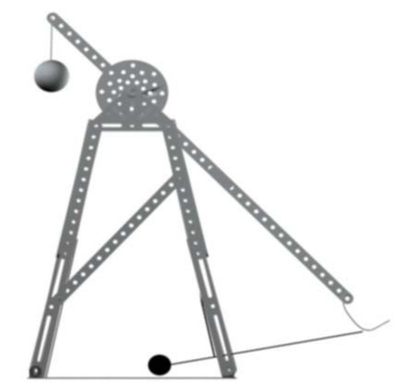
GEARS-EDS . . . technology education in a box

Build the GEARS-IDS Trebuchet

Build and Use the Trebuchet to Explore These Engineering and Physics Principles:



DESIGN/BUILD/TEST/ PLAY

Use The GEARS-IDS™ Invention and Design System to build and study trebuchets**.** Trebuchets were powerfully effective medieval siege engines that battered enemy fortifications with large masses of rock hurled hundreds of feet.

The people who designed and built these and other siege engines were called Ingeniators (Engineers).

Designing, building and using a trebuchet is an excellent engineering exercise. There are many variables that affect the trebuchet's performance, and thus, there are many solutions. Multiple solutions provide young engineers with many \creative opportunities to develop science, math and engineering insights through the iterative process of experimenting, building, modifying and playing the trebuchet's they design and build.

Mechanical Principles

- Bearings and Structures
- Levers

Science and Engineering Principles

- Force Mass and Motion
- Unbalanced Forces
- Work and Power
- Friction
- F=ma and Newton's Laws of Motion
- Testing and Analysis
- Design and CAD

Design Principles

- Systems and Interactions
- Rigidity and Structures
- Threaded Fasteners

Mathematics

- Create and Use Basic Mathematical Models to Evaluate and predict Component Performance
- Assess Performance
- Algebraic and Geometric Manipulations

History of Science and Technology

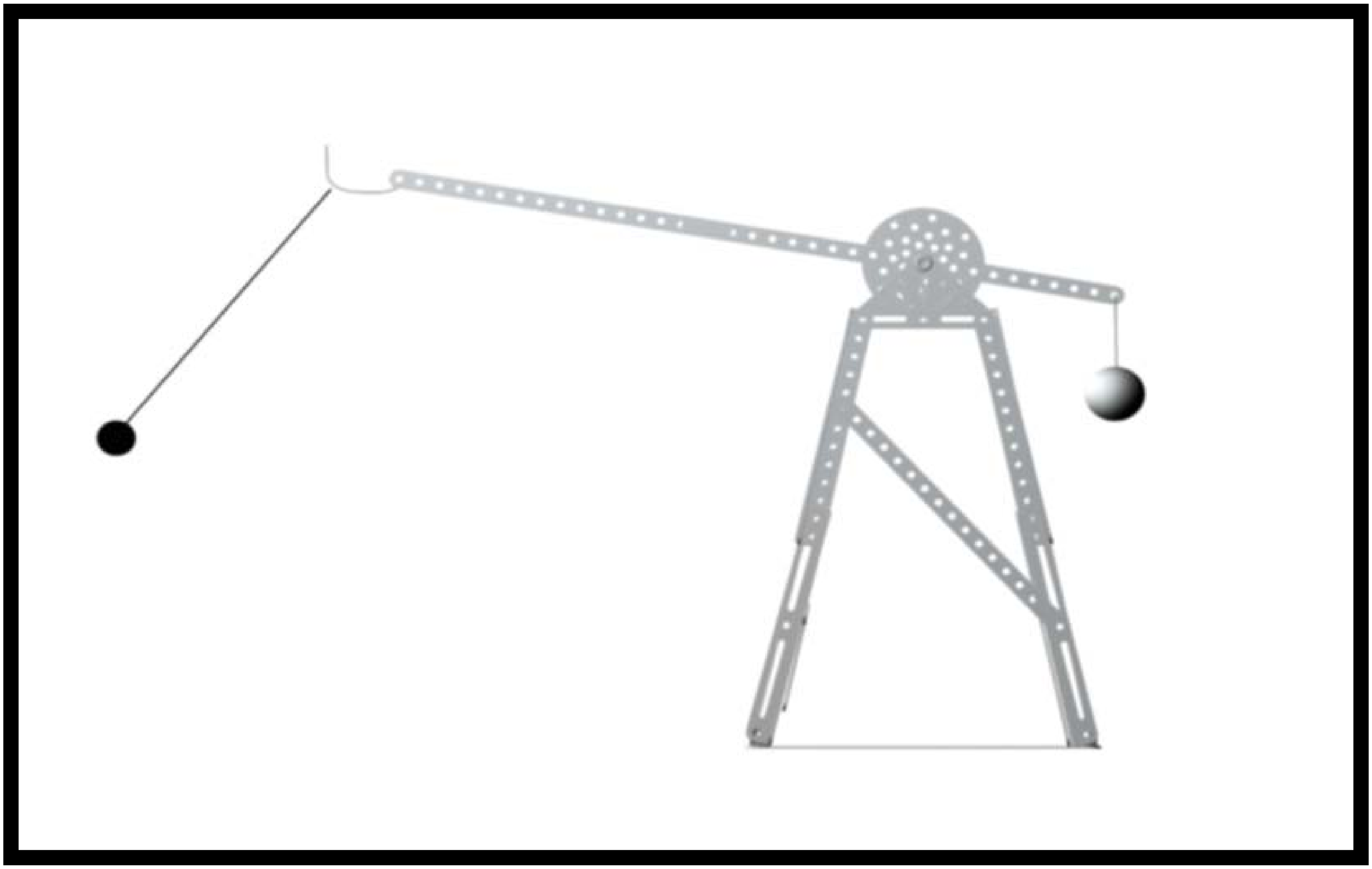
- The Genesis of Engineering
- Siege Engines

Personal and Interpersonal Skills

- Acquires and Evaluates Information
- Allocates and Organizes Time and Materials

NOTE: GEARS-IDS Components can be used to construct mechanisms that demonstrate physical science principles. These mechanisms allow students to experiment with simple machines, investigate work power and energy or construct devices that demonstrate the effects of force and motion.

DESIGN – BUILD – TEST - PLAY



Performance Tip. Before beginning any project, it helps to have a sense of what the beginning, middle and end of the project looks like. For **Best Results Read the Entire Document Before Beginning**

The Trebuchet can be built in less than 45 min. by a team of 2-3 people. Each team member can build 1 or more of the subassemblies *(2 frames, 1 lever arm assembly)* **from which the trebuchet is constructed.**

Performance Tip. Engineering is a team sport. Be an engineering MVP. Accept and commit to completing specific responsibilities.

1. **Obtain and organize the Tools and Materials** *(Listed below)*
2. **Build one or more of the subassemblies** *(Illustrated in this document)*
3. **Integrate the subassemblies into a working trebuchet.**
4. **Test and experiment with different sling lengths, counter weight arm lengths, launch angles and throwing arm lengths.**

Caution: Always wear safety glasses when working on, testing or using trebuchet models

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Organize the Tools and Materials

The trebuchet can be completed quickly and with minimal frustration and mistakes by taking the time to read through the directions and readying the necessary tools and materials before beginning the assembly.

Required Tools

Safety Glasses
2-3 Phillips Head Screwdrivers
5/16" Combination Wrench *(For the Stand Offs)*
3/8" Combination Wrench
6" Needle Nose Pliers
5/64, 6/32 Allen Wrenches or Hex Keys
Dial Calipers and Tape Measures

Materials

Use the GEARS-IDS online catalog of parts and components to identify the following components.

Structural Components

1 6x9 Flat Plates GIDS-SC-10002
8 13 Hole Angles GIDS-SC-10006
2 17 Hole Flat Bars GIDS-SC-10001-17
2 11 Hole Flat Bars GIDS-SC-10001-11
2 9 Hole Flat Bars GIDS-SC-10001-7
2 7 Hole Flat Bars GIDS-SC-10001-7
2 5 Hole Flat Bars GIDS-SC-10001-5
1 3" Hex Wheel GIDS-SC-10014
1 4" x 3/16 Axles GIDS-SC-10018
1 3/16" Hex Adapter GIDS-SC-10013-1875
1 ½" Shaft Collar
4 3/16" Shaft Collars
2 Sine Triangles GIDS-SC-1005
4 90 Degree Fish Plates GIDS-SC-1004-90

Hardware

40+/- #10-24 x 3/8" PH Machine Screws
6 #10-24 x ¾ PH Machine Screws
50+/- #10 Nuts and Lock washers

Miscellaneous Supplies and Materials

1 or 2 12 ounce lead ball fishing weights
1 or 2 wood balls, 1" in diameter.
Masons line or heavy string
Thread
Paper clips or 1/32" welding rod

Performance Tip. Go to www.gearseds.com to download a complete catalog and description of **GEARS-IDS™** Invention and Design System components. This will help you locate the parts.

Construct the Trebuchet using these Subassemblies

Note: 2 assemblies are required for the right and left side frames

1. **Base Plate**
2. **Left and Right Frames**
3. **Lever Arm Assembly**
4. **Counter Weight**
5. **Projectile and Sling**
6. **Cross Bracing**

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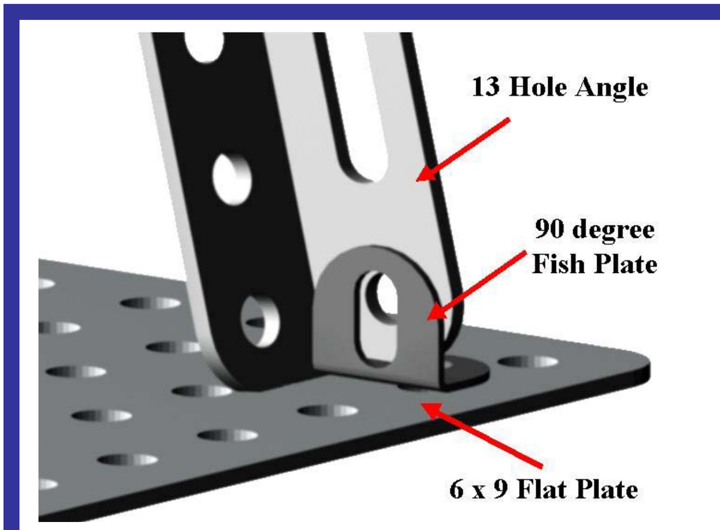

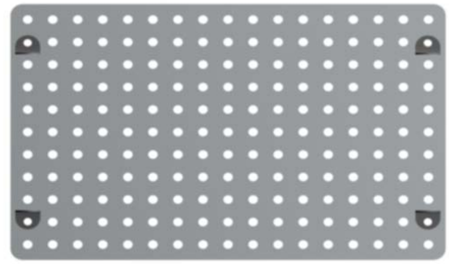

Base Plate with 4 Fish Plates

Step 1
Base Plate Assembly

Note: Use #10-24 x 3/8” machine screws with a flat washer, star washer and #10-24 nut on every connection. Leave the setscrews loose until the final assembly.

Study the illustration and align and mount the 90 degree fish plates as indicated in the illustration above.

It is possible to assemble the components in several different ways and still create a working trebuchet. This is particularly true regarding the selection and use of flat bars for cross bracing and the throwing arm assembly. As your familiarity with the components, and your knowledge of the operating principles that govern the function of the trebuchet grows, you will be able to customize and improve your trebuchet’s design.

Step 2
Assemble the Side Frames
(2 required)

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Note: You can choose to use both 17 hole flat bars as cross bracing, or you can elect to use one 17 hole and one 11 hole flat bar. This will leave you with the option of using the longer 17 hole flat bar for the throwing arm assembly if you wish.

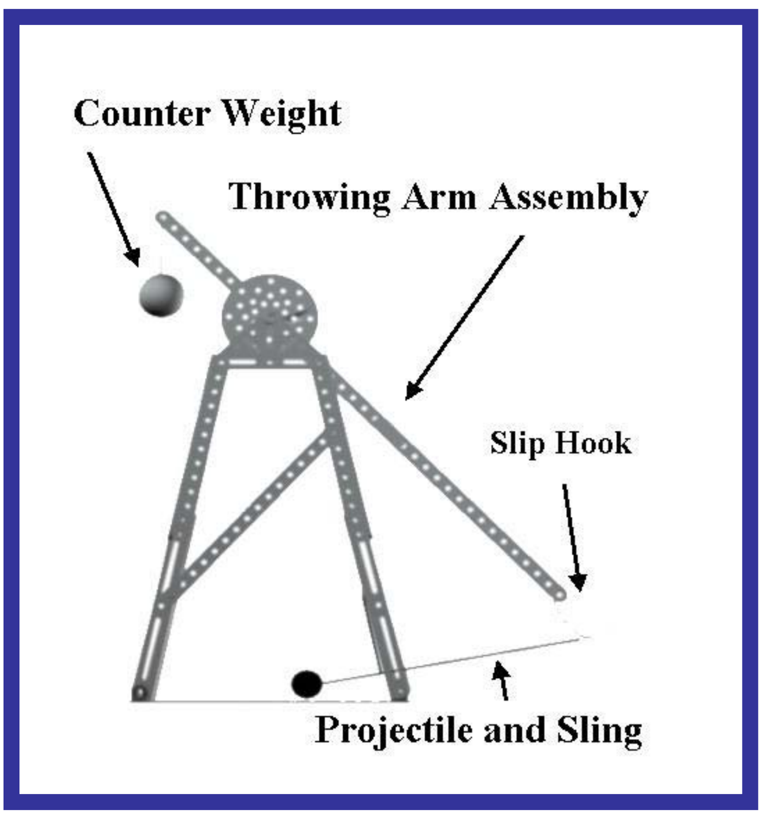
The trebuchet frame must be rigid. Rigidity prevents unwanted movement and vibration in the frame structure. A loosely constructed frame will reduce the trebuchet's accuracy. The frame must also be high enough to allow the throwing arm to have a full range of motion.

Step 3

Attach Both Frames to the Base

Be certain that the frames are carefully aligned and mounted to the 6" x 9" base plate in the same (respective) positions.

Cross bracing is used to provide rigidity in many structures like bridges, buildings and truck chassis to name a few. Cross bracing adds important structural rigidity to the trebuchet frame. Be careful to position the cross bracing similarly but in opposite orientation on each frame assembly.



Step 4

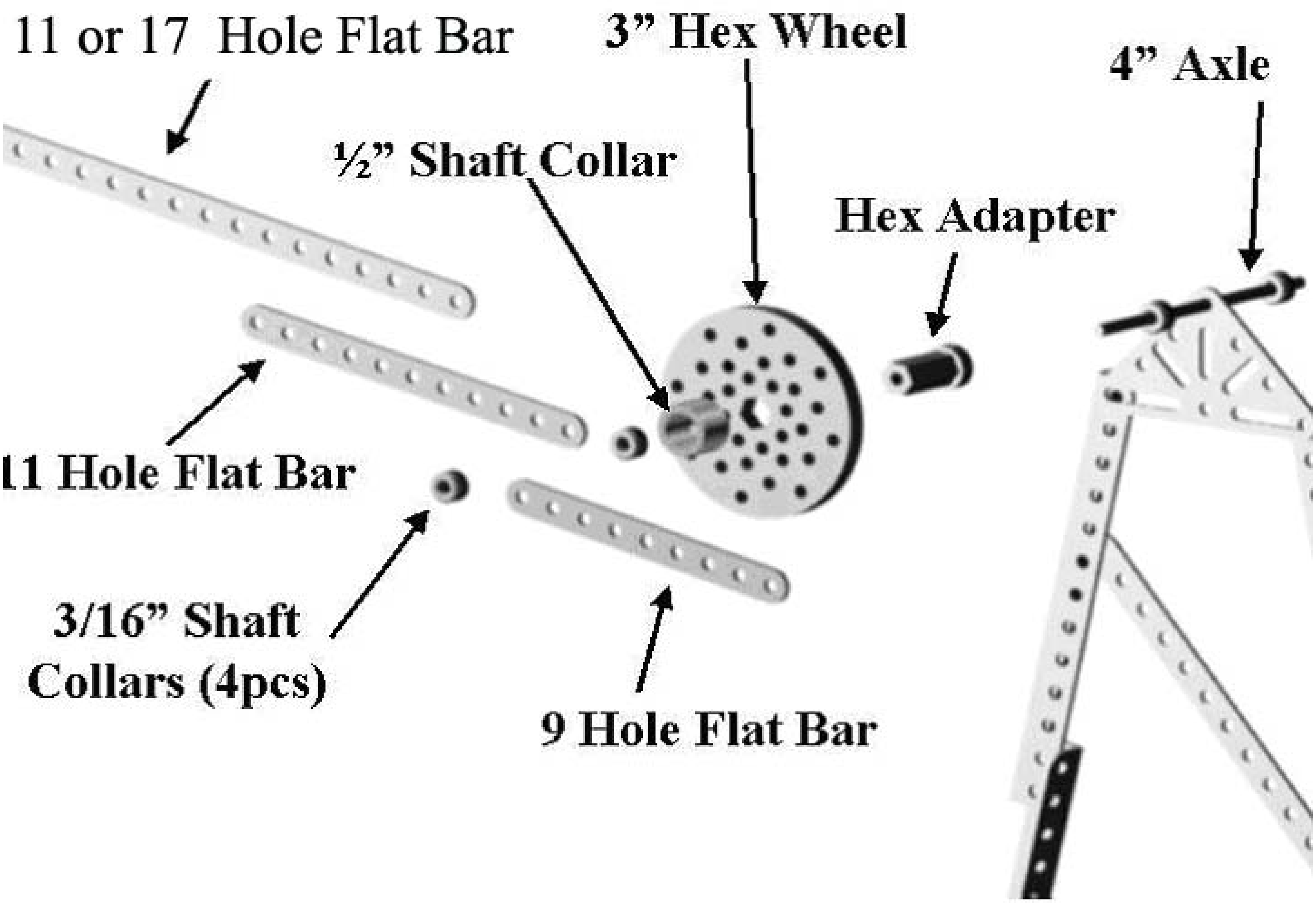
Construct the Throwing Arm Assembly

The throwing arm is the business end of the trebuchet. There are many variations, and adjustments that can be made in the design of the throwing arm in order to increase the speed and angle of the projectile.

The combination of projectile speed, and angle of release is determined by these factors:

1.) Throwing arm length and weight
2.) Counter weight arm length and weight
3.) Friction at the turning point or fulcrum
4.) Counter weight mass
5.) Projectile sling length
6.) Projectile mass
7.) Projectile release angle

Exploded View of the Throwing Arm Assembly



Construct the Throwing Arm Assembly

Note: Leave the screws and nuts loose until the final assembly.

1.) Select a 4" x 3/16" diameter axle
2.) Slide a 3/16" shaft collar onto the axle, about 3/8" from the far end.
3.) Slide a hex adapter with a 3/16" bore onto the (approximate) center of the shaft. Do not tighten the hex adapter set screws.
4.) Slide a 3" hex wheel onto the hex adapter.
5.) Secure the 3" hex wheel with a ½" shaft collar as shown above.
6.) Slide a 3/16" shaft collar onto the axle, about 3/8" from the near end.
7.) Attach a 9 hole flat bar to the 3" hex wheel using two #10-24 x ½" machine screws
8.) Attach an 11 hole flat bar to the 3" hex wheel, directly opposite to the 9 hole flat bar. Use two #10-24 x ½" machine screws to attach it to the 3: hex wheel.
9.) Attach either a 17 or 11 hole flat bar to the 11 hole flat bar using two #10-24 x ½" machine screws.

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10.) Attach the throwing arm assembly to the trebuchet frame by gently spreading the frame sections and positioning the axles in the top holes of the sine triangle pieces.

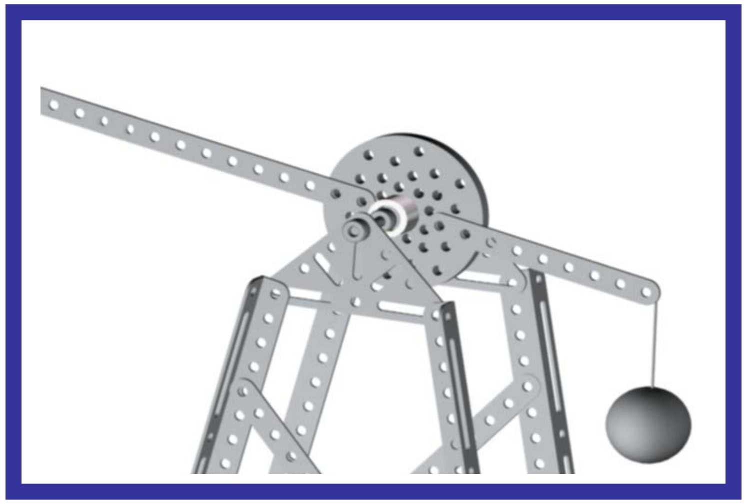
11.) Use a 3/16” shaft collar on each end of the axles to secure the throwing arm assembly to the frame.

12.) Use the shaft collars to position the wheel and arm assembly, and secure it in place in a such a manner as to reduce side play.

Note: For best results, do not use the hex adapter set screws. Allow the hex adapter and wheel assembly to rotate on the axle. The hex adapter turning on the axle makes a better bearing assembly than the axle turning on the holes in the sine triangle components.

Step 5 Attach the Counter Weight

The GEARS-IDS Trebuchet works well with a counter weight of 8 – 16 ounces or 224 - 448 grams. Attach the counter weight to the throwing arm assembly using masons line, fishing line or a paper clip. Be certain to attach the counter weight in a manner that will secure it from breaking away during use while allowing it to swing freely on the end of the throwing arm assembly.

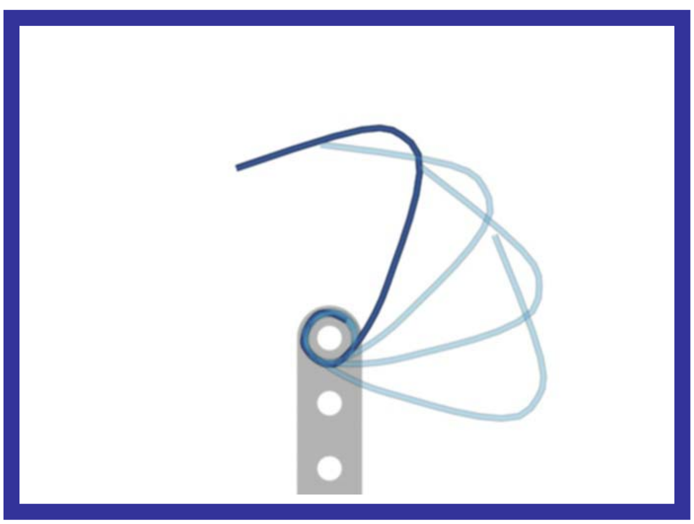


Suggested Experiment

Which of the following will throw a given projectile a further distance, and why?

1.) The Counter weight is rigidly affixed to the throwing arm.

2.) The Counter weight is allowed to hang freely from the throwing arm as shown in the illustration above.



Step 6

Attach the Slip Hook

Caution: The slip hook is a sharp pointed object swinging on the end of a shaft. Always use safety glasses when working on or testing the trebuchet!

The slip hook can be fashioned from a paper clip, welding rod or similar materials. Use needle nose pliers to form the hook.

Attach the slip hook to the end of the throwing arm using a #10-24 x 3/8” machine screw, flat washer and nut.

The shape and angle of the slip hook controls the angle of release of the projectile. For best performance, make slight adjustments to the shape and angle of the slip hook, and test the flight of the projectile after every adjustment. It often takes 100 or more test launches in order to “Tune” the counter weight, throwing arm assembly, projectile sling length and projectile weight for optimum performance.

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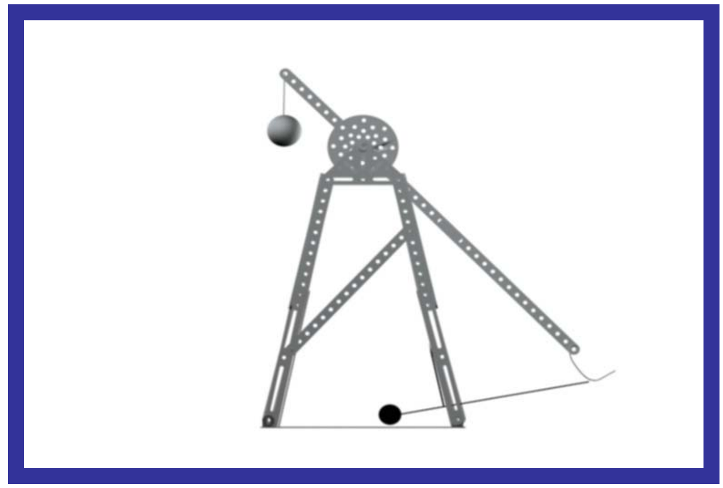
Step 7

Assemble the Projectile and Sling

The projectile is round wooden ball approximately 1” (25.4 mm) in diameter and weighing approximately 5 grams (0.18 ounces). The sling is a fine thread with a loop on one end.



The projectile and sling length can range between

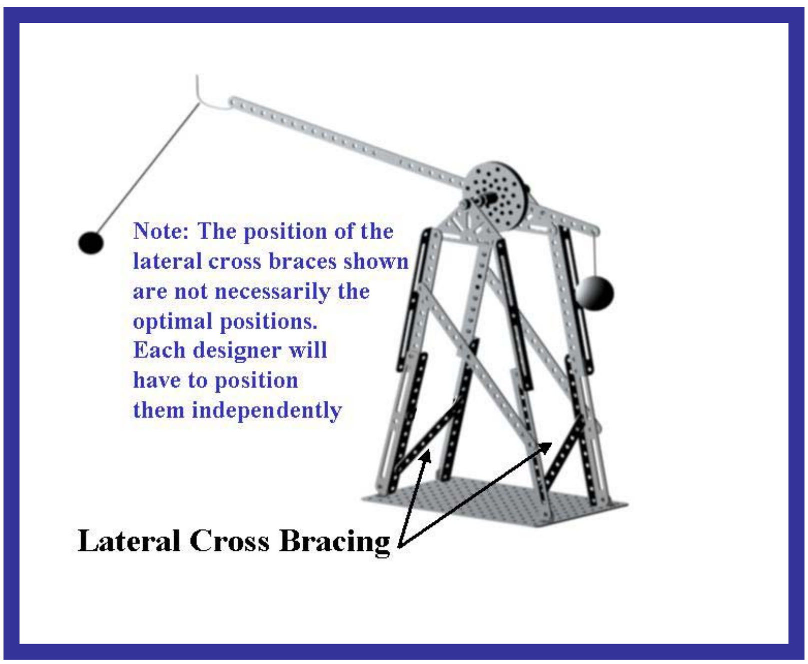
The sling is attached to the wooden ball in one of two ways.

1.) Attach the sling by drilling a small, 1/32” hole through the wooded ball and passing the non looped end through the hole and knotting it to the ball
2.) Tape the sling to the ball.

Step 8

Add the Lateral Cross Bracing

The final step in the trebuchet assembly is to add the lateral cross bracing. The trebuchet frame must resist torsion (twisting) and racking forces acting on all axis (x,y, and z). The lateral cross bracing adds torsion rigidity and prevents the frame from twisting about the vertical (y) axis.



The reason the lateral bracing was added last is because it can potentially interfere with the swing of both the projectile and the counter weight.

Take precautions to ensure that the 5 and seven hole pieces used for the lateral cross bracing are positioned in such a way as to not interfere with the swing of the projectile or counter weight.

Remember: **<u>A rigid frame will ensure consistently accurate throws</u>**. A frame that is wobbly or loosely constructed will allow the throwing arm to release the projectile at a different angle on every throw. A loose frame that twists will induce right and left (azimuth) angle error. *Angular rotations along the vertical or y axis are referred to as azimuth angles. Angular rotations along the horizontal or x axis are referred to as altitude angles.* A right or left angle error of 5 degrees will result in a 1.7 foot error over 20 feet!

Many builders elect to fasten their trebuchets to weighted wood bases in order to further stabilize the mechanism and ensure repeat accuracy. Remember that engineering is an iterative process and optimizing the performance of your trebuchet can take many dozens of trials.

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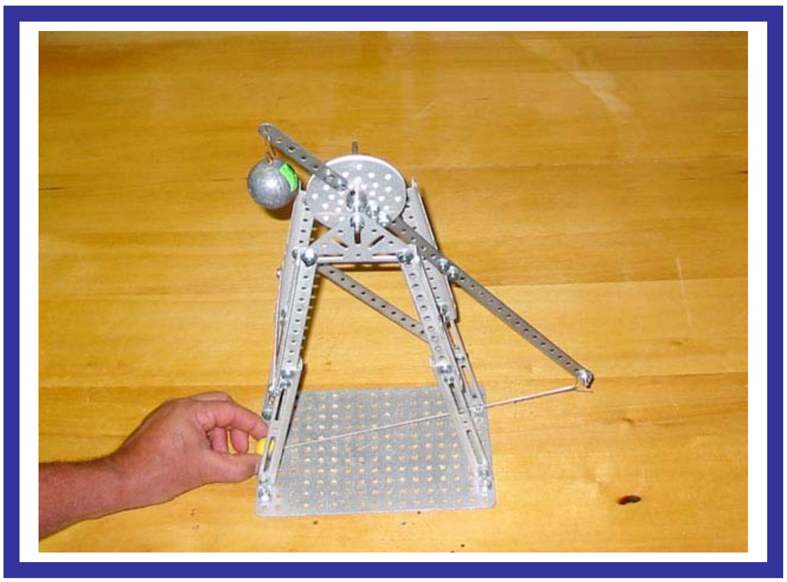
Using the GEARS-IDS Trebuchet

The trebuchet is a gravity-powered class one lever mechanism. The potential energy of the raised counter weight is converted into kinetic energy as the weight falls. The disproportionate ratio between the counterweight lever arm length x the counterweight mass and the projectile lever arm length x the projectile mass, creates a significantly unbalanced force that acts to accelerate the projectile to a very high velocity in a very short period of time.



Launching the Projectile:

1.) Attach the projectile and sling to the slip hook.
2.) "Cock" the trebuchet by pulling down and back on the projectile ball and raising the counter weight.
3.) Release the ball by gently and slowly releasing your grip.

The GEARS-IDS Trebuchet pictured on the left uses a counter weight made from a 12 ounce (336 grams) round lead fishing weight.

The projectile is a 5 gram (0.18 oz), 1" diameter wood ball with a total ball and sling length of 12" (305 mm).

The slip hook angle is set to release the projectile at an angle of 45 degrees to the horizontal.
This trebuchet consistently hurls the projectile 18-20 feet (5.48 – 6 meters).

While this trebuchet design works well, it is in no way optimal. This design can be significantly improved. By experimenting with the variables listed in step 4 it should be possible to obtain consistently accurate throws of up to and in excess of 25 feet or more.

CAUTION: The slip hook is an important component of the trebuchet and it controls the angle at which the projectile is released from the throwing arm. The slip hook has a sharp end that can scratch your skin and lacerate an eye. Always wear safety glasses when working on, using or experimenting with a trebuchet.

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Gravity Games

Designing Building and Using a GEARS-IDS Trebuchet

The following document outlines a trebuchet challenge activity that was developed by Michael Bastoni for his engineering classes. This same activity was presented by Michael Bastoni at the Robo-Educators CAD Institute held at SolidWorks world Headquarters in Concord MA on August 2003.

The **Trebuchet Gravity Games** is an “Engineering Immersion” activity that challenges students to design, build and experiment with an engineering model they construct and use in a competitive game of math, science and engineering skills.

Activity Description

Student teams of up to 4 competitors can work co-operatively to design and construct a model trebuchet. The “Deliverables” can be all or some of the following:

1.) A 3 ring binder that *(chronologically)* documents:
   a. Work Sheets associated with this lesson
   b. Assignments such as library and internet Research on the history, development and societal impact of trebuchets.
   c. Notes from class discussions, demonstrations lectures or video presentations.
   d. CAD Drawings
   e. Sketches
   f. Design process notes and photo documentation
   g. Related tests, and quizzes on related math, science, engineering or historically related concepts.

2.) Trebuchet Model using the GEARS-IDS kit

3.) Student produced presentation of a slide show or web page documenting the knowledge and skills gained through participation in this activity.

Activity Overview

The Gravity Games Instructional Unit includes a performance activity in which students apply basic CAD, Math, Science and Engineering knowledge and skills to build trebuchet models capable of hurling (lightweight) projectiles precisely and accurately over distances ranging from a few feet to more than 20 feet.

Making Up the Game Rules

The following strategies and methods for making up trebuchet game rules are offered as suggestions only. Specific game rules and regulations are the prerogative of the classroom teacher and his or her students.

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1.) After thoroughly researching and discussing the subject of trebuchets, students create the specific objectives, targets and game playing procedures. This is an appropriate strategy for high school classes.
2.) The teacher, working in cooperation with the students, develops game playing rules and constraints.
3.) The teacher considers the learning objectives and subject matter emphasis and creates a trebuchet targeting game that best reinforces the material covered.
4.) Combinations of the above strategies.

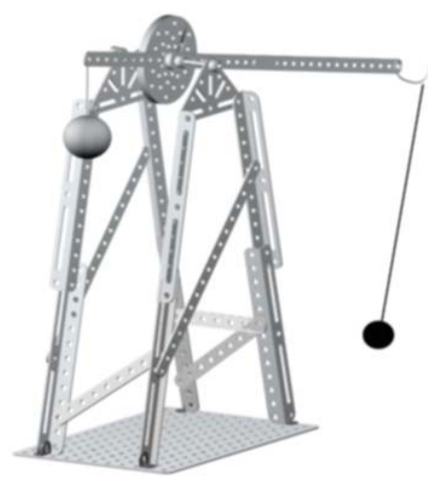
Example Tournament Rules and Regulations for Gravity Games

The Playing Field

An unobstructed area of roughly 200 square feet with a minimum width of 10 feet and a minimum ceiling height of 8-10 feet *(Higher is better).* The playing field needs to accommodate all the students, and their trebuchet projects and still provide enough unobstructed space to play on.

The Projectile

Wooden balls can be purchased from hobby and craft stores or online at several locations. To locate online vendors use the keyword search "Wood Balls".



The Counter Weights

Counter Weight Mass is restricted: Weights cannot exceed 16 ounces or 450 grams

Creating The Target

1.) Tape 4, 81/2" x 11" letter size papers together to form a 17" x 22" sheet.
2.) Make 2 of these sheets
3.) Create the same form using 4 sheets of carbon paper.
4.) On one (1) sheet draw concentric circles with radii of:
    a. 2" = 16 points
    b. 4" = 4 points
    c. 8" = 1 point
5.) In use, the target is made up of a "Sandwich" of three materials layered in this order:
    a. Concentric circle target face up.
    b. Carbon Paper
    c. 17" x 22 " blank sheet

Note: The target point value rationale lends itself to a geometric application of the inverse square law.

Game Playing Process

1.) A student team positions their *(Completed)* trebuchet on the floor of the playing field at any distance from the target are they choose.
2.) The team is allowed to make (1) a single "Ranging" shot, and the shot contact point is marked on the floor with a dry erase marker or coin.
3.) After the ranging shot, the team is not allowed to move the target or their trebuchet.

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4.) The center of the target is placed over the shot contact point and taped to the floor. The base of the trebuchet can also be taped to the floor. This is optional.
5.) The student team is given 5 *(regulation)* shots. As each shot contacts the surface paper, a blue carbon contact point is registered on the target sheet in contact with the carbon paper.

Scoring

1.) Scoring is based on the following algorithm. Developing the algorithm can be a creative experience, and there are absolutely no specific rules that govern the development of the scoring algorithm. The following scoring algorithm is offered as an example.

$$\text{Score} = \text{Point Total of 5 Shots} \times \text{Distance from Target in Feet}$$

Note: Each student team is allowed to score only the 5 consecutive shots following the ranging shot. The ranging shot is not scored.

Winning the Game

The team with the highest point total wins the Gravity Games Competition.
In the event of a tie, the game is decided by a sudden death play off. Each team is allowed 1 shot without benefit of a ranging shot. They are however, allowed to use a tape measure for their firing set up.

Note: Many possibilities exist for creating a variety of game play and scoring strategies. Students and teachers are encouraged to create their own variations and add their own creative twists.

Further Your Knowledge

The web offers nearly limitless resources on how to build trebuchets, as well as historical information and sophisticated mathematical modeling tools that can help you optimize and engineer more performance from your trebuchet model, in less time.

Take advantage of the opportunity to learn about the massive trebuchets designed and used by medieval engineers to lay siege to castles by spending an evening researching trebuchets on the web. It's an enjoyable and informative use of your time, and it's a great way to study the impact that engineering and technology have on culture and economy.

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