PULLEY POWER

LEVEL

Year 11

VCE: Systems Engineering

ACTIVITY DESCRIPTION

At Puffing Billy Railway's workshops, they use winches and pulleys to position locomotives allowing workshop staff to complete specific tasks. The equipment used to move Puffing Billy Railway locomotives is old and needs replacing. To design this new equipment students need to use specific engineering calculations to determine and validate the required pulley's size and strength. Consequently, students will also develop an understanding of the internal friction required to move a locomotive within the workshops.

Students will undertake a range of theoretical calculations to determine the mechanical advantage. They will complete physical experiments in the classroom to understand and explain the difference between measured values and predicted values. Students will use this information to explain any differences in the experimental mechanism that account for any variation between measured values and predicted values.

SUBJECT AREA

Systems Engineering Unit 1: Mechanical Systems

Area of Study 1 – Mechanical System Design

MATERIALS REQUIRED

- "Pulley Power" Worksheet
- "Pulley Power" Experiment sheet
- "Pulley Power" Experiment data sheet
- Pens/pencils
- Calculator
- Ring stand
- Pulleys
- String
- Spring scale
- Weight
- Meter stick

INSTRUCTIONS

1. As a whole class, introduce students to Puffing Billy Railway's locomotives. Show students Puffing Billy Railway 6A steam train 3D model (Image 1). Show where the bearings are located on this train (Image 2).
2. As a group watch this video about bearings - https://www.youtube.com/watch?v=Jt0ou8Q5Fo8
   a. Explain what bearings are.
   b. What type of bearings does Puffing Billy Railway use?
      i. Plain metal bearings/journal bearings (different to the video but work similar) **HINT**: show this video to outline the type of bearing that Puffing Billy Railway locomotives have- https://www.youtube.com/watch?v=_cN1E8KUvmk
   c. Where do we use these bearings on a steam train?
   d. All bearings have friction. What affects the level of friction?

3. Ask the class, *"What is a pulley?"* Show examples of a pulley. Describe the mechanical advantage of a pulley.
4. Ask students *"What formula would we use to calculate mechanical advantage?"* Draw the formula on the board. Explain the elements of the formula.
5. Have experiment materials ready. Hand out the "Pulley Power" Experiment and "Pulley Power" Experiment data sheet. Split students into pairs or groups and have them undertake the experiment to create their own pulley system following the method on the "Pulley Power" Experiment sheet. Have students write their findings on their "Pulley Power" Experiment data sheet.
   HINT: show students the safe way to use experimental equipment.
6. Bring students back together and discuss observations and results. Set them up for their next challenge.
7. Hand out the "Pulley Power" Worksheet to each student. Give students time to complete the worksheet.
8. Once the worksheet is complete. Discuss with students the answers.

SUGGESTIONS FOR ASSESSMENT

Students' ability to work safely in teams to complete "Pulley Power" Experiment. Collection of data and completion of the "Pulley Power" Experiment data sheet. Ability to complete the "Pulley Power" Worksheet.

CURRICULUM LINKS

SYSTEMS ENGINEERING

Unit 1: Mechanical Systems

Area of Study 1

Mechanical System Design

Outcome 1: On completion of this unit the student should be able to describe and apply basic engineering concepts and principles and use components to design and plan a mechanical system using the systems engineering process.

Outcome 2: On completion of this unit the student should be able to produce, test, diagnose and evaluate a mechanical system using the systems engineering process.

BACKGROUND INFORMATION

IMAGE 1 – PUFFING BILLY RAILWAY STEAM LOCOMOTIVE 6A

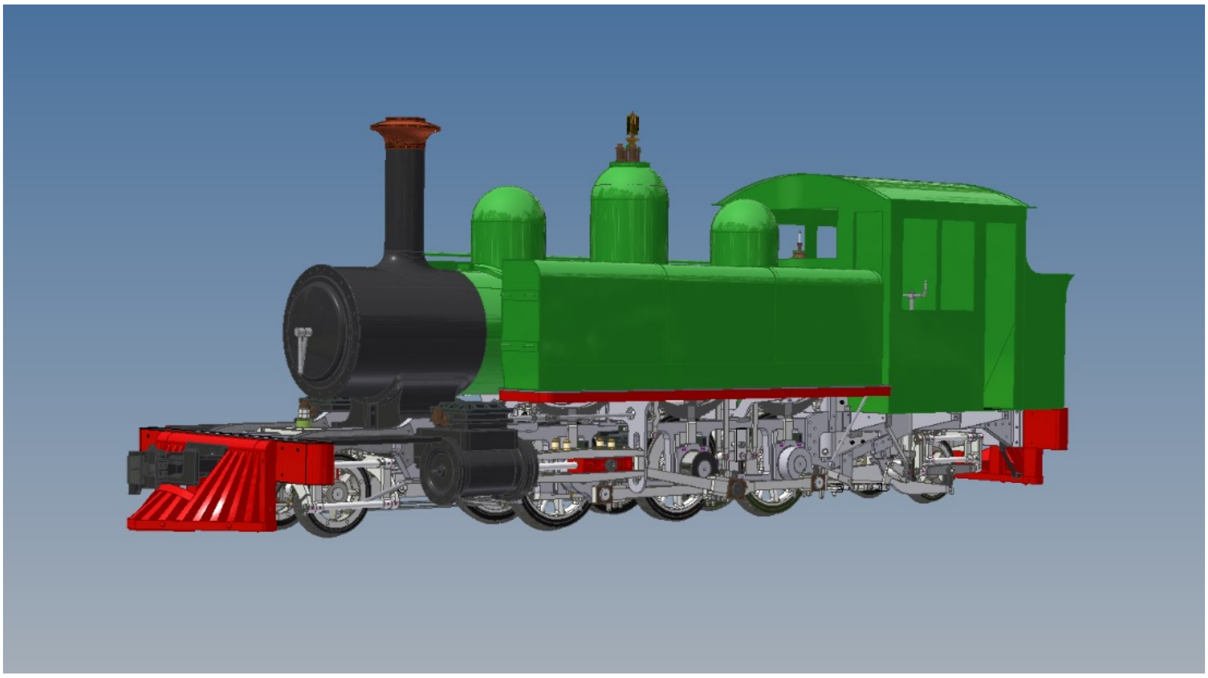
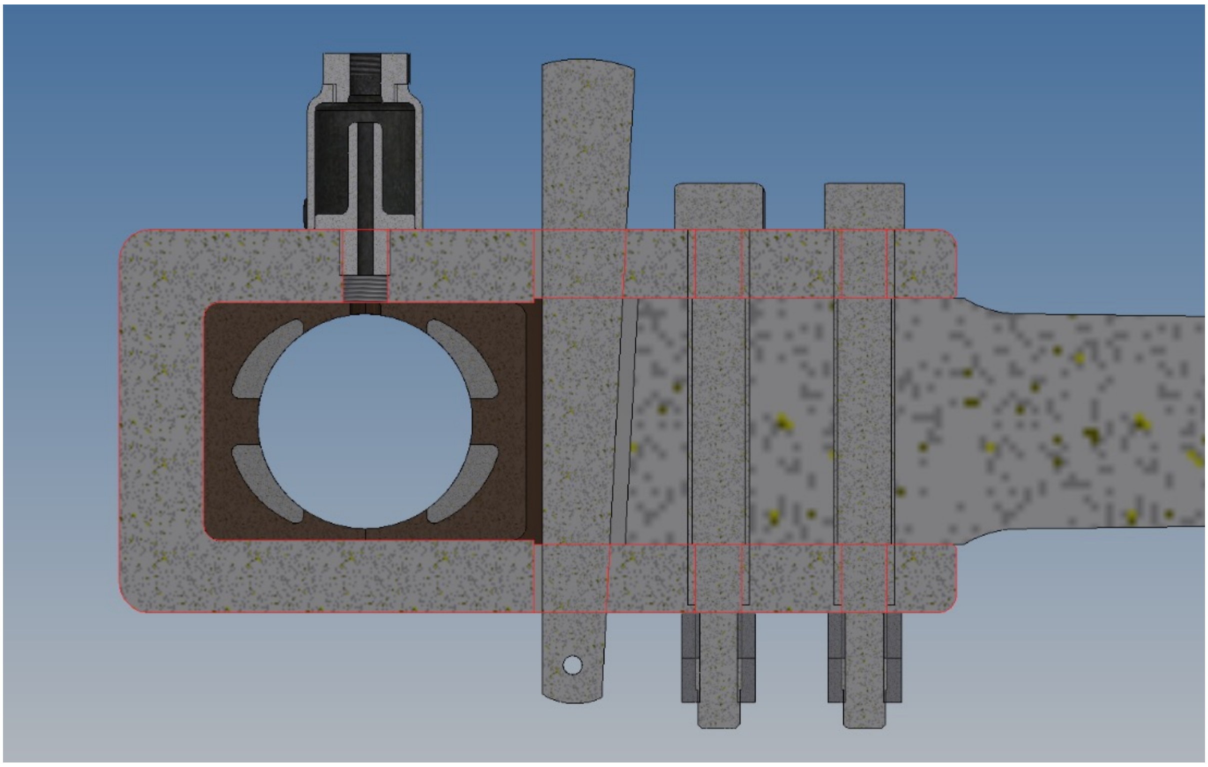


IMAGE 2 – STEAM ENGINEER BEARING LOCATION



BEARINGS

***Reference**: NSK Global*

From a small supermarket trolley to huge power plants, a great number of light-duty, as well as industrial equipment, could not function without the use of bearings in some form.

Bearings are a crucial component of many types of machinery and exist in a variety of forms and shapes. They can be defined as a machine element that supports/permits only a specific type of motion (restriction of degrees of freedom) in a system that may be under static or dynamic loading.

An example is a sliding door. The door cannot be lifted or removed from its place. It only permits sliding to open it. The possible movement is restricted to sliding motion by bearings

The main purpose of bearings is to prevent direct metal-to-metal contact between two elements that are in relative motion. This prevents friction, heat generation and ultimately, the wear and tear of parts. It also reduces energy consumption as sliding motion is replaced with low-friction rolling.

BEARINGS AT RAILWAYS

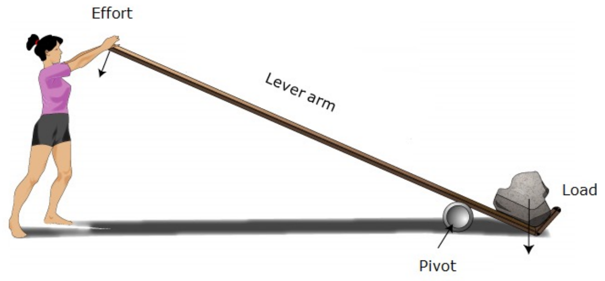
The railway industry stands as a testament to human ingenuity and technological advancement, providing efficient and sustainable transportation solutions across the globe. At the heart of this expansive network lies a multitude of components working harmoniously, among which bearings play a pivotal role. Bearings serve as fundamental mechanical elements that facilitate motion, reduce friction, and enable the smooth operation of various machinery within trains and railway systems.

Bearings serve as critical components within locomotives, freight cars, passenger coaches, and various railway infrastructure, enabling the seamless movement of wheels, axles, and other rotating parts. Their primary function is to minimize friction between moving surfaces, thereby reducing wear and tear, enhancing efficiency, and extending the lifespan of mechanical components.

In the railway industry, various types of bearing designs are employed across different components and systems to facilitate smooth movement, reduce friction, and ensure the reliability of trains and infrastructure. These bearings are meticulously designed to withstand heavy loads, high speeds, and diverse environmental conditions prevalent in railway operations.

Reference: https://www.bdsbearing.com/blog/bearings-in-the-railway-industry-enhancing-efficiency-safety-and-reliability#:~:text=Commonly%2C%20cylindrical%20roller%20bearings%20and,loads%20and%20moderate%20axial%20loads.

MECHANICAL ADVANTAGE



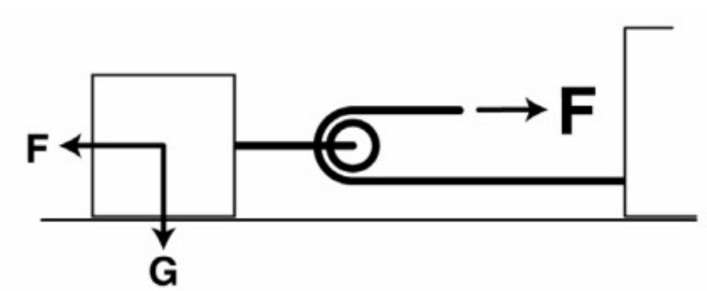
Mechanical Advantage is a measure of the ratio of output force to input force in a system, used to analyse the forces in simple machines like levers and pulleys.

Mechanical Advantage = Load/Effort

We can assume that when the mechanical advantage is >1, the output force is more than the input force. When the mechanical advantage is <1, the output force is less than the input force. When the mechanical advantage is =1, then the output force is equal to the input force.

What is mechanical advantage?
https://study.com/academy/lesson/mechanical-advantage-definition-formula.html

PULLEYS



A pulley consists of a wheel with a groove for a rope, cord, belt, or chain to rotate around. Pulleys make work easier by lifting and lowering a load. A flagpole is an example of a pulley. Flags are attached to a rope with hooks. Flags are lowered and raised by pulling the rope that rotates around a grooved wheel at the top of the flagpole.

THE ROLE OF FRICTION

The law of conservation of energy is one of the fundamental principles of science and a powerful mathematical model for analysis and prediction of the behaviour of objects within systems. It is often difficult if not impossible to analyse all of the many types of energy in a system. It is much easier to analyse the three types of energy that make up mechanical energy. Conservation of mechanical energy is a valuable tool for understanding motion. For example, the aerial moves of circus acrobats, high divers, and snowboarders can be analysed as transformations of gravitational potential energy and kinetic energy. Collisions among several objects, such as a number of cars in an accident or balls in a game like billiards, can be analysed as transformations of kinetic energy and elastic potential energy.

There is almost always friction acting. If there is, the quantity of mechanical energy in the system is not constant. For example, consider a toboggan and its passengers going downhill on rough snow and ice (Figure 6.20). This toboggan-passenger system is a mechanical system. At the top of the hill, all of the energy of this mechanical system is mechanical energy, consisting of the gravitational potential energy of the toboggan and its passengers. As the toboggan slides, friction is an opposing force transforming some energy from the toboggan into thermal energy. By the time the toboggan gets to the bottom of the hill, it is moving quite fast, but not as fast as it would have been without friction. The mechanical energy of the system at the end of the run is less than at the beginning. The "missing" energy has been transferred from the toboggan as heat. Energy is always conserved, but the mechanical energy in a system may or may not be conserved.

Figure 6.20 Friction acts to reduce the mechanical energy in a system. A toboggan sliding over a rough snowy surface will be brought to rest by the force of friction. There is no way to get back the original kinetic energy of the toboggan after friction has brought the toboggan to rest. The motion of the toboggan has been transformed into kinetic energy of the atoms that make up the toboggan and the snow.

Reference: https://userfiles-secure.educatorpages.com/userfiles/MsKlein/19P11SEch06.pdf

EXPERIMENT SAFETY

Teaching your students to recognise the dangers that exist in the workshop and how to combat them is an important skill.

Risk assessing is a process we all do in our everyday lives, without even realising. When we cross the road we make a risk assessment – identifying the hazard of crossing in traffic, the harm of being hit by a vehicle, the severity of that harm. We identify control measures of looking for traffic, selecting safter places to cross, moving across the road quicky.

All this might happen very quickly in our minds, so we don't see it as a process. This comes from having internalised our training when we were younger and applying the control measures frequently.

When we carry out practical work, we are risk assessing both in the situation and, more deliberately and formally, in our planning. As part of their scientific education, students need to develop knowledge and skills in risk assessment. This starts from their first day in the laboratory, right up to self-directed extended investigation. Knowing about hazards, risks and control measures is key to keeping themselves and others safe.

Reference: https://edu.rsc.org/ideas/how-to-teach-risk-assessment-skills/4016786.article

Reference: https://www.safepointapp.com/lab-safety-poster-form

REFERENCES

https://www.technologystudent.com/gears1/geardex1.htm

WORKSHEET – PULLEY POWER

At Puffing Billy Railway's workshops, they use winches and pulleys to position locomotives to allow workshop staff to complete specific tasks on them.

The equipment used to move Puffing Billy Railway is old and needs replacing. You need to determine how many pulleys are required to move a Puffing Billy locomotive around the workshop.

1. Calculate the mechanical advantage (MA), MA is the ratio of the load to the effort:

$$mechanical\ advantage = \frac{load}{effort}$$

The **load** of a Puffing Billy locomotive = 35 tonnes

A workshop motor that will attach to the pulley can provide an **effort** of = 5 tonnes

What is the mechanical advantage? (Show your workings)

2. Use the formula below to determine the number of pulleys that are required to move the locomotive:

$$mechanical\ advantage = 2 * n$$

How many pulleys are required? (show your workings)

3. The locomotive was moved 10 metres in 30 seconds. Calculate the **Work** done (show your workings). Use Si units.

Velocity = $velocity = \frac{distance}{time}$

Acceleration = $Distance = velocity * time + ½ * acceleration * time^2$

Force = $force = mass \times acceleration$

Work done = $work\ done = force\ in\ direction\ moved \times distance$

4. When Puffing Billy Railway have tested their new equipment they got the results below, explain why there is a difference?

Work done = 4000 J

What is the actual Mechanical Advantage =

$$\frac{Workactual}{Worktheory} = \frac{MechanicaAdvantageActual}{MechanicalAdvantageTheory}$$

PULLEY POWER EXPERIMENT

Name: Date:

PURPOSE

To demonstrate the purpose of the mechanical advantage provided by different pulley systems

You will be examining different pulley configurations to help you understand the concept of Mechanical Advantage (MA). Simply put, the ideal or theoretical MA of a pulley system is the number of ropes pulling up on the object being lifted.

Observed MA = (weight of the object)/(measured force required to life the object)

MATERIALS

- Ring stand
- Pulleys
- String
- Spring scale
- Weight
- Meter stick

METHOD

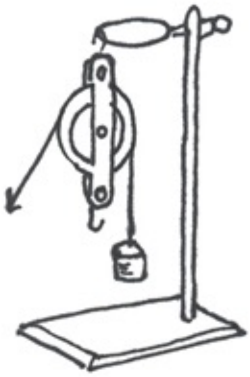
Step 1: Pulley Set-up

1. Record all data on the data sheet provided
2. Calibrate your spring scales.
3. For each configuration, you will be measuring the force required to lift the weight. You will also record the height you lift the object and how far the string pulled during the same lift. Record all of this information on the data sheet.
4. Weigh your weight using a spring scale. You will use this same weight throughout the entire experiment.

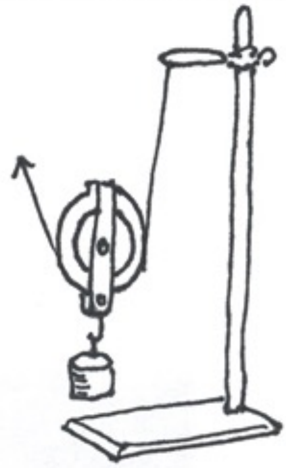
   Weight = Newtons (N)

5. For each of the following five configurations, answer the following questions on the data sheet:
   1. Based on your class notes, what is the theoretical MA of this system?
   2. Measure the force required to lift the weight
   3. Determine the observed MA of this system
   4. Measure the height the object is lifted
   5. Measure how far the string was pulled to lift the object
   6. Calculate the ratio of the length of string pulled to the height the object is lifted
   7. Explain why someone would want to use this type of pulley system

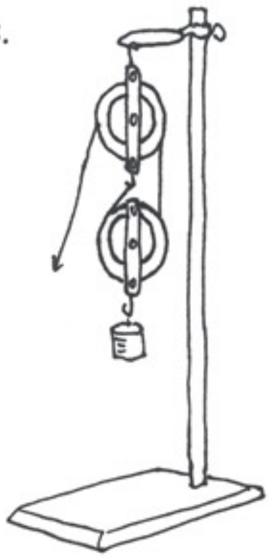
#1: Single Fix Pulley



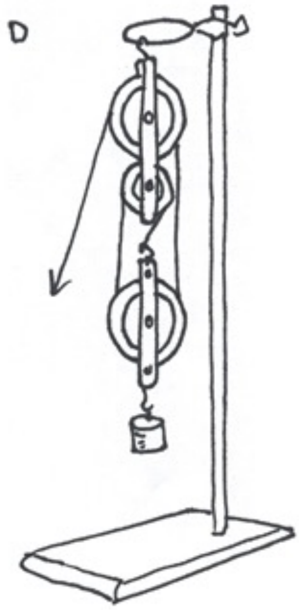
#2: Single Moveable Pulley



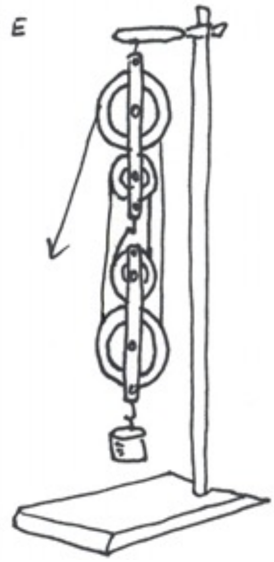
#3: Single Fixed, Single Moveable



#4: Double Fixed, Single Moveable



#5 Double Fixed, Double Moveable



6. On your data sheet, explain why the number of supporting ropes determines the mechanical advantage? Why can you count a section of rope you are pulling up on, but not a section you are pulling down on?

7. When using a simple machine, you use less force. What do you have to do more of in exchange? Write your answer on your data sheet.

EXTENSION: Look carefully at the string pattern around the pulleys. Find the relationship between the pattern and the Mechanical Advantage. Using only the two double pulleys, experiment with an arrangement of pulleys that has an MA of 5. Draw that arrangement on the back of your data sheet.

PULLEY POWER EXPERIMENT DATA SHEET Weight = Newtons

Pulley Configuration	Theoretical MA	Force Required to Lift Weight	Observed MA	Height Lifted	Length of String Pulled	String Pulled / Height Lifted	Why use this type of configuration?
Single Fixed							
Single Moveable							
Single Fixed, Single Moveable							
Double fixed, Single Moveable							
Double Fixed, Double Moveable							

Summary:

6.

7

Extension: Draw configuration on back of this page.