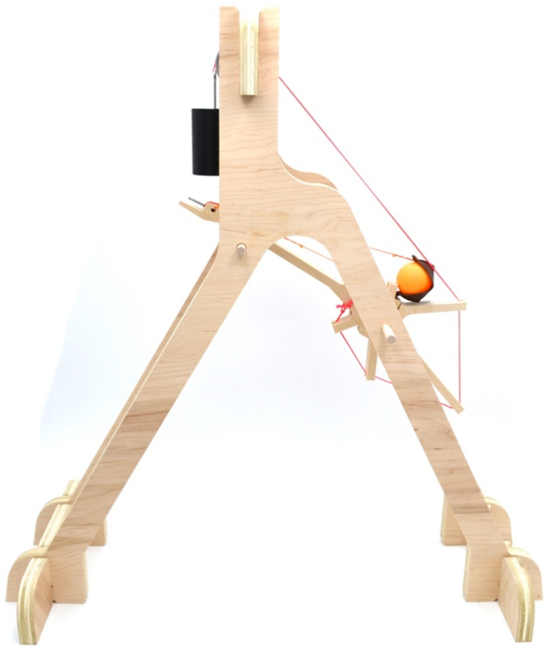
GARAGE PHYSICS

by eisco



MURLIN Trebuchet DIY Kit
GP00015

Guide for Educators

Step aside standard trebuchet! The **Mu**lti-**R**adius **Li**near-**N**ode (MURLIN) Trebuchet combines the throwing advantage of the standard trebuchet with a highly efficient spinning wind-up. The result? Projectiles launch **much** farther compared to the size of the trebuchet. This MURLIN trebuchet throws the included ping pong ball more than 30 feet. The throwing arm in this model is half that of our Large Trebuchet (GP0009), but throws just as far. Explore how the use of a simple machine (a pulley) efficiently redirects gravitational potential energy to achieve this amazing result. A small Phillip's screwdriver is required for assembly. Kit includes instructor's manual.

NGSS Standards

Motion and Stability: Forces and Interactions
MS-PS2-2

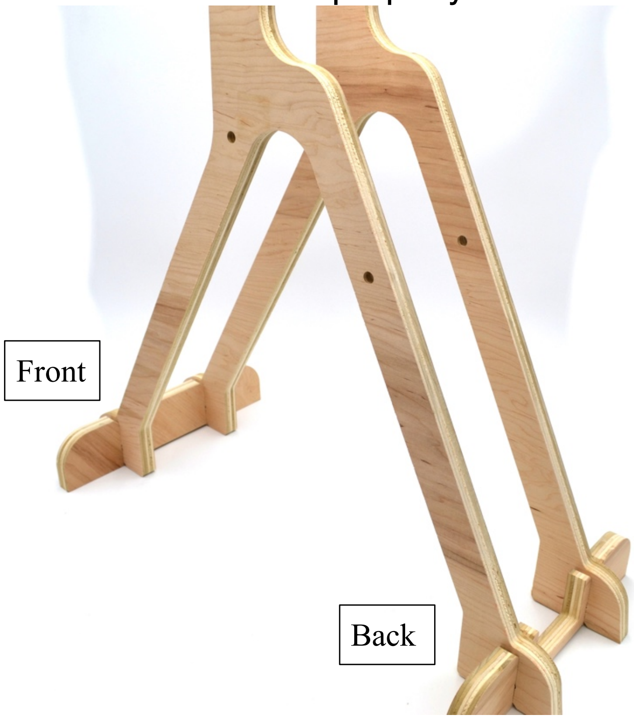
Contents of Kit

2 A-frame supports, front and back base struts, pulley mount, swing arm, 3/8" diameter dowels (one 8.5" long and one 7" long), release pin, leather pouch, sliding pouch holder, 1 kg counterweight, pulley, 2 wood screws (for pulley), 2 orange strings (one long, one short) for sling, 1 pink string for counterweight, 1 ping pong ball, and 1 rubber band.

Pedagogical Guide

Assembly

1) Insert the 2 A-frames into the front and back base struts. The back base strut has a 3” wide channel cut in it and should be opposite the forks for the pulley mount. The bottom of the struts should be flush with the bottom of the A-frame when seated properly.

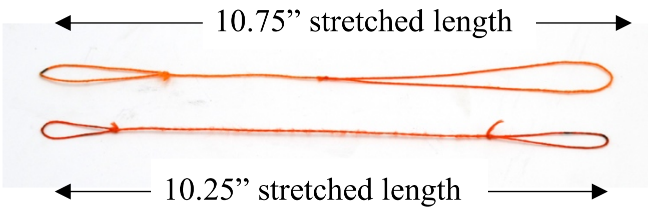


2) Attach the pulley to the pulley mount using the included wood screws.

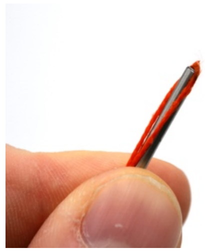
3) Insert the pulley mount into the forks for the pulley mount with the screws to the front of the trebuchet. The top of the pulley mount should be level with the top of the forks when seated properly.

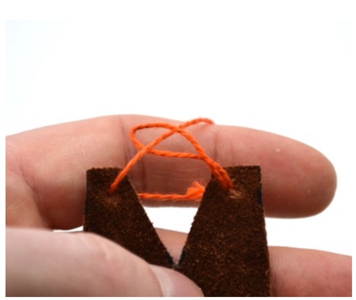
4) Tie the sling assembly. *This is a critical part of the assembly instructions and must be followed closely for the trebuchet to fire and release correctly.*

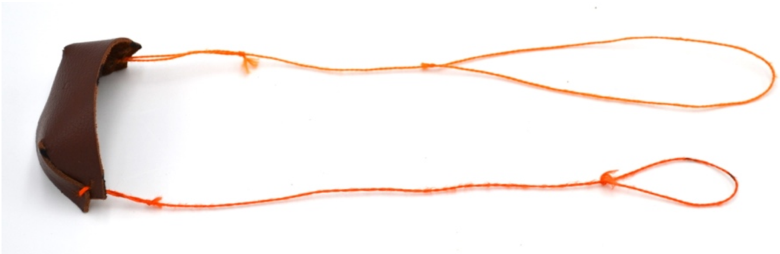
At the end of this section, you should have two strings resembling the following picture.



a) Longer string: begin by tying a roughly 1 inch “overhand loop knot” on one end of the string (see demonstration videos on Youtube - https://youtu.be/i3pIizxiB94).
b) Then tie a roughly 5 inch long overhand loop knot on the other end of the string **so that the total stretched length of the string is 10.75”.** Hint: it helps to mark a point on the string 10.75” from then end of the first loop. Then fold the string at that mark to make the end of the loop. Finally, tie the overhand knot to form the loop.
c) Repeat the process for the shorter string so that it has two roughly 1” loops. You can see from the previous picture that the precise size of the loops are not critical. The total stretched length is crucial, however.
d) Use the pin to thread the small loop down through one hole of the pouch and up the other hole. Then insert the other end of the string though the loop and cinch down on the leather pouch so that the pouch flaps overlap. Repeat on the other side of the pouch.

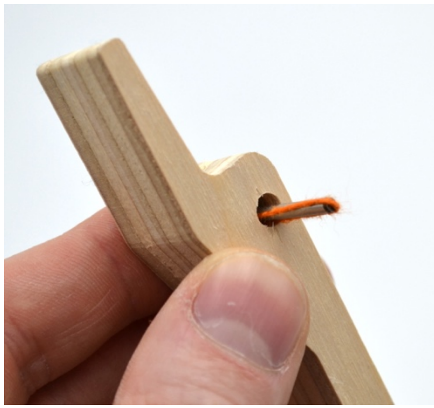






The purpose for having one string longer than the other is to compensate for the extra length required in one string to attach the sling to the throwing arm.

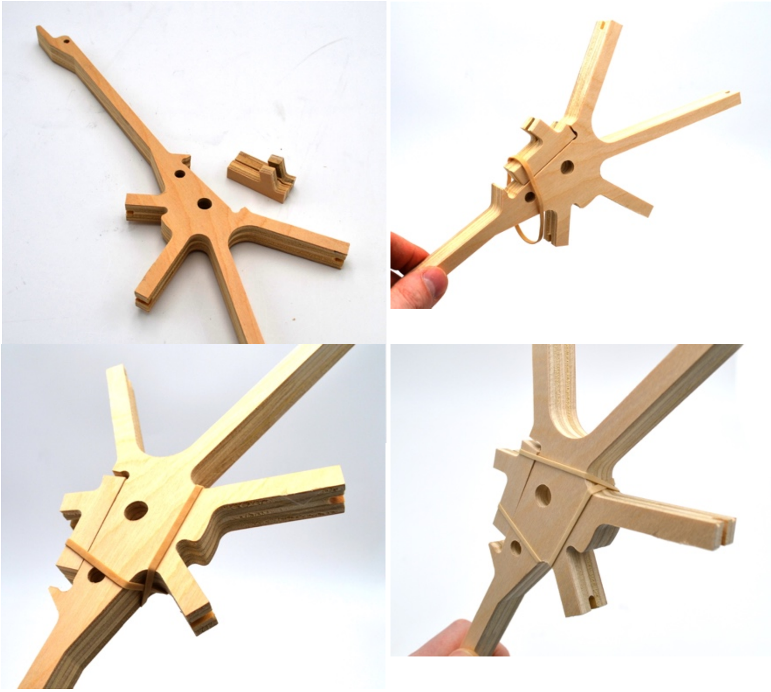
5) Thread the big loop of the longer string through the hole at the end of the throwing arm using the steel rod. A bit of tape can help keep the string attached to the rod. Remove the tape once you've threaded the loop. Thread the pouch through the loop and cinch up against the



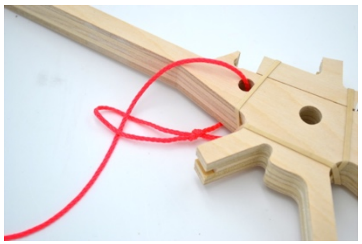
arm on the side of the throwing arm with the release pin hole.

6) Insert the release pin in the predrilled hole in the end of the throwing arm. The fit is quite snug – when seated properly, there should be only about 0.75" of the pin showing. Be sure the orange string is cinched tightly so that pin does not push it down into the pin hole.

7) Attach the sliding pouch holder to the throwing arm and use the included rubber band to secure it in place by twisting the rubber band around the throwing arm as shown in the following pictures. Be sure the rubber band does not cross over the large hole.



8) Tie a 2” long overhand loop in the pink string. Insert the loop through the hole at the base of the throwing arm. Thread the end of the string through the loop and cinch up against the release pin side of the throwing arm.



9) Attach the swing arm to the A-frame using the 8.5” long dowel. The swing arm should be oriented so the release pin is up when the throwing arm is pointing forward. The dowel is not intended to be glued to either the swing arm or the A-frame, but is allowed to rotate freely.

10) *This is a critical part of the assembly instructions and must be followed closely for the trebuchet to fire correctly.*

a) Insert the 7” support dowel into the remaining set of holes in the A-frame.

b) Rest the throwing arm on the support dowel.

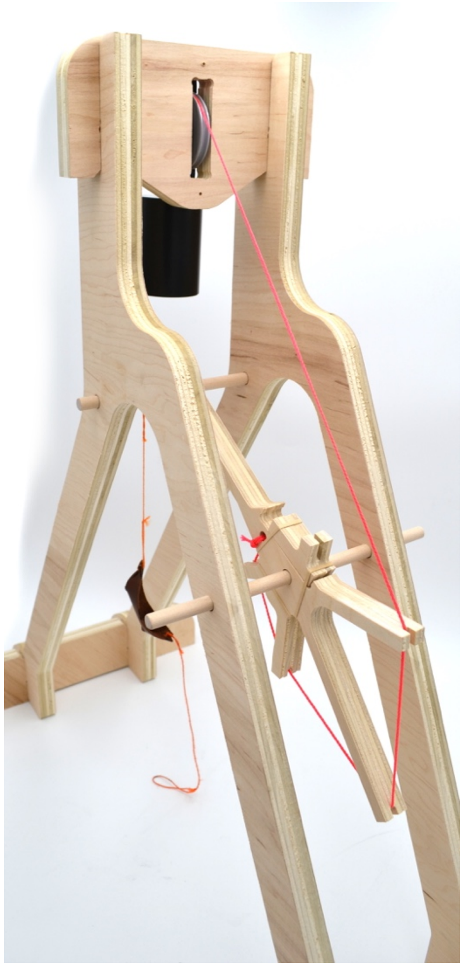
c) Thread the pink string through the channels on the swing arm and up through the pulley.

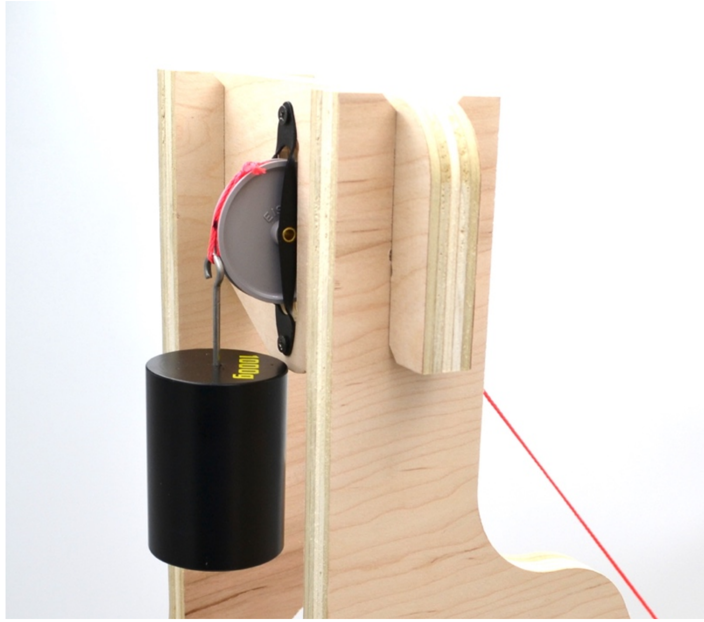
d) Pull the string taut and make a mark on the string where it leaves the pulley. Remove the pink string from the pulley.

e) Make a second mark, 0.5” past the first mark and tie an overhand loop knot with about a 0.5” loop.

f) Thread the loop through the pulley and hang the 1 kg counterweight from it. The counterweight hook should be just below the pulley. The bottom of the counterweight should be above the end of the throwing arm. If this is not the case, you need to retie the pink string so that it looks like the image below.

g) Cut the excess pink string.





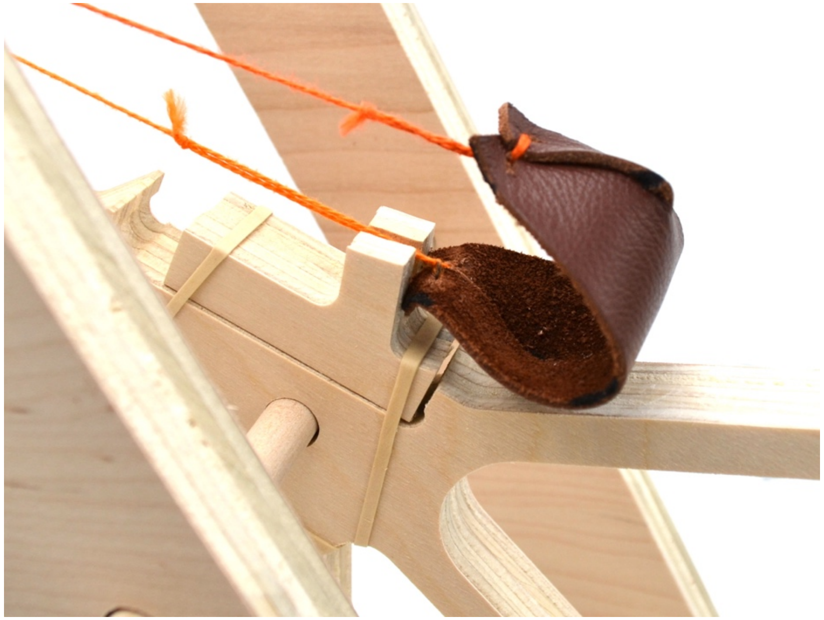
Loading and Launching

10) The trebuchet is now cocked, but needs to be loaded prior to firing (DO NOT FIRE AN UN-LOADED TREBUCHET – THE ORANGE STRING CAN BREAK IF IT GETS CAUGHT SOMEWHERE).

a) Hook the remaining loop of the sling on the release pin and insert the ping pong into the pouch.

b) Place the pouch just below the sliding pouch holder so the pouch strings are not twisted.

c) Adjust the position of the sliding pouch holder so there is minimal force on the pouch. IF YOU DO NOT DO THIS THE TREBUCHET WILL ALMOST CERTAINLY MISFIRE. See image below showing the properly loaded pouch with ping-pong ball removed for visual clarity.



Here is a picture of the properly loaded pouch with the ping pong ball. Note that the pouch strings are not twisted.

11) Check that the center of the swing arm is aligned with the center of the pulley. IF YOU DO NOT DO THIS THE TREBUCHET IS LIKELY TO MISFIRE.

12) Hold the throwing arm with your finger as you pull out the support dowel. Then release the throwing arm to launch the projectile. Be careful not to twist the arm when you release it.

Be sure to keep your head back so you don't get hit in the face by the throwing arm!

Always be sure you have a clear firing range when you launch so that no one gets hit with a flying projectile!

Understanding Projectile Motion

13) Use the slow-motion capture feature on a cell phone camera to record the launch. What do you observe?

14) What factors do you think influence the design length of the arms on the swing-arm? Why are they shorter at the end of the swing as opposed to at the beginning?

15) Measure the total travel h of the counterweight by measuring the distance from the top of the counterweight when the trebuchet is loaded to the top of counterweight after launch. Express h in meter units [$\sim 0.43\ m$]. Calculate the potential energy available, $U = mgh$, where $g = 9.8\ m/s^2$ [$U \sim 4.2\ J$]. Be sure to use SI units (kg for the mass and m for h) so the result is in Joules. A perfect trebuchet would be able to

convert all this potential energy into kinetic energy.

16) Calculate the maximum possible release velocity for your projectile,

$$v_{max} = \sqrt{\frac{2U}{m}}.$$

[With a $2.8\ g$ ping pong ball, the maximum release velocity should be about $32\ m/s$].

17) How can you estimate whether the projectile achieves this velocity? [Use your phone camera in slow-motion and use the size of the ping pong ball as a length reference. Then use the frame rate and the distance between ping pong ball positions to calculate the velocity].

18) What other factors could account for the discrepancy between what you observe and what you measure?

[After the projectile has been released, any extra potential energy in the counterweight cannot be transferred to the ping pong ball. So we can't use the final resting height of the counterweight to calculate the potential energy; we must use the height when the projectile is released. Also, the total kinetic energy of the system is shared among four systems when the projectile is released: the projectile itself, the pouch (3.8 g), the rotational kinetic energy of the swing-arm (about 75 g), and the remaining kinetic energy of the counterweight. Friction in the pulley, between the rod and the swing-arm, between the rod and the frame also reduces the kinetic energy of the projectile. Heat generated by tensioning the pink and orange strings, and in flexing the throwing arm, axle, and frame also reduces the projectile kinetic energy.]

19) Launch modeling putty of various masses (not included) and record your observation in the chart below. How does the release angle change for different masses? Why might this be the case? Can you compensate by adding mass to the counterweight?

	Projectile description	Projectile mass	Counter-weight mass	Projectile distance	Notes
1	Ping pong ball	3 g	1 kg	30 ft	About 45 deg. release angle.
2					
3					
4					
5					
6					
7					
8					
9					
10					

Follow-up Questions and Activities

Comparison with standard trebuchet.

The standard trebuchet is primarily limited by the amount of potential energy which can be put into the system relative to its size. The travel of the counterweight h is constrained by the geometry of the throwing arm. The maximum travel of the counterweight is twice the length of the short arm of the trebuchet throwing arm, $h \leq 2l$. Thus, to put more energy into the system (without changing the counterweight), we have to lengthen the throwing arm.

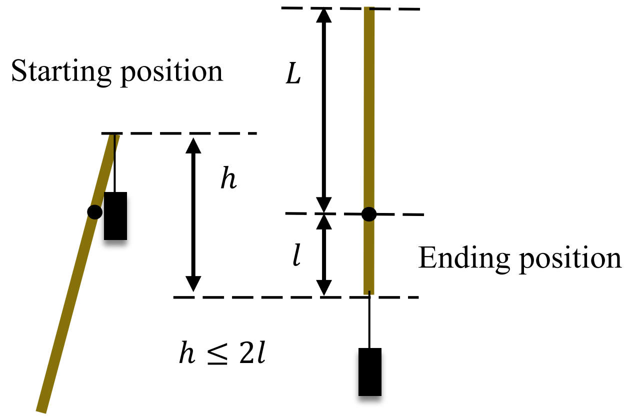


Figure 1. Standard Trebuchet

The MURLIN trebuchet is not limited in this way. By using a pulley to transfer the direction of the force from the counterweight, can use much more potential energy for the same size throwing arm. This is done by wrapping the cord around the throwing arm and winding up the throwing arm. In fact, the counterweight travel h can be greater than the length of the long arm, L, of the standard trebuchet. In fact, in this kit $h > 2L$. Thus, for the same size throwing arm and counterweight, much more potential energy can be converted into kinetic energy of the projectile.

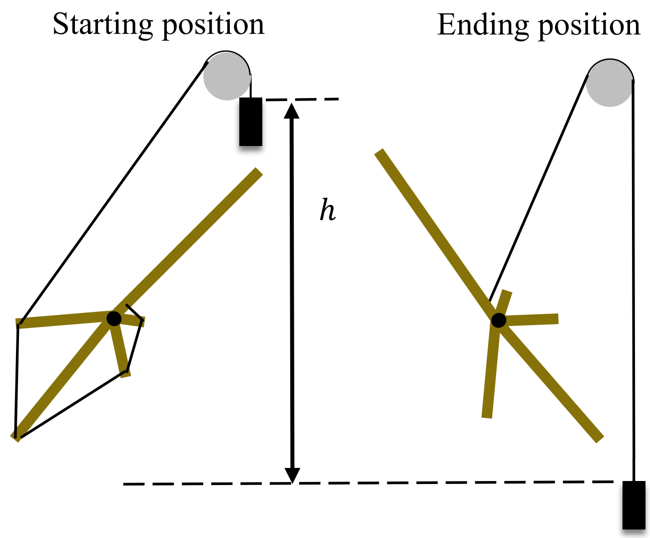


Figure 2. MURLIN Trebuchet

Recoil Forces

The standard trebuchet uses wheels to absorb and then return energy generated when lateral forces are exerted on the frame. These forces are called recoil forces, and are generated by the interplay between the throwing arm and the falling counterweight. It's easy to picture these forces if the frame is fixed – the centripetal force causing the counterweight to travel in a circular path is countered by an equal and opposite force on the frame. Adding wheels allows the frame to move in response to this force. As the throwing-arm swings around the trebuchet returns to nearly its original position.

In a frictionless world, how would the final position of the standard trebuchet relate to its initial position?

[The total energy would be in three places: the kinetic and potential energy of the projectile, the kinetic and potential energy of the throwing arm and counterweight pendulum system, and the kinetic energy of the trebuchet system as a whole. Conservation of momentum dictates that the center of mass of the trebuchet system must have a non-zero velocity in the direction opposite the projectile.]

In the MURLIN trebuchet, the counterweight falls straight down. This drastically reduces the forces acting laterally on the frame. Thus, there is no need to add wheels to the MURLIN trebuchet.