Robotics Engineering

DoDEA – Career and Technical Education

Simple and Compound Machines

Exercise 2 – Inclined Plane, Wedge and Screw

Objective: At the completion of this exercise, you will demonstrate the effects of mechanical advantage regarding the use of inclined planes, wedges and screws. You'll build models of these simple machines and then calculate, test, and verify the results of your inclined plane machines.

Deliverables: *Copy and paste the required deliverables to another document for submission. All deliverables must be word processed with the required student ID information in the footer of the document. The header of the document should contain the title of the assignment. Both the question and answer must be included in the deliverable with the answers highlighted. All work must be complete and accurate to receive credit.*

1. Detailed definitions for each of the terms found in the Nomenclature section.
2. Detailed answers to the queries listed in the Questions section.
3. Completed Spreadsheet Math Model for the Inclined Plane.

Information: The inclined plane is ancient simple machine. It was used for more than a millennium before Archimedes and Heron of Alexandria first theorized its physical operations and discovered how it provided for mechanical advantage. Over 1000 years later, inclined planes might have been used to place the largest blocks at Stonehenge. Another 1000 years later, inclined planes in the form of ramps were used to build the Great Pyramid at Giza.

An inclined plane is a flat surface (plane) that slopes at an angle (inclined) to provide a path to move an object from one level to another. Examples of inclined planes include ramps, graded roads, or a playground slide. Wedges are an example of double inclined plane and a screw is an inclined plane that's wrapped around an axis. Examples of wedges would be an axe, chisel or doorstop. Worm gears, screw jack, and a screw (duh) are examples of the simple machine known as a screw.

Research Resources: Use your search engine to research information on Inclined Planes, Math and Simple Machines.

Web Site	Description
http://www.slideshare.net/jbishopgcms/planewedgescrew	Explains different types of Inclined Planes
http://www.cosi.org/downloads/activities/simplemachines/sm1.html	Describes Inclined Planes and how they reduce force
http://zonalandeducation.com/mstm/physics/mechanics/forces/inclinedPlane/inclinedPlane.html	Apply math to Inclined Planes

Nomenclature: *Research and develop a detailed (two to three sentences) definition for each of these terms. It's important to realize that many words have multiple definitions. Some of which may have nothing to do with this course of study. Make sure your definitions fall within the context of this lesson.*

- *Mass*
- *Gram*
- *Centimeter*
- *Joule*
- *Slope*
- *Thread*
- *UNC*
- *UNF*
- *TPI*
- *Foot Pounds*

Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section.
2. Who is Hero (Heron) of Alexandria? What do you feel were his most significant contributions to engineering?

Procedure:

Required Materials and Equipment: Get these materials and tools from your instructor.

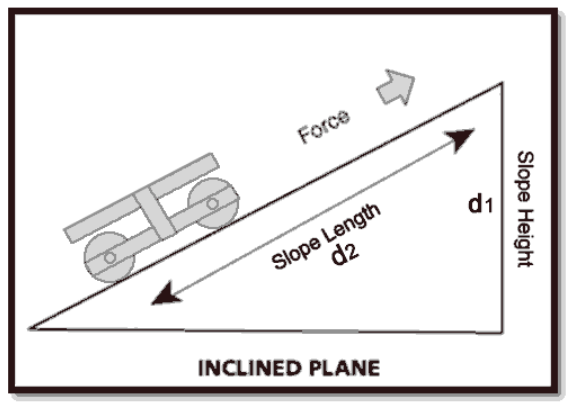
Lego NXT Mindstorms Kit   String: 1 Meter   Vernier Dual Force Sensor

Steps: Complete each of the following steps in the assigned order:

Inclined Plane: There's always a trade-off when using simple machines to perform work. With inclined planes you choose to lift an object a short distance using more force, or can use a ramp to lift the same object the same height, but over a longer distance using less force. The mass of the object and the work accomplished stays the same it just takes more time (distance) to get the job done. You should consider this relationship of proportions as you build and test the Inclined Plane model.

The Math:

Terms -	M = Mass	W = Work	F = Force	d = Distance	MA = Mechanical Advantage
Equations -	*W = Fd*	*MA = d2/d1*	*F = Mass/MA*		*Joule = Newton-Meter*



As before, we define Work as applying force to move an object a certain distance. An inclined plane reduces the effort necessary to move the load by distributing the force required to perform the task over the distance of the inclined plane. Reducing effort is a good thing, but we do sacrifice having to exert the reduced Force over a greater distance. There's always a trade-off.

*If we wanted to lift an 80 lb. bag of concrete from the floor up to a tabletop 3 ft. up we could calculate the Work required as **W = Fd** or… The Work is equal to 80 pounds multiplied by 3 ft. for a total of 240 foot-pounds of Work.*

*When we use an inclined plane to do the same task, it takes the same amount of Work to perform the task. However it takes less Force to get the Work done because of the Mechanical Advantage provided by the inclined plane. In an inclined plane, Mechanical Advantage is equal to the Slope Length divided by the Slope Height or **MA = d2/d1**. If we used a 12 foot long ramp to move a bag of concrete up to the same height of 3 feet, the equation for Mechanical Advantage would be MA = 12 ft./3ft. or 4 ft. To determine how much force is actually required to move the bag of concrete up the (frictionless) ramp we would apply the formula **F = Mass/MA** or… F = 80 lb./4 or… 20 foot-pounds. Here's the sequence of calculations:*

Step 1.	***W=Fd***	*240 foot-pounds = 80 lb x 3 ft.*
Step 2.	***MA=d2/d1***	*4 ft. = 12 ft. / 3 ft.*
Step 3.	***F = Mass/MA***	*20 foot-pounds = 80 lb / 4 ft.*

Using an incline plane 12 ft. long and 3 ft. high, it now takes only 20 lbs. of Force to move an 80 lbs. bag of concrete.

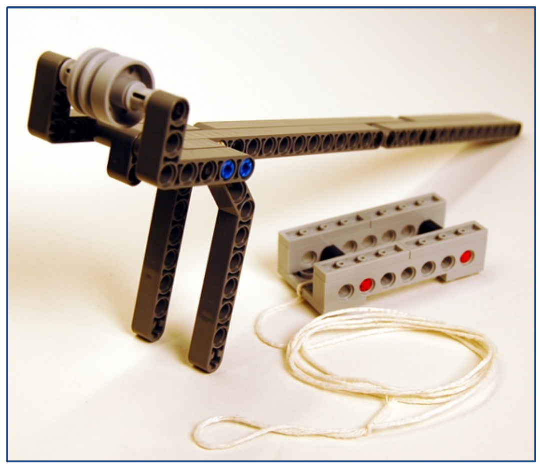


Figure 1. Inclined Plane Model with Trolley

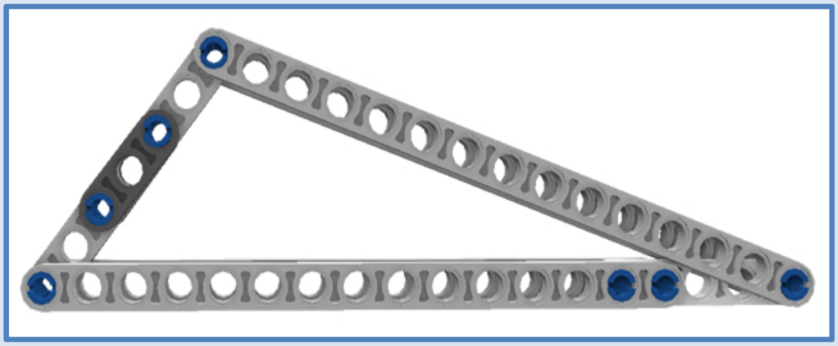
1. ( ) Carefully examine the model of the Inclined Plane and Trolley shown in Figure 1. Construct a model similar to the one shown in the photograph. The trolley must slide easily up and down the model of the Inclined Plane.
2. ( ) Tie one end of the string to the Trolley as shown and tie a loop on the opposite end. Place the Trolley onto the rail of the model of the Inclined Plane with the rollers facing down. Secure a load to the Trolley in a way that won't interfere with its travel on the rail and route the string from the Trolley over the pulley hanging freely off the edge of a table or bench.
3. ( ) Measure the dimensions of the Inclined Plane and use the Excel model to calculate the Mechanical Advantage for the first version of the Inclined Plane.
4. ( ) Attach the looped end of the string to a number of wheels, gears and tires that (when combined) will allow the weighed trolley to ride slowly and continuously up the Inclined Plane without assistance.
5. ( ) Measure the amount of force exerted on the trolley by the string and counter weight with a force sensor.
6. ( ) Modify the Inclined Plane model making it a little longer by adding one more section of Studless Technic Beams. Repeat the force and distance measurements. Operate the Inclined Plane in the new configuration noting any difference in the machine's behavior.
7. ( ) Modify the Inclined Plane model again adding one more section of Studless Technic Beams. Repeat the measurements and then the experiment noting any difference in the machine's behavior.

Wedge: The basic difference between an Inclined Plane and a Wedge is that a Wedge moves and an Inclined Plane does not. Wedges can be either single-sloped like a doorstop or double-sloped like an axe or knife. The mathematical analysis of wedges is essentially the same as with Inclined Planes. Instead of using the term Height, we'll use the term Thickness. The Mechanical advantage is determined by dividing the length of the slope by the thickness of the wedge (MA = d2/d1). The shaper the angle of the wedge, the less effort is needed to operate it.

The Math:

Terms - d2 = Slope Length   d1 – Thickness

Equations - *MA = d2/d1*



Let's look at the cross-section of a wedge. you'll notice it is really nothing more than a triangle. Applying the equation ***MA = d2/d1****, you should notice that the relationship between the length of the wedge (****d2****) and the thickness of the wedge (****d1****) are considered inversely proportional because d2 is being divided by d1. This means that the smaller the thickness of the wedge compared to its length, the more mechanical advantage it can deliver. The opposite is also true. As d1 increases, mechanical advantage is reduced if the length of the wedge remains the same.*

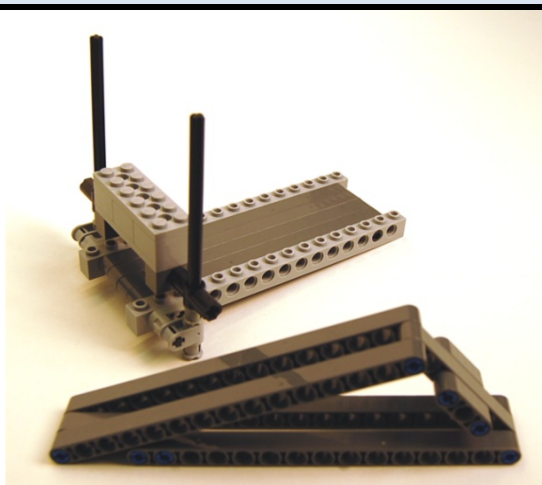


Figure 2. Wedge Model and Test Apparatus

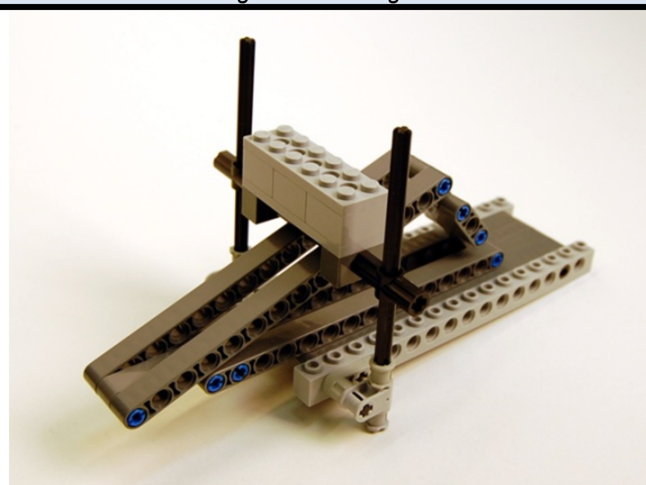


Figure 3. Long Wedge Inserted into the Test Apparatus.

1. ( ) Carefully examine the model of the Wedge and the test apparatus shown in Figure 2. Construct a model similar to the one shown in this photograph.
2. ( ) Secure a load to the lift platform on the test apparatus in a way that won't interfere with its travel on the two vertical support rails.
3. ( ) Measure d1 and d2 on the wedge and then calculate the mechanical advantage if the longest slope of the Wedge is used to lift the load as shown in Figure 3.
4. ( ) Measure d1 and d2 on the wedge and then calculate the mechanical advantage if the Shortest slope of the Wedge is used to lift the load.
5. ( ) Alternately push the long and the short slope of the Wedge through the test apparatus making note of the difference in the force required to perform the work.

Screw: A screw is an Inclined Plane where the plane is wrapped around an axis like a cylinder. The threads of the screw act as a single plane while the spacing between the threads form the slope of the plane. The greater the spacing of the threads means the greater the angle of the Inclined Plane requiring greater effort to drive the screw. The finer the threads indicate a smaller angle of the Inclined Plane and subsequently, the lesser effort to drive the screw. The trade-off again… Although Mechanical Advantage increases, more turns will be required to do the same amount of work with a screw with fine threads as the one with larger thread spacing. The relationship between the number of threads and a specific distance is called the "Pitch." The screws that come with the Tetrix robotics kit are identified as #6-32 and #10-32 screws. Although both screws have a pitch of 32 Threads Per Inch (TPI), the diameters of the screws are different as indicated by the first number. It's important to note that these screws are not interchangeable.

The Math:

Terms - Pitch = 1/Threads Per Unit of Measure (TPI) Π = Pi FP = Foot Pounds r = Radius " = Inch

Equations - *MA = 2Πr / Pitch*

The English and Metric systems of measurement are used to determine the specifications of lots of things including hardware like screw, nuts and bolts. The Metric system is based on the Meter as the standard unit of measure and is considered to be more logical because it's based upon decimal units. A Meter is divided into 10 equal parts called decimeters, 100 equal parts called centimeters or 1000 equal parts called millimeters. The English system, also known as the inch system or the Imperial system is based on the Foot measurement. A foot is divided into 12 equal parts called inches. However, when we consider threads on a bolt like the one shown to the right we're not talking about inches. We're really talking about very small measurements like 1/16", 1/32" and 1/64".

This bolt is a ¼" in diameter. It's a course thread (UNC) bolt 1¼" long with a Pitch of 20 TPI. To determine the Mechanical Advantage of this simple machine we'll simple apply the formula. Before we start, you'll need to know that the radius is half the diameter. Since the diameter of this bolt is ¼", to find half of any fraction, simply multiply its denominator by two or… 2 x 4 is 8 equaling 1/8" for the bolt's radius.

1. *MA = 2 Π r / Pitch*
2. *MA = 2 x Π x 1/8" / (1/20)*
3. *MA = 2 x 3.14 x .125 / .05*
4. *MA = 15.7*

This means that this screw will multiply the turning force 15.70 times. So if we apply 14 foot pounds of force to turning this bolt, the tightening force of the nut will be 14 ft lb x 15.7 resulting in 219.8 ft lb of energy. 14 lb of effort results in 219.8 lb of force using this simple machine called a screw. That's pretty impressive.

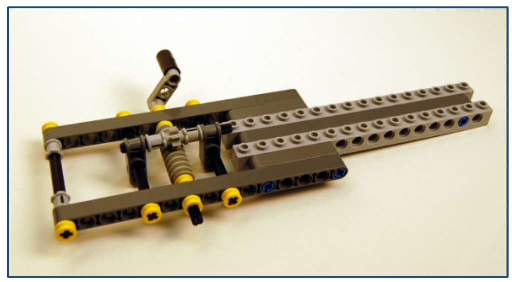


Figure 4. Model of a Screw Machine

1. ( ) Carefully examine the model of the Screw Machine shown in Figure 4.
2. ( ) To build the model of the Screw Machine you can refer to the photographs of this model you'll find in the photo gallery on the course's webpage.
3. ( ) Take a closer look at the part of this machine that resembles the threads of a screw. This is also called a worm gear primarily because it sort of looks like a worm when it's turning. Now here's a tricky question: How many teeth does this worm gear have? Did you think it has ten or perhaps twelve teeth for its entire length? Would you believe it has only one tooth? It's one tooth that continuously spirals around the axis of the worm gear's axle. As the handle is turned clockwise and counterclockwise it will drive the tiny non-spinning worm drive gear from one side of the machine to the other.
4. ( ) Use a ruler to measure the number of threads this worm gear has in one inch. This will be the screw's pitch or threads per inch (TPI).
5. ( ) Now… How many turns of the handle does it take to make the little worm drive gear travel one inch?
6. ( ) Do you see the relationship between the screw's pitch and the turns needed for it to drive one inch?
7. ( ) Refer to the Math section for the Screw and calculate the Mechanical Advantage for this machine.

Conclusion:

Inclined planes, wedges and screws seem like they may be different types of machines but they're really all the same simple machine but in different forms. The math used to determine how they work is closely related to each machine as well. That's easier to see when comparing the math used to calculate mechanical advantage using an inclined plane with that of a wedge. After all, a wedge is really just a mobile version of an inclined plane. The math is a little harder to see when determining the Mechanical Advantage of a screw. The relationship in the equation *MA = 2Πr / Pitch* is clearer to see if you realize that *2Πr* represents the slope length of an incline plane for one revolution of the screw or it's circumference. The *Pitch* is the height of the slope or the thickness as it relates to a wedge.

Like in all applications of simple machines, there is always a trade-off between the effort made to make the machine operate and the amount of actual work it performs. In simple machines, as the amount of effort is reduced and the amount of work stays the same, then the distance must increase to get that work done.