Robotics Engineering

DoDEA – Career and Technical Education

Simple and Compound Machines

Exercise 4 – Wheel and Axle

Objective: At the completion of this exercise, you will demonstrate the mechanical advantage inherent to the wheel and axle combination. You'll measure the diameters of wheels and axles and develop a mathematical model describing their relationship.

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 defining the mechanical advantage for various wheels and axle combinations.

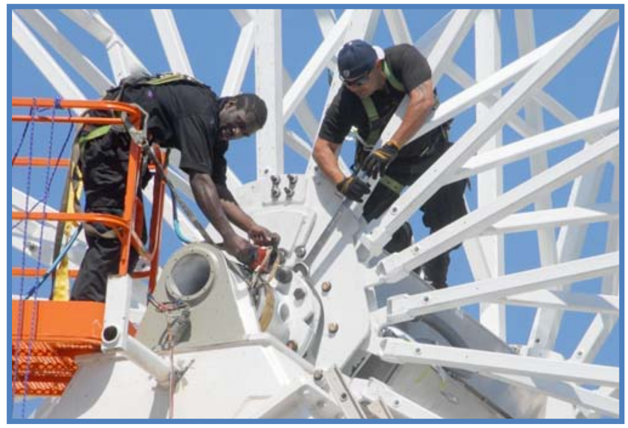


Figure 1 – Mechanics work at the axle as they assemble and maintain a huge Ferris Wheel.

Information: The wheel… It's been around since the dawn of man. It's hard to pinpoint when it was invented or what culture invented it. It seemed to simultaneously appear in Central Europe, the Caucasus and Mesopotamia during the Copper Age (about 4000 BC) give or take a millennium or two. We're talking ancient history here.

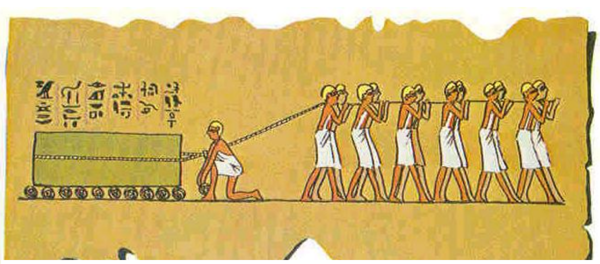


Figure 2 – Wooden rollers are swapped-out one at a time as a heavy stone block towed along.

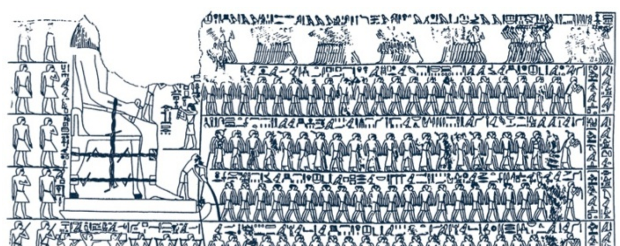


Figure 3 – Hundreds drag a stone sculpture that's secured to a sledge.

Before wheels, people would move very heavy objects using tree logs as rollers. They also used sledges (big sleds) to slide stuff around. Sledges worked well on low-friction surfaces like ice, snow and sand but not as well on grass and rock. When the going got too tough… When they couldn't get the sledge to budge, someone had the great idea to combine the roller and the sledge. They discovered as the rails of the sledge cut deep grooves into the rollers, they didn't need to use as many rollers to keep the sledge moving. That was good, because it wasn't a lot of fun swapping-out rollers every two or three second to keep the sledge moving. Larger rollers were heavier and more difficult to reposition as well, but they also made it easier to roll the sledge. If there was only a way to reduce the weight of the larger rollers and secure it to the sledge so it didn't have to be swapped-out all the time. At first they just carved out the center portion of the roller making it a single piece construction of the

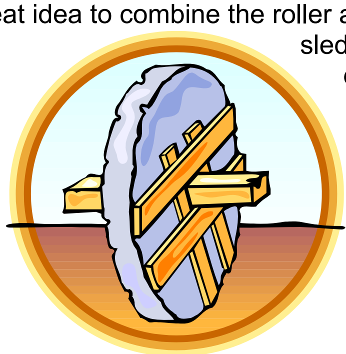


Figure 4 – Stone grinding wheel with axle for grinding grain or minerals.

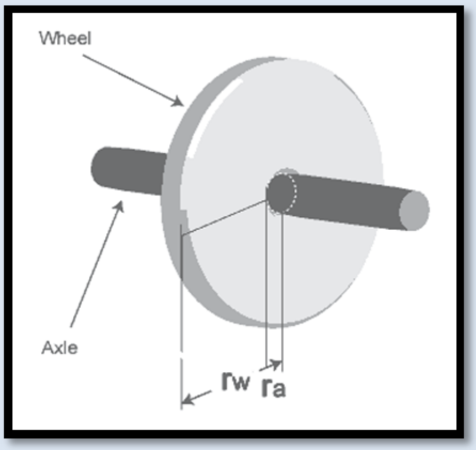
Figure 5 – By the courtesy of Fred's own two feet. Even as a kid I always wondered how that back roller just didn't fall off.

wheels and axle. The axle was pegged into a fixed position on sledge and thus… the wheeled cart was invented. Later enhancements included spoke wheels to make them lighter and repairable. As new materials have been developed, wheels and axels have improved significantly. When methods were developed to apply force to the wheel or to the axle, mechanical advantage became part of this simple machines engineering importance. The wheel and axle has become the most prevalent and significant invention in the history of mankind.

The Math:

Terms -	MA=Mechanical Advantage	Dw = Diameter Wheel	Da = Diameter Axle	
	C = Circumference	R = Radius	Lb-ft = Foot Pound	
	RPM = Revolutions Per Minute	D = Diameter		
Equations -	*MA = Dw/Da (Input at Wheel)*	*MA = Da/Dw (Input at Axle)*	*R = D/2*	*C = 2ΠR*

*One way to look at a wheel is to consider it as a continuous lever of the 2nd class. The axle would be the fulcrum and the radius at any point would be the bar. Like the lever, turning the steering wheel in a car will multiply the force at the axle. The bigger the steering wheel, the greater the leverage and the more rotational effort (torque) would be applied to the axle. An automobile's wheels are different. The effort is applied at the axle. Therefore, the effort at the axle is divided as it reaches out to the road's surface. Mathematically, this is represented by the equation **MA = Dw/Da** if the input effort is at the wheel and **MA = Da/Dw** if the input effort is at the axle.*



Tire sizes for my Jeep Wrangler go from 27" to 44" in diameter. The size that came stock with the vehicle are 28". The axle that drives each of the wheels has a diameter of about one inch. With the stock tires, the MA is 1/28" or .036. Slap on a set of 44 inchers, the MA would be 1/44" or .023. So what does that mean?

If the engine applied 222 lb-ft of torque at the axle, I would lose about 2.88 lb-ft of torque if I changed my wheels from the stock 28" to the oversized 44" tires. In essence, I would lose power but my Jeep would look awesome! Here's the application:

1. $MA_{28} = .036$
2. $MA_{44} = .023$
3. *.036 - .023 = .013*
4. *222 lb-ft x .013 = 2.88 lb-ft difference*

As with all applications of mechanical advantage, there is a trade-off. The smaller the tire, the more force is transferred to the where the rubber hits the road. Since the tire is smaller, its circumference is too. That means the wheel will have to make more revolutions to acquire the same speed using the larger tires. You'll get more power at the wheels, but your top-end speed will be reduced.

*The circumference of a 28 inch diameter wheel is calculated using the equation **C = 2ΠR** and results in 2 x 3.141 x 14" or about 88 inches. One rotation of the 28" wheel would push the Jeep 88 inches down the road. Using the 44" tires, that application of the same equation (C = 2 x 3.141 x 22) would result in a circumference of about 138 inches. One rotation of the axle would push the vehicle over 10 feet down the road. Although the larger tire would require fewer rotations to travel a specified distance and the vehicle would have a higher top-end speed, it would require more torque to perform the task. There's always a trade-off.*

Research Resources:
The WWW changes all the time. If the listed links do not work, first inform your instructor then use a search engine to research information regarding the described subject.

Web Site	**Description**
http://library.thinkquest.org/C004203/science/science02.htm	Ancient Civilizations – Invention of the Wheel
http://en.wikipedia.org/wiki/Wheel_and_axle	Wiki on the Wheel and Axle
http://en.wikipedia.org/wiki/Caliper	How to Use Calipers
http://www.ehow.com/how_2273770_read-metric-ruler.html	How to Use a Metric Ruler

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.

- *RPM*
- *Foot - Pound*
- *Caliper*
- *Wheel and Axle*

Questions:
1. Research and develop a detailed definition for each of the terms found in the Nomenclature section.
2. The drive system of a robot features drive wheels that have a diameter of 3". If the robot's gear box has rotated the drive wheels 10 revolutions… About how far has the robot traveled?
3. The wheels of a drive system for a robot are 64mm in diameter. The maximum speed for the motor's gearbox at the axle is a 160 RPM. If the robot is driven at its highest speed for 30 seconds… How far will it have traveled in meters?
4. Repeat the same calculations as in question 3 replacing the wheels with ones that are 128mm in diameter.
5. Calculate the maximum feet-per-minute for a robot that uses 8" drive wheels attached to a direct drive gearbox with a maximum output speed of 400 RPM.

Procedure: *In the following activity you'll have to measure the diameter of an axle and various sizes of wheels. The best tool to perform this task is a **vernier caliper**. These calipers come in dial and digital varieties but you'll have to make sure your measurements are in millimeters and not inches for this activity. Hopefully you have access to one of these nifty measurement tools. If not, you might also be able to transfer the measurements using an **outside caliper**, but it takes some effort to make accurate measurements. As a last resort, you can directly measure the diameter of the axle and wheels using a **metric ruler**, but you'll also throw the concept of accuracy out the window. There are informative links in the Research Resources section describing how to use calipers and rulers. The most important consideration is accuracy… Learn how to use the tools, make accurate measurements, but verify your results. I understand that the precise dimensions of many LEGO components can be found on the Internet if all else fails.*

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

- Mindstorms Robotics Kit
- Mindstorms Resource Set
- Tetrix Robotics Kit
- Outside Caliper
- Linear Caliper
- Metric Scale

Steps: Refer to these figures as you take your measurements. Complete each of the following steps in the assigned order:

Tetrix Omni Wheel

Diameter: mm

Tetrix 3" Wheel

Diameter: mm

LEGO Tractor Wheel

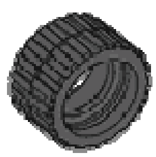
Diameter: mm

Balloon Tire

Diameter: mm

Tire Ring

Diameter: mm



Small Tire

Diameter: mm

Bushing, Grey

Groove Diameter: mm

Bushing, Small

Groove Diameter: mm

Axle

Diameter: mm

1. ( ) Measure and record the diameters of each of the wheels (and axel) shown above.
2. ( ) Enter the measured information into the Wheel and Axle Excel Model following the instructions posted on the model's worksheet.
3. ( ) Make a temporary mark somewhere on the circumference of one of the larger wheels. Place the wheel with that mark positioned on a flat surface. Making a temporary mark at that point on the flat surface. Carefully roll the wheel precisely one revolution making another mark on the surface at that point. Measure the distance between the marks on the flat surface. Does this measurement match the circumference the model calculated for that wheel?

Figure 4 - Digital vernier caliper used to measure inside and outside diameters in either inches or millimeters at a press of a button.

Conclusion: In completing this exercise you discovered that the mechanical advantage of a wheel and axel can be determined by dividing the diameter of the input by the diameter of the output. Driving this simple machine by the wheel multiplies effort at the axle while driving it by its axle divides the effort at the wheel. You also discovered that the circumference of the wheel and its number of rotations per unit of time determines the distance the wheel can travel in a specified period of time. That's speed baby and speed takes into consideration this simple machine's mechanical advantage when it comes to converting effort into motion and determining the trade-offs needed to get work done.