Practice building a theoretical model for a physical phenomenon, e.g. friction in the bearings of a pulley.</td>
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<td>5. Apply basic concepts to analyze a block and tackle.</td>
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Reading Assignment:
Read the following sections. (Section numbers may be slightly different depending on the edition of your textbook: Check the section titles.) Study the following sections of your textbook before coming to lab. There will be a check to see that you have done this.

Knight, Jones & Field (161): 5.8 Ropes and Pulleys, 10.2 Work
Serway and Vuille (211): 5.1, Work
Serway and Jewett (251): 7.2 Work Done by a Constant Force

In the ideal situation the rope would have no mass and neither would any pulley. Further, there would be no friction. Thus the tension would be the same in the rope on either side.

This lab unit is about, mechanical advantage and efficiency. It involves work and energy. You will be part of a group working for a freight company. The problems assigned have to do with loading large objects, such as crates and barrels, onto ships. Your team sets up laboratory models of cargo handling.

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Block and tackle

PRELAB EXERCISES (Do these problems before you come to lab)

1. Find the definitions of mechanical advantage and mechanical efficiency and record them here.

2. In the figure on page 1, suppose the hand is pulling straight upward. If the pulley blocks shown both weigh 1 pound, how much force must the hand exert to lift the weight? Explain.

3. In the same case, if the weight is to be lifted five inches, how far must the hand move upward during the motion? Explain.

4. In the ideal case, how does the work done by the block and tackle in lifting the weight plus lower pulley block compare to the work done by the hand pulling the rope? Calculate both of these quantities in the case the weight goes up two inches, show your work and explain your conclusion.

Equipment: Vertical aluminum masts that anchor to the table, iron rod to go horizontally between the two vertical rods, hook for attaching upper pulley block to the horizontal rod, two pulley blocks (three pulleys each) heavy masses to lift, spring scale, meter stick, various connecting hardware. In the room there will also be a triple beam balance.

Exploration: Rig up a block and tackle using the two pulley blocks provided. (Warning: One way you might hurt yourself is if the iron bar falls. Don’t let it.)

Be extra sure the clamps holding it to the verticals are secure. Have your TA inspect this before you proceed.) To do the rigging will take at least two team members. It is best to maintain some small amount of tension in the string while rigging, so you may want to anchor the lower pulley block to a heavy object or something. When your block and tackle is rigged, you should be able to demonstrate that it will lift a heavy load. Start with around 5 kilograms.

Each team member should fiddle around with the block and tackle. Record any relevant observations here.
Problem 1: Mechanical advantage

The loading crew will use the block and tackle as a force multiplier. At issue is how much force a person has to exert on the end of the rope to lift a certain amount of weight. The ratio of weight lifted to force applied is the mechanical advantage. (However: These forces must be measured when the load is moving upward at constant speed, since that is the way the machine is used.)

1. Prediction question: In the ideal case of no friction, and including all the weight lifted by the machine as the load, what do you predict, theoretically, should be the mechanical advantage? Is this the maximum you can have using this many pulleys? It is really important to explain your reasoning here.

2. Method question: If you use the spring scale provided to measure tension in the string, what is the maximum possible precision? Also, do you figure it makes any difference what angle you hold the spring scale at when you make a measurement? What other measurement problem do you anticipate using the spring scale?

Plan: Your team needs to determine the actual mechanical advantage of your set-up. In so doing, be sure you include all the mass that is lifted as part of the load. Don’t forget anything. What do you need to measure? Write down how you are going to do this. For example, will the load be moving or stationary? Can you determine a range of possible values, hence an estimate of precision, etc.?

Implementation: Carry out your plan and record the relevant data here. Make notes and record units as appropriate.
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**Analysis:** Figure the actual mechanical advantage here and say what you can about the limits of precision. Explain showing work as needed, of course. Numbers without explanation will get you fired.

**Conclusion:** Compare the actual with the theoretical mechanical advantage.
1. Does the experimental result agree with your theoretical prediction? Probably not exactly. About how much of the discrepancy should be due to measurement limitation and how much due to another cause?

2. What other cause? Explain.
Problem 2: Effect on mechanical advantage due to friction in the pulley bearings

Of course the company wants to know how this frictional force depends on loading.

1. Prediction question: Should the pull on the end of the string be greater or less when the load is going up at constant speed, compared to when the load is standing still? How about when the load is going down at constant speed, compared to when it’s at rest? How is this all consistent with Newton’s first law?

2. Method question: What should the difference in pull on the end of the rope for going up versus going down tell you about the frictional force on the pulley bearings? Derive an equation for the friction in the pulleys based on this idea in terms of the difference in the applied forces in the two cases.

3. Prediction question: Guess the mathematical relation between the friction force and the amount of loading on the bearings. (What determines “loading” on the bearings?)

Plan: Write down your group’s measurement plan for getting the force of friction on the pulley bearings and how this will depend on the load. Describe and explain any graphical analysis you might want to make.
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Implementation: Carry out the plan; record the data with units and any relevant notes or comments here.

Analysis: Describe the mathematical analysis as you write it down and explain the result. As part of the analysis you should consider efficiency, which is a percentage determined from the work input by the hand pulling on the string divided into the work output to lift the load (including all parts of the load). Attach any appropriate graphs to the report.

Conclusion: What did you learn?
1. Did your measurements uphold your work group’s theory about how friction should depend on loading? If so, to what extent? Do the differences fall within a range consistent with measurement precision?

2. Can you suggest anything that might improve the mechanical efficiency?
Problem 3

The foreman of the loading crew says he thinks that with a strong enough rope, if he had six separate pulleys rather than pulley blocks, he could get a mechanical advantage of over 20. Is he right? As a laboratory experiment, can you get a theoretical mechanical advantage of 8 using only 3 pulleys?

1. Prediction question: Show by means of a diagram how you could use six pulleys to get a theoretical mechanical advantage of 32.

2. Method question: Can you see a safety problem with this method of rigging pulleys that is much less of a problem with the conventional block and tackle?

Plan: Taking safety into account, devise a measurement plan to see how much mechanical advantage and how much efficiency you can actually get from three separate pulleys including frictional losses. Record the plan here.
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**Implementation**: Carry out the plan, and record the data and relevant comments here.

**Analysis**: Figure out the actual mechanical advantage, with enough explanation. Separate the effects of measurement precision from frictional effects as well as you can.

**Conclusions**: What did you learn?

1. How does the mechanical advantage compare with the theoretical maximum?

2. What are the advantages and the disadvantages of using separate pulleys as compared to a block and tackle?

3. Do you think the foreman is right? Explain your reasoning.