PULLED ALONG BY THE WIND

The sail is a key part of any yacht. It harnesses the wind's energy and transforms it into kinetic energy. The better the sail, the more energy can be captured from the wind and the faster the yacht will go.

Yachts are not blown along by the wind - they are pulled along! Otherwise they would only ever be able to sail away from the wind: yachtsmen would always have to hope the wind changed direction so they could sail home again. A sail works exactly like an aeroplane wing. The wind blowing across it causes it to curve into the same shape as the top of an aeroplane wing. Air flowing across pulls the sail along in exactly the same way that air flowing across the top of an aeroplane wing pulls the wing upwards. So, a sail is really just the same as an aeroplane wing stood on its end. The sail needs to stay in the correct curved shape; if the material stretches, the sail will change shape and won't work as well.

Two things affect how much a sail might stretch:

- the stretchiness of the thread the sail is made from. You will investigate the stretchiness of several different types of thread. Which would be most suitable for a sail? Of course, there are other properties to consider as well.
- whether the thread is woven to make the sail or whether lengths and layers of thread are glued together. You will find out more about this in your follow up work.

EQUIPMENT

- selection of sewing threads (e.g. cotton, linen, nylon, polyester, viscose)
- 2 clamps and stands
- pulleys, with clamps to fasten them to the end of a bench
- metre ruler, marked in millimetres
- hanger and adjustable slotted masses (up to 1.5 kg, in units of 100 g and 50 g)
- pen or brightly coloured, thin sewing thread
- scissors
- large box containing crumpled paper
- hand lens
- balance

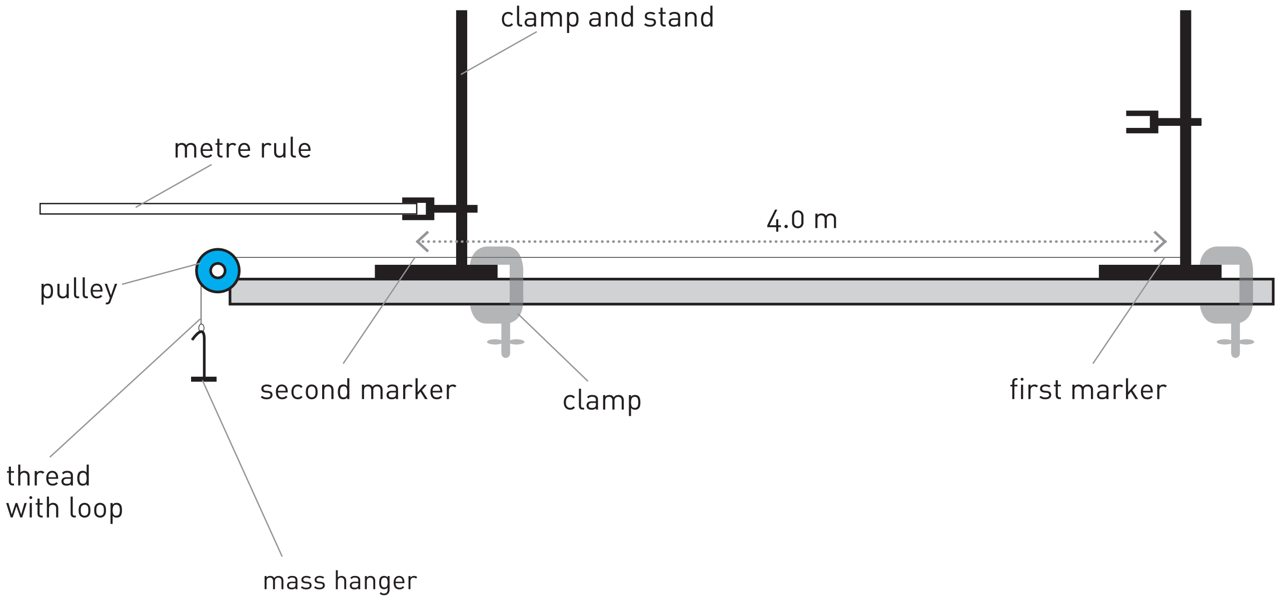
SAFETY NOTES

Take care when handling heavy masses. A box of crumpled paper, placed under the masses, will help protect feet from falling masses.

METHOD: MEASURING STRETCHINESS

1. Fasten the pulley. Clamp it to the end of the bench so that a thread passed over the pulley will hang down freely.
2. Fasten one of the clamps and stands to the bench about 4.5 metres from the pulley, so your thread can run straight along the bench from clamp to pulley.
   - If it is not possible to do this because your bench is too short, use the other pulleys to create a *path* about 4.5 m long back and forth across the bench.
3. Cut a piece of your first thread about five metres long. Take care it doesn't tangle.
4. Tie one end of the thread to the clamp and stand. Make a pen mark on the thread close to the clamp and stand.
   - Alternatively, mark the thread by tying a short length of coloured thread around it. Your teacher may discuss the advantages and disadvantages of marking the thread this way.
5. Holding the thread out straight, but not stretched, make a second mark exactly 4.0 m from the first mark.
6. Pass the other end over the pulley and tie a loop in the end so that you can hang the slotted masses from it.
   - The loop for the masses should be close to the level of the bench, to allow as much room as possible for the thread to stretch. Shorten the thread and re-tie the loop if necessary.
   - If you are using several pulleys, check that the thread slides smoothly over each pulley and the pulleys turn freely. Adjust the positions of the pulleys slightly if necessary.
7. Set up the second clamp and stand next to the second mark. Clamp a metre ruler next to, but not touching, the thread. Fix the ruler so that the 0 cm mark is next to the second mark and with the numbers increasing towards the pulley.

[not to scale]



8. Hang a 50 g mass from the loop in the end of the thread. Use the ruler to measure how much the thread stretches. Record the extension (how far the mark has moved from the 0 cm position) in the *extension (mass increasing)* column of a results table.
   - Support the slotted mass as you hang it on the thread. Then lower it **gently** so that the thread extends gradually.

type of thread:		
mass / g	extension (mass increasing) / cm	extension (mass decreasing) / cm

9. Increase the mass on the thread by 50 g. Measure the extension again. Record it in the table. [Support the slotted mass as you increase it, then lower gently as before.]
10. Keep increasing the mass on the thread, in 50 g steps. Record the extension until either:
    - you reach a mass of 1.5 kg, or
    - you think the thread is in danger of snapping.
11. Decrease the mass on the thread by 50 g. Record the new extension for this mass in the *extension (mass decreasing)* column.
    - You will already have one value for extension for this value of mass in the *extension (mass increasing column)*
12. Continue to remove masses from the thread, in 50 g steps. Record the new extension for each mass in the *extension (mass decreasing)* column.

13 Repeat Steps 3 to 12 until you have measured extensions for each of the different threads.

METHOD: MEASURING OTHER PROPERTIES

1. Use the balance to compare the weight of the different threads you used.
   - Comparing will be much easier if you weigh the same length of each thread.
   - The length you need to weigh depends on how accurately your scales can measure.
2. Find out how the weight of each type of thread changes when it is wet. To ensure your comparison is fair you must:
   - soak each thread in water for the same length of time
   - allow each thread the same length of time to dry or use the same method to dry each thread.

RESULTS

1. For each thread, plot a graph of *extension (mass increasing)* against the *mass on the thread*.
   - *extension (mass increasing)* is the dependent variable, so it goes up the *y*-axis.
   - the *mass* is the independent variable, so it goes along the *x*-axis.
2. For each graph, draw a line of best fit or a curve through the points. You may find that the first part of the graph is a straight line, and the second part (for larger masses) is a curve.
3. For each thread, decide whether or not you exceeded the thread's **elastic limit**. If you did, decide at what mass this happened.
   - If you did not exceed the elastic limit, the graph will be a straight line.
   - If you did exceed the elastic limit, the graph will start to curve at that mass.
4. Use your graphs to calculate the stretchiness of each thread. This is a measure of *how much the thread extends per unit load*. The gradient of each graph will give you the stretchiness in centimetres per gram (cm/g).
   - You must calculate the gradient using the straight line part of the graph. Choose points as far apart as possible to calculate the gradient.
   - Calculate the gradient using the formula:

$$\text{gradient} = \frac{\text{change in y}}{\text{change in x}}$$

EXPLANATIONS

1. For each mass you hung on your thread, you only took one reading of the extension. How does this affect the reliability of your results? Is there any way to spot readings that might be incorrect?
2. How could you use the graphs to tell if the thread has been permanently damaged?
3. How could you use the readings for *extension (mass decreasing)* to tell whether or not the thread has been permanently damaged?
4. Suggest some ways in which you could improve the accuracy and the reliability of this investigation.

SOME MORE QUESTIONS

The type of thread used for making a sail is important. Equally important is how the sail is made from the thread. Many years ago, sails were made by weaving thick cotton threads into a tough material called canvas. Modern sails are much lighter and much stronger.

- Find out how sails are constructed to increase their strength.
- Find out some of the ways used to describe and measure the strength of sails.
- Examine the threads with a hand lens. Is there anything, other than natural *stretchiness*, that might contribute to how much the threads extended? Explain your answer.
- The weight of each thread changed when it was wet. Would salt water have had any other effect on the thread besides changing its weight?
- Based on the measurements you made, which type of thread would be best for making sail material? Decide which properties you think are most important and come to a group decision. Be prepared to justify your choice to another group.
- Do these investigations give enough information to make a fair comparison between the threads? If not, how could you improve the investigations? What other investigations could you do, to give the information you need?
- What other properties are important in a sail material? It might help to imagine you were buying a sail: how and where you might use it? What would you want to know?

HEALTH AND SAFETY

A risk assessment must be made before starting any practical work. There is no risk of injury from snapping threads here, as there would be from snapping elastic bands, but students should be careful not to allow very taut threads to slide across their fingers as there is a small risk of cuts if they do. Nylon fishing line poses a hazard and should not be used. A box of crumpled paper, placed beneath the masses hung on the thread, will catch falling masses if the thread does snap, eliminating risk of injury to feet or fingers.

THE INVESTIGATION

Students investigate how different types of thread stretch when masses are applied to them. They then use this, together with other information such as the weight of the thread both dry and wet, to decide – and justify – which thread they would recommend for making a sail material. [The reasons for investigating thread rather than fabric are 1) that real sail materials are generally supplied pre-stretched and obtaining a range of realistic, non-pre-stretched fabrics is difficult and 2) larger masses are needed to obtain a measurable stretch for fabrics, than for threads.]

As an introductory, teacher led activity, students could attempt to find out how difficult it is to get a measurable stretch on a piece of real sail material, to indicate why they are investigating the stretch of threads rather than ready-made materials. To do this, you will need at least two clamps holding the top of a piece of material (preferably clamped between two strips of wood to hold it flat and steady) and at least two places along the bottom of the material from which masses can be hung (again with the material clamped between two strips of wood).

The selection of threads used here has been chosen because they are all readily available from sewing or craft shops. There is a mixture of natural and synthetic materials and a mixture of twisted and smooth threads, enabling students to consider whether or not this may affect the stretchiness of the thread. Most threads selected in this way will be No. 40 or No. 50 sewing threads. The nylon can be nylon beading thread and linen thread is usually only available as a heavier thread. One point to evaluate with students could be the effect that thickness may have on stretchiness and whether there is any way to work out a measure of 'stretchiness' that takes this into account. (The No. 40 or No. 50 of sewing threads is related to the weight of the thread but is not an exact measure. More detail about this can be found at http://www.superiorthreads.com/index.php?option=com_content&task=view&id=41&Itemid=100

The inherent ability of a material to resist stretch is called its 'initial modulus' and is usually measured in grams of load per unit stretch for a given fibre weight. This is distinct from the 'modulus' of a material, which gives information about how much a sail material will stretch, and is dependent on both the inherent ability of the thread to resist stretch and on the way the sail has been constructed, either woven or as a composite laminate.

RESULTS

Sewing threads are thin enough that students will obtain a measurable stretch in a piece of thread 1 metre long, using masses that are not too large. Using masses of up to 500 g, you can expect to get an extension of several centimetres for the synthetic threads, and up to a couple of centimetres for cotton thread. Linen tends to be supplied as a thicker thread, meaning that you may require about 1.5 kg to get a measurable stretch. If you do not wish students to use masses this large, you could restrict them to smaller masses and expect them to get the result that 'linen does not stretch'.

Example results obtained using sewing threads

All threads had an initial un-stretched length of one metre.

All values are approximate.

type of thread	mass hung from thread / g	extension / cm
cotton	500	2
linen	1400	0.5
nylon	500	3
polyester	250	4
viscose	250	6

SUGGESTED SEQUENCE

Whilst this investigation could be carried out by students working in pairs, the tasks of holding and marking the thread and supporting the masses can sometimes be fiddly and students may benefit from working in threes. This gives more hands and eyes to check that masses are supported, thread is not in danger of snapping and threads used for marking have not slipped, for example.

Your group sizes may be determined by your bench space; even a long bench will only provide room for two groups, as each group will need access to a length of bench about 1.5 metres long, and one end of a bench over which they can hang the pulley and masses.

As with all other practical investigations, students may benefit from sharing their ideas with another group for the evaluation and follow up questions.

Time required

Parts of this investigation can be fiddly, and students will probably need more time than you would allow for a standard practical activity if they are to investigate several types of threads. One way of reducing the total time needed would be to allocate just one or two thread types to each group and 'pool' results into a class set before drawing the graphs and carrying out the evaluations and follow up questions.

Plenary activity

Students could, as a group or as a class, consider whether they would expect there to be any difference in the properties of materials suitable for making a sail for an ocean going yacht and a sail for a land yacht. They might think about the 'margin for error' that would be desirable for materials used in each situation and why.

NOTES

If students are able to run a single straight strand of thread along the bench, it is better to mark the thread using short strands of brightly coloured thread tied around the test thread, as this eliminates the risk of the pen mark causing a weak spot in the thread. However, there is a possibility of the marker thread sliding if the thread is handled. Also, if the thread is passed around several pulleys after it has been marked, it becomes very hard to check whether or not the marker threads are still exactly 4 m apart. So, in this circumstance it is probably better to mark the test thread using a 'biro' (this will not soak in as readily as a felt tip). Students have been instructed to use pen as most students will probably be using multiple pulleys, but you may wish to discuss with them the pros and cons of each method of marking.

It is extremely important that the threads run straight through the centre of each pulley and that the pulleys are very freely moving, so that the tension in the horizontal thread is the same as the mass on the end of the thread.

Students will enjoy using long lengths of thread, and this raises several practical difficulties for them to overcome, but this may not always be possible. If your students are unable to use very long threads, the threads suggested will give measurable extensions using only a 1 metre length. To give accurate results, greater precision will be needed in measuring the extensions, but certainly not greater precision than students are capable of at this level.

TECHNICIAN EQUIPMENT LIST

per group

- selection of sewing threads (e.g. cotton, linen, nylon, polyester, viscose)
- 2 x clamps and stands
- pulleys, with clamps to fasten them to the end of a bench
- metre ruler, marked in millimetres
- hanger with adjustable slotted masses (up to 1.5 kg, in units of 100 g and 50 g)
- pen or brightly coloured, thin sewing thread
- scissors
- large box (containing crumpled paper) to place below masses
- hand lens
- balance