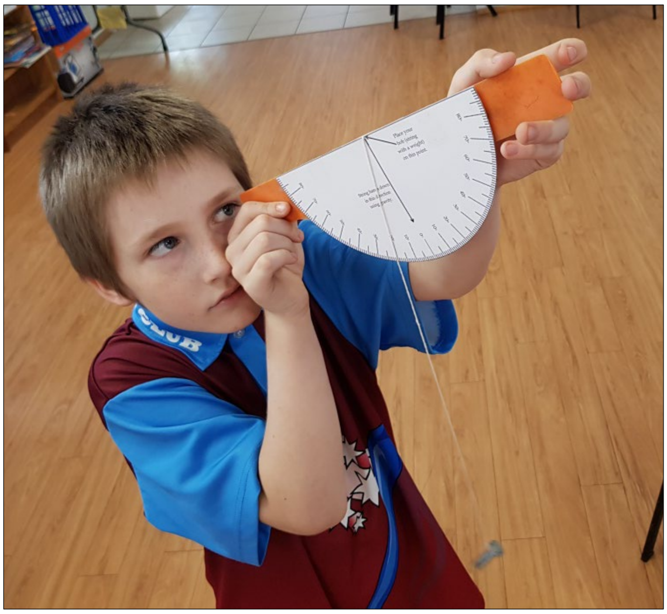
Creating Science 2 – Sextant “Sixth-tants”

How can you find out how high up an object, like a rocket, actually goes?

DANGERS!

This section cannot explain every possible danger in this activity. Adult care and surveillance is required at all times. Please exercise all appropriate caution at all times.



You may want to use bottle rockets at some point to help students develop their altitude measurements, please be careful with rockets and other projectiles.

There will be scissors, knives, and cutting implements (including paper) in this activity, please be careful.

People will still manage to poke their eyes, and other people’s eyes, with this device. Remind all student to be careful, and don’t run around with these pressed to their eyeballs.

Suggested Outcomes

(NOTE: This is by no means an exhaustive list of possible outcomes, neither is it intended that ONLY these outcomes can or should be met. Science is a deeply interrelated activity, and you may find cross curriculum links you can and should use.)

Science understanding

- Physical sciences 4: Forces can be exerted by one object on another through direct contact or from a distance (ACSSU076)
- Physical sciences 7: Change to an object’s motion is caused by unbalanced forces, including Earth’s gravitational attraction, acting on the object (ACSSU117)

Science inquiry skills

- Planning and conducting 5: Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS086)
- Processing and analysing data and information 5. Compare data with predictions and use as evidence in developing explanations (ACSIS218)

Science as a human endeavour

- Use and influence of science 5: Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE083)
- Nature and development of science 9: Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE158)

Cross curricular outcomes

- Mathematics. Measurement and Geometry 5: Geometric reasoning. Estimate, measure and compare angles using degrees. Construct angles using a protractor (ACMMG112)
- Mathematics. Measurement and Geometry 9: Pythagoras and trigonometry. Use similarity to investigate the constancy of the sine, cosine and tangent ratios for a given angle in right-angled triangles (ACMMG223)

Science vocabulary words

Tier 1 (Everyday words) – Rocket, gravity, angle

Tier 3 (Specialised vocabulary)

- Apogee – the highest point of a rocket flight, just as it's stopped going up but hasn't yet started heading back down yet.
- Sextant – the Latin word for 'the sixth part of a circle', and it refers to the tool we'll be using today, and that is still in use in navigation occasionally.

Preparation

- If you'd like to take your 'sixth-tant' home, please bring along a straight stick or 30cm ruler.
- You'll need a calculator with a 'tan' function. Most phones have one, or download an app.

Learning Intent (student friendly)

'We are learning to' (WALT) measure the height of an object we cannot otherwise reach.

Success criteria

'What I'm looking for' (WILF) a working sextant and related maths, successful measurement of heights, and an oral presentation on the creation, use and uses of a sextant.

Student learning goals

Help students make a self-monitored learning goal for this lesson.

Evidence of learning

How will you know when the learning goal is achieved? What EVIDENCE do you have that your students have met or exceeded the learning expectations?

Students may prepare an oral presentation on the history, construction, use and uses of a sextant.

Suggestions for other year levels

As always, more material is presented here than can be used by the average class during the average lesson time. However, since the students questions can and should guide student learning, more material is presented for you convenience. Remember, it is not uncommon for students to only remember those points which answered their personal questions.

Younger:

This activity is moderately challenging to this group, and they are unlikely to understand the Tangent function and its ratio, but may still appreciate how some maths and a protractor can help you know how tall something is – like a building or airplane, once you know how far away you are from it.

Middle:

This activity is well suited to this group

Teen:

Throw in the challenge of understand the history and alternative uses of the sextant. Explore unusual problems that can be solved with a sextant, such as finding the distance your boat is out to shore if you know the distance between two landmarks. Is the Tan function still the one you need?

Engage

- ⇨ Note the Learning Intention of this lesson for students.
- ⇨ Make sure all students write down any questions they may have generated during this phase regarding the topic for today.

Perform a rocket launch.

Ask students to brainstorm ways of knowing exactly **how high up** the rocket went.

Ask if it's sometimes helpful to know the heights of other things, such as buildings or power poles?

Explore

- ⇨ Encourage and validate student explanations of this phenomenon. You may like to ask students to write or draw their explanation personally to avoid embarrassment to students unfamiliar with this material. Remember, 'I don't know' is a valid explanation in science – it is the beginning of learning new things!

Have students try to estimate the height the rocket flew.

Present the sextant, and explain its basic functions and working.

Find out if students can think of a way to measure rocket flight height using the sextant, the distance to the rocket pad, and angle the rocket went up.

Explain

- ⇨ Ask students if they can design new ways to test this explanation, is it really sufficient? Can they think of further or better explanations, and the experiments needed to test them?

Sextants work by knowing the distant to the base of the rocket launch, and use a special ratio called a TAN. This works by pretending the distance to the base of the rocket launch is the radius of a circle, then making a right angled triangle up. Once we know the angle and the distance to the rocket launch pad, we can mathematically estimate the high the rocket will fly.

To calculate the height of the rocket we'll need:

- Distance between the viewer and the base of the object (in meters).
- To measure the angle between the ground and the viewer. This is the 'angle of error'
- To measure the angle between the viewer and the topmost part of the object to be measured. In rockets the highest point is known as the apogee. This is the 'angle of elevation'.
- Add the two angles
- TAN (angle)
- Multiply this result by the distance to Launchpad = height of the rocket (most calculators require you to type in the angle before pressing tan, so just a heads up.)

For example; how high is the power pole outside Dr Joe's laboratory?

- Distance between the viewer and the base of the object = 10 meters.
- Angle between the ground and the viewer = 9^o
- Angle between the viewer and the topmost part of the object to be measured = 51^o
- Add the two angles = 60^o
- TAN (angles) = 1.732
- Multiply 1.732 by the distance to base of pole = height of the power pole = ~17 meters – that's a very big power pole!

Need more explanation on TAN, try https://www.mathopenref.com/trigtangent.html

Want to see how easy it is to make your own Sextant, you might be inspired by https://www.youtube.com/watch?v=p-u9Kh5HxjM Remember he's using a normal protractor, so must take the angle away from 90 to get the correct answer!

Other kinds of sextants

The octant is 1⁄8th of a circle (45°), quintant (or pentant) 1⁄5th of a circle (72°) and the (doubly reflecting) quadrant 1⁄4th of a circle (90°). All of these instruments may be termed "sextants" in respect to the job they do, and not their size. Perhaps you can think of a better name for this tool?

Improving the accuracy of results

Make sure your ruler is straight and your reading is accurate. Have you taken into account the angle of error?

What else can help improve the accuracy of results?

Try doing multiple trials and average results, just like a real scientist would do!

Elaborate

Extending the learning

Questions and extensions

- What is a tangent?
- What is the speed the rocket travelled at?
- What is the effect of gravity on the rocket?
- What is acceleration? At what points is the rocket accelerating and decelerating?
- Use this formula distance = $1/2\ g\ t^2$ (where g = the 9.98 the gravitational constant, and t equals the time in seconds) to determine how far the rocket falls from its highest height, if you know how long it takes to fall. Use this to check your estimating from the sextant.

Uses for sextants

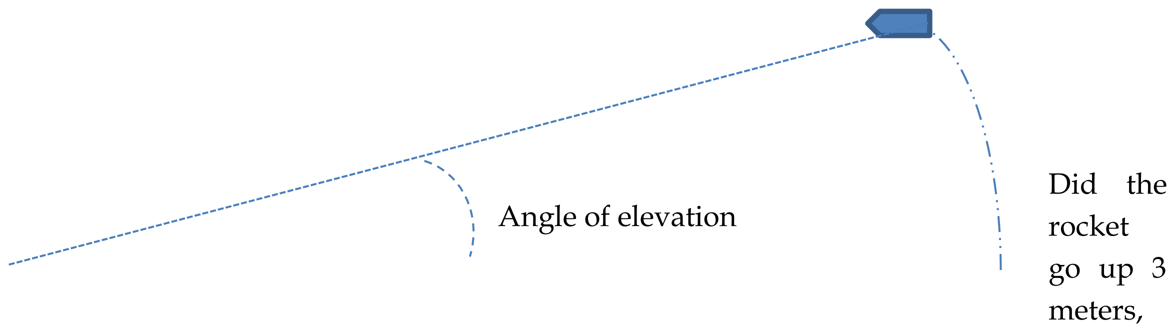
[Wikipedia] Sextants can be used very accurately to measure other visible angles, for example between one heavenly body and another and between landmarks ashore. Used horizontally, a sextant can measure the apparent angle between two landmarks such as a lighthouse and a church spire, which can then be used to find the distance off or out to sea (provided the distance between the two landmarks is known). Used vertically, a measurement of the angle between the lantern of a lighthouse of known height and the sea level at its base can also be used for distance off.

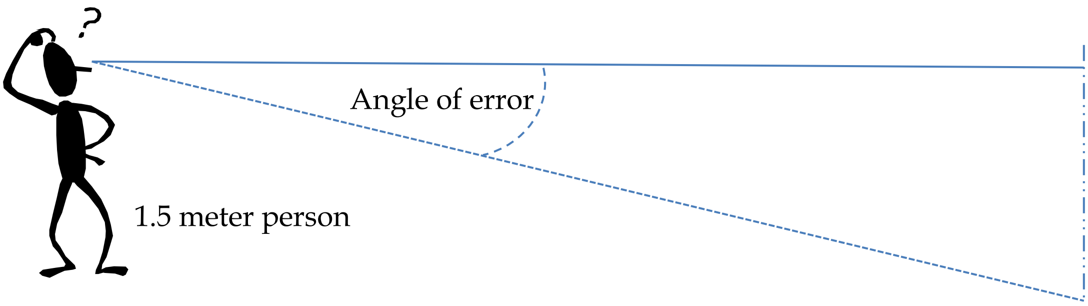
Angle of error

Can you calculate your angle of error?

Notice how you (usually) are holding the sextant up above the ground? Maybe even a meter or two? This makes you higher than (most) of the starting height of the objects you are trying to measure.

This makes your measurement a meter or two LOWER than the actual height of the object (as measured from the ground)





How can you compensate for this? How will you compensate for this if you're on top of a very tall building, or on a moving boat?

1. You can first measure the angle of the object downwards from your sextant, and subtract this angle (usually 1 or 2 degrees) from your final measurement.
2. You can measure how high you are holding the sextant above the ground (in meters), and add this number to the final result of the height of your object.

Deeper maths – high school

Your sextant, is one half of a circle, so be sure to put your string right in the middle. It is the centre of a circle, the ruler runs right along the diameter of the circle, and the TAN function is a straight line that just touches, i.e., runs tangential, to that circle.

Try understanding the excellent work up at http://www2.estesrockets.com/pdf/2844_estes_math_of_model_rocketry_tn-5.pdf

Check your measurements

Feeling uncertain about your measurements? Try this activity with a normal power pole on a sunny day, taken 22 Feb 19 from https://preschem.com/how-tall-is-a-power-pole/

So how do you determine the height of a specific pole in the field?

If it's a sunny day, then it's quite easy to do safely. We measure its shadow. Here are the steps:

Find a stick or straight edge 1 m long. If can be another length but as long as that length is known. 1 m is easy to do the maths.

Place that stick vertically and measure its shadow. Write that value down.

Measure the shadow of the pole.

Calculate the shadow height to shadow ratio of the stick and then divide

Eg. Let's say the 1 m stick is throwing a shadow of 0.6 m. The height to shadow ratio is therefore:

1.0/0.6=1.67.

We measure the shadow of the pole as being 3.0 m. Now we multiply it by the ratio we calculated to find the height of the pole.

3.0 x 1.67 = 5 m

It won't be to the nearest millimetre, but it will be surprisingly accurate provided you don't leave it too long between measuring the stick and pole shadow. Remember the sun will shift in the sky and alter the length of the shadow.

Evaluate

- ⇨ Review with students what they felt they learnt from this lesson. Did they have any questions at the start that they feel were answered?

Success criteria

- ⇨ Review the Learning Intentions of this lesson with students. Was it met?

At the end of each class, review the learning objective and see how we did. Ask:

- ⇨ Did you achieve your learning goal?
- ⇨ What did You learn?
- ⇨ What worked to help you achieve it?
- ⇨ What might you do better next time?
- ⇨ (If needed) where can you go for extra help or information?

Assessment

Prior learning:

Do the 'draw the forces on a rocket' activity in the appendix. Box 3 and 4 have the exact same forces as box 1, and box 2 has an upwards force overpowering gravity (the water pushing out does not push on the rocket – it's going out!)

Take time to focus on planned content material during the engage phase, for example,

- How can we know how high something is if we can't touch it?

Formative:

As students are learning, help them self-monitor their own learning and achievements.

Focus on the outcomes – how can we create the BEST scientific knowledge?

- How can we be more accurate in measuring with a sextant?
- What can we do if it's a windy day?
- What can we do if the rocket flies off sideways?

Summative:

Help students consider ways they can communicate their new understanding to others, just as scientists need to do.

Consider putting together an oral presentation such as online tutorial to answer such questions as;

- How to work a sextant
- How to build a sextant
- How to use a sextant

But why?

Research how useful ***is*** a sextant? What advantages, and disadvantages, does it have over other navigational tools such as electronic devices or telescopes? Do modern navigators still have sextants? Present your research in a symposium just like real scientists do.

So what?

Knowing how high up something is, when all you know is how far away you are from its base and how to use a sextant, is very cool. No more guessing for you!

Maths is actually useful! Now we can use this technique to more accurately explore how to make our own rockets go higher and faster!

Creating science

Science understanding

As we explored the forces on the rocket, we learnt that;

- Physical sciences 4: Forces can be exerted by one object on another through direct contact or from a distance (ACSSU076)
- Physical sciences 7: Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object (ACSSU117)

Science inquiry skills

By building and safely using sextants to estimate the height of certain objects, we can learn how to;

- Planning and conducting 5: Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS086)
- Processing and analysing data and information 5. Compare data with predictions and use as evidence in developing explanations (ACSIS218)

Science as a human endeavour

Using this cool scientific and mathematical tool to solve every day and scientific problems, such as finding out the height of a rocket, a building, or a child stuck up a tree, we can learn that;

- Use and influence of science 5: Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE083)
- Nature and development of science 9: Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE158)

Cross curricular outcomes

As we use the trigonometry of TAN to solve everyday problems, we;

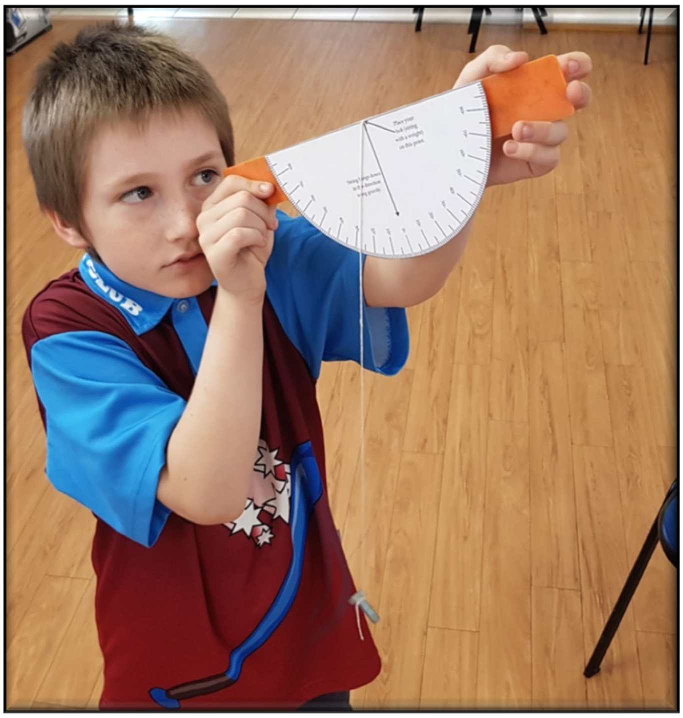
- Mathematics. Measurement and Geometry 5: Geometric reasoning. Estimate, measure and compare angles using degrees. Construct angles using a protractor (ACMMG112)
- Mathematics. Measurement and Geometry 9: Pythagoras and trigonometry. Use similarity to investigate the constancy of the sine, cosine and tangent ratios for a given angle in right-angled triangles (ACMMG223)

Tips from the Masters to make it work:

- Use a guillotine to make sure the long edge of the protractor is very straight.
- The curved edge of the protractor can be cut out anyway you like, even in a huge rectangle. But we like it round for tradition's sake.
- If it's windy, use a heavier bob.
- Be sure to tape the string right in the middle of the protractor. It is the centre of a circle, the ruler runs right along the diameter of the circle, and the TAN function is a straight line that just touches, i.e., runs tangential, to that circle.
- Place your eye carefully right down the straight edge of the ruler. It should look like a dot, not a line.

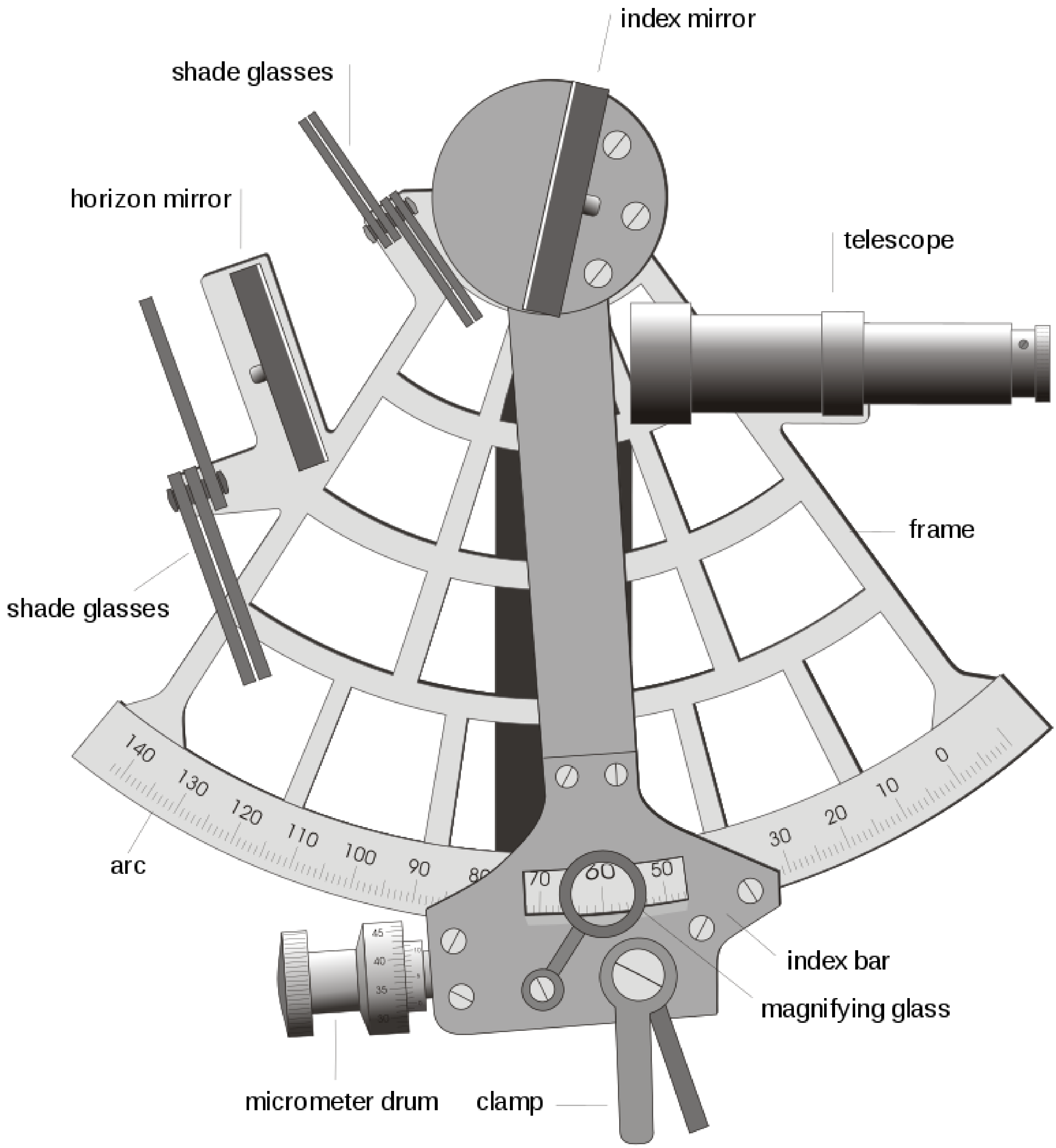
How high is a basketball hoop?

Excellent technique, be sure to look straight down the ruler, not at it!



Appendix: Modern Sextants

Modern sextants are quite elaborate, but allow for some pretty impressive accuracy:



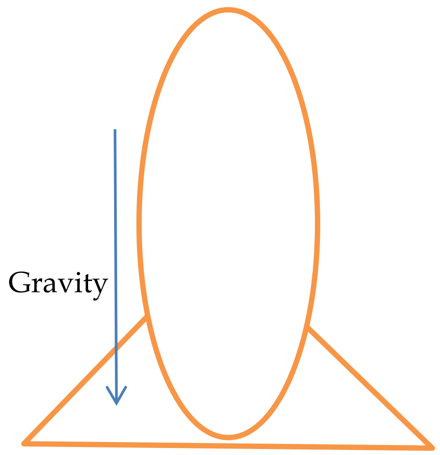
Taken 22 Feb 19 from By Joaquim Alves Gaspar - Own work, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=1314046

Appendix: Summary of the forces acting on a rocket

Note – a CHANGE in speed or direction happen ONLY when a force is acting on an object and there's no opposing force to stop it. Otherwise objects just keep doing what they were doing.

Can you ***DRAW the forces*** acting on the rocket at each stage? We're ignoring air pressure.

1. Rocket is on the launch pad. Gravity holds it down so that it doesn't float away.



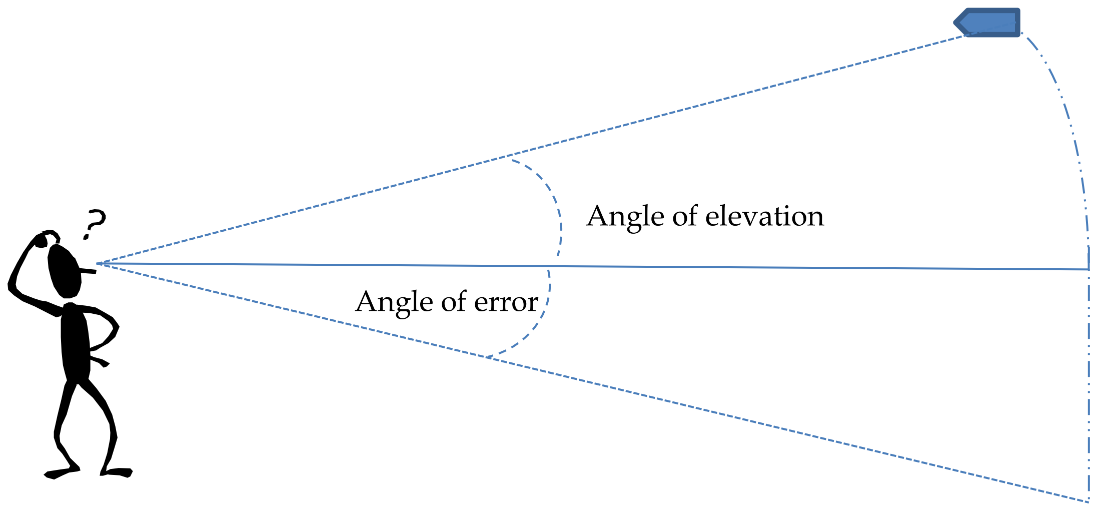
2. High air pressure in the rocket pushes the water down, and the reaction force of the air pushing on the top of the rocket pushed the rocket up. Gravity is still pulling the rocket, slowing it down, otherwise the rocket would go much faster and just keep going up!

3. At the top of the rocket's flight, AKA the "Apogee", gravity has *slowed* the rocket down, but it's still pulling! Otherwise the rocket would stay floating up there!

4. Just as the rocket hits the ground, gravity is still pulling it down, but the ground pushes back much harder than gravity and makes the rocket stop (the ground has the electrostatic forces between the atoms to hold it together, otherwise the rocket would plough straight on through the ground like a brick in water!)

How to use your sextant

1. Measure the exact distance between you and the base of the object / launch (in meters)
2. Point your sextant down at the base of the object to measure the angle of error.
3. Point your sextant up to measure the angle of elevation. This can be very tricky for a moving rocket! Once the rocket reaches its apogee (highest point) you need to STOP moving your sextant, wait for the string to stop moving about, and record the angle.
4. Add your two angles.
5. Find the TAN of your angles using a calculator with the TAN (tangent) function. Be sure it's set to DEG (degrees) and not RAD (radians) or you'll get the wrong answer!
6. Multiply this answer by the distance you are from the base, and you have a very good estimate of how high the object is or how high your rocket went!



Make sure you do your experiment several time to get the best results!!!

Steps	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
1. Measure the distance between you and the launch (in meters)					
2. Angle of error (point sextant at the base / launch pad)					
3. Angle of elevation (point sextant at the highest spot)					
4. Now add your two angles together					
5. TAN the result					
6. Multiply step 5 by your distance to the rocket (step 1) to get estimated height.					

Appendix: The sextant, AKA "Sixth-tant"

1. Cut out along the outside of the special protractor very carefully. You can use normal protractors, but will need to adjust the angles accordingly.