# <u>College Physics Summer Assignment for GSIP Juniors 2023/2024</u>

The summer assignment consists of four separate so-called case studies:

**(1)** The Cheerleader and the Football Player (5 pts.)

**(2)** Applying Newton's Third Law of Motion in the Graviton Ride (5 pts.)

**(3)** Escape from Colditz Castle (10 pts.)

**(4)** The Itsy-Bitsy Spider: An Analysis of Spider Locomotion (10 pts.)

Read through each case study and do your best to solve it. Please submit the summer assignment in class on Wednesday, August 23.

Good luck!

# The Cheerleader and the Football Player:

# Physics and Physical Exertion

by
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"They'll never be able to do it! We're gonna win!" Dave, the captain of the football team, told his teammates.

It was already a school-wide wager, but soon people from the city came in to drop off their spare change into either the football team's jar or the cheerleading squad's jar. The rules were simple: whichever team acquired the most money had to lift a member of the opposite team off the ground. It was unthinkable! A cheerleader lifting a 300-pound football player off the ground? Nobody thought it possible, and everybody wanted to see the cheerleaders try to do it.

Dave laughed, "Can you imagine Tracy—the tiniest girl ever—trying to lift one of us?" All of Dave's friends laughed. As they discussed the challenge further, the team decided to make it their goal to ensure that the task would fall to the cheerleaders. They organized a campaign and lobbied the student body to donate their money to the cheerleading squad's jar. The boys had a week in which to raise as much money as possible. The event would take place at Friday's pep rally and the donated money would go to the favorite charity of the winner in the contest. If the cheerleaders were given the task and couldn't do it, then the money would be donated to the football team's charity, the Make a Wish Foundation, but if the cheerleaders were chosen and somehow managed to lift a football player off the ground, then the money would go to the American Cancer Society.

The contest had just been announced earlier that morning, but already the jars were half full. "This is going to be a great fund-raiser!" noted Principal Robinson. "I can't wait to see what the cheerleaders will come up with this time!" The high school had a history of fundraisers like this—bets between the football team and the cheerleading squad—though nothing this demanding.

Each team wanted the money to go to their charity. Both teams were found huddled in between classes, discussing their strategy. For the football players it was simple, "All we need to do is lift one of the girls onto our shoulders. That should be good enough for the judges," said Darren, the quarterback. They all agreed and decided that Dave, the biggest guy on the team, would do the lifting if the football team earned the most money, and that he'd be the one the girls would have to lift if the cheerleaders ended up with the most money in their jar.

"Let's see how tough we can make it on them!" laughed Dave as the team dispersed after lunch.

On the other hand, the girls were hard at work. They had an idea of what they wanted to do and just needed time to execute their plan. Many of the girls stayed after practice to formulate their strategy. "Don't worry, girls! We know what it takes to win and we definitely have what it takes!" encouraged Nikita, one of the seniors on the squad. "We've been through a lot of these bets and we've been undefeated since I've been here. Let's keep up the tradition!"

The girls took her encouragement to heart and came up with a master plan to outwit the football team. It would be Tracy's job to lift the football player using a special apparatus that the girls had developed. "The rules don't say anything about us using something that we've built to help us, so let's go for it!" Tracy exclaimed. "We're definitely going to keep this tradition alive!"

The day was fast approaching. The girls were hard at work on their project and weren't telling anyone about it. Students and community members kept filling and refilling the jars with change. Since Principal Robinson was in charge of the jars and the money, no one had a clue which team would have to perform the task.

"It's Friday!" exclaimed Dave. "Are we ready, guys?"

"Yeeeaaahhh! We're gonna beat them and win all that money for our charity!" screamed the football team.

You could feel the tension between the football players and the cheerleaders during the pep rally. Each team was thinking of their strategy and couldn't wait to see the results.

After a rousing cheer from the audience, Principal Robinson took the microphone to announce the details of the contest: "Thank you students, faculty, and community members for contributing to this worthy cause. We raised over $500 in only one week! We should all congratulate ourselves on this tremendous generosity, but it's not over yet! I have the results of the competition and it seems that the cheerleaders will be given the task of trying to lift one of the football players off the ground!"

The crowd went wild. This was what they had come to see, but they quickly quieted down when Tracy, a member of the cheerleading squad, took the microphone. "We expected this to happen and we're ready for the challenge! I will be lifting Dave into the air with a little help from my friend, the pulley!"

No one in the crowd moved. They hadn't expected this. "I wonder what is going to happen?" said a few students. "Do they really think they can lift a 300-pound football player over two feet in the air with just a pulley and some rope?"

The crowd watched expectantly as the cheerleading squad set up their apparatus. From the ceiling descended four pulleys, all connected by a single rope. There was a sling connected to the two lower pulleys for Dave to sit in. As he sat in the sling, he wondered if the girls were really going to be able to pull it off. They certainly seemed to have thought of everything they needed to do the job.

The moment of truth came for Tracy. She pulled the rope gently and watched as Dave was lifted off the ground and into the air. She pulled the rope a little harder as the crowd gasped.

"The impossible has been made possible. Tracy has just lifted Dave off the ground! The cheerleaders win the bet and the money raised by this contest will go to the American Cancer Society! Congratulations, girls!" announced Principal Robinson. "But we have one question for you. How did you know what to do? Dave weighs at least twice as much as Tracy does. She couldn't possibly have lifted him that high."

## Questions

1. How did the pulleys aid the cheerleaders in their quest to beat the football players?

2. What is the minimum weight of a person pulling the rope in order to lift a football player who weighs 300 pounds (approximately 136 kg) by just hanging on the rope?

3. What if the cheerleaders had only set up a 2-pulley system? Would this 2-pulley system require more or less force than the 4-pulley system? Would a person weighing 120 pounds be able to lift the 136 kg football player, using the 2-pulley system, by just hanging on the rope?

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# Applying Newton's Third Law of Motion in the Gravitron Ride

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In this story, concepts including frictional force, centripetal force, centrifugal force, Newton's first law of motion, Newton's second law of motion, and Newton's third law of motion are elucidated through an exchange between two students enjoying an amusement park ride.

It is 1 p.m. Bobby and his friend Joe are at the amusement park. Bobby is an undergraduate student studying physics at his local community college. Joe is also a college student, majoring in English literature, and has never taken a course in physics before. Bobby is going to challenge Joe intellectually in his attempt to understand a ride called the Gravitron.

*Bobby:* Hey, Joe, look over there. The line for the Gravitron is short. Let's go on it.

*Joe:* Well, what does the ride do?

*Bobby:* It's a really fun ride. Basically, you stick to the wall of a spinning chamber while the floor drops out from under you.

*Joe:* That's impossible! No one can stick to a wall...unless they use glue on themselves!

*Bobby:* *(Bobby laughs.)* That's really funny. Nope, no glue or any other sticky stuff is used. You will stick to a wall.

*Joe:* Okay, Bobby...Let's see.

Bobby and Joe board the ride and enter a big circular room with rubber-padded walls. They stand up against the wall next to each other. Then the room begins to spin slowly, gradually spinning faster until they reach a high angular (or rotational) velocity. Just as Bobby promised, once they reach this high angular velocity, both boys stick to the wall so much that they can barely move. At that point, the floor below them drops about a half meter and both boys are now 50 centimeters above the floor as they stick to the wall. Eventually, the floor rises and the ride slows down. Once it stops spinning, the boys are able to freely move from the wall.

After the ride, Bobby and Joe go to a restaurant for lunch. While waiting for their food they talk about the ride they just went on:

*Bobby:* Well, I told you that we would stick to the wall.

*Joe:* I don't get it, why did we stick to that wall when the room spun?

*Bobby:* In order for you to understand why, I have to explain a few things to you. Are you up for learning some physics instead of your usual Shakespeare?

*Joe:* Absolutely, I really want to know what went on in that ride. It doesn't make sense to me. I really want to understand it.

*Bobby:* It's a bit complicated, so stick with me.

*Joe:* Okay Bobby, go ahead and explain.

*Bobby:* Well, first you have to understand the three vector definitions of motion.

*Joe:* What do you mean by "vector"?

*Bobby:* A vector quantity is a quantity that specifies not only a magnitude, which is basically a number, but also a direction, which is usually specified as an angle.

*Joe:* Oh, you mean like five meters northeast?

*Bobby:* Yes. That is an example of displacement where a position is measured with respect to an origin. Instead of saying northeast, we specify an angle between zero degrees (north) and 90 degrees (east). Now, velocity is also a vector quantity that is a measurement of how the displacement or location of an object changes with time, basically speed as in kilometers per hour, distance per unit time. Finally, acceleration is the rate of change of velocity with respect to time.

*Joe:* Okay. So what do these motion definitions have to do with me sticking to the wall?

*Bobby:* Well, what made you stick to a wall is a vector quantity called a force that is essentially a "push" or a "pull" on an object. Isaac Newton described the three fundamental laws of motion regarding forces in the 17th century. The first law states that if an object is not moving or moving with a constant velocity, then all of the forces exerted on the object (or the net force acting on the object) will add up to zero. The second law says that if an object's velocity changes over time (accelerates or decelerates), the net force acting on the object will equal an object's mass times the acceleration it is encountering.

*Joe:* So during the ride I was accelerating as the room spun faster and faster. Our speed increased.

*Bobby:* That's right Joe.

*Joe:* But once the room reached full speed, we weren't accelerating any more. There was velocity, but no acceleration. So why did we stick to the wall if there was no acceleration?

*Bobby:* I see why you're confused, this is a complicated process. Velocity is a vector quantity so it doesn't just have magnitude (speed), it also has direction. If an object's direction is changing, then the velocity of the object is also changing. Since we were moving in a circle, our direction was always changing.

*Joe:* So, from one point in time to the next, we were always moving in a new direction as we spun around the circle—and, since we had been going in a different direction the instant before, we were accelerating into the new direction. I see. If you travel in a circle, you're always accelerating even though you're traveling at a constant speed.

*Bobby:* You're right, Joe! This net force is one that causes an object to accelerate by changing its direction so that it stays in a circular path (see Figure 1). Without this acceleration, the object would just continue in a straight path tangential to the circular path (see Figure 2).

*Joe:* I get it. I was traveling in a circular path and the wall of the chamber resisted the force of my body against it, preventing me from flying out in a tangential path.

*Bobby:* Not exactly. According to Newton's second law of motion, as long as there is an acceleration acting on an object (your

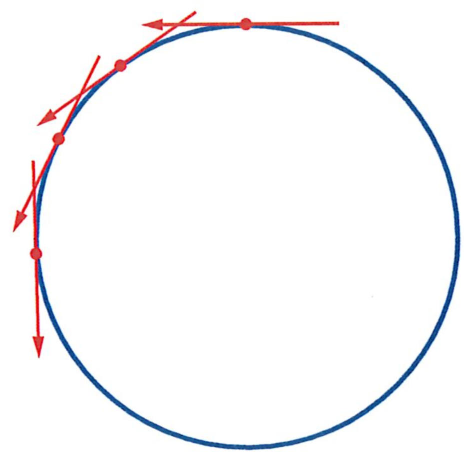


*Figure 1.* Here you see a blue circle with a small red circle representing an object traveling in a circular path around its perimeter. The red arrows represent the instantaneous direction of movement of the red circle as it travels in its circular path. As you can see, its direction is constantly changing so that its velocity is constantly adopting a new orientation, resulting in an effective acceleration as it travels at a constant speed since the velocity is always going from zero to something in every new direction. It is this acceleration that keeps the object moving in its circular path.

body), in this case caused by the change in direction, there is a net force acting on the object. In the Gravitron, the net force is generated by the wall of the spinning room that caused you to follow the circular path. The vector quantity of this net force is directed towards the center of the chamber. Since this net force is directed towards the center of the circle, it is defined as centripetal force.

*Joe:* Okay, now I'm confused. If the force was directing me towards the center of the circle, why did I stick to the wall? It felt like I was being pressed against the wall, towards the outside of the circle. You still haven't explained why we stuck to the wall.

*Bobby:* Many people have the misconception that there is an outward "centrifugal force" that acts on them and causes them to stick to the wall. However, that theory is totally wrong. Newton's third law of motion states that if one object exerts a force on another object then the second object will exert an equal and opposite force on the first object. Newton calls these two forces "action" and "reaction" forces, respectively. You've probably heard people say that for every action there is an equal and opposite reaction—that's true.

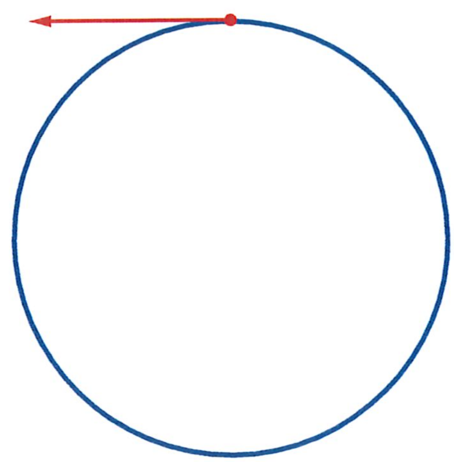


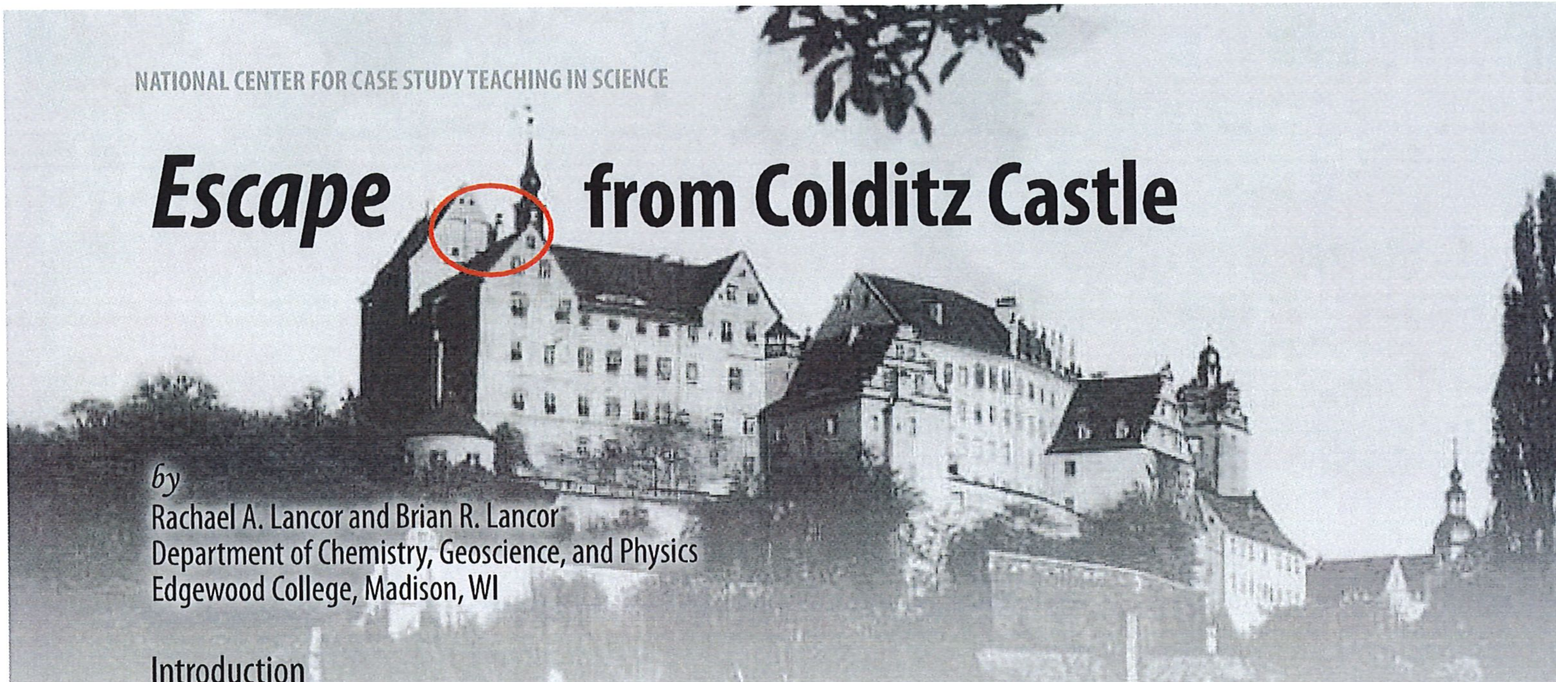
*Figure 2.* In this figure you can see what would happen if the object did not accelerate into a new direction. Since the direction does not change, the object flies out of the circular path along a line tangential to its instantaneous motion.

*Joe:* Oh I think I get it. So the wall is exerting a force on my body, making me move into the circle, but my body is exerting an equal and opposite force on the wall so the result is that my body doesn't move with respect to the wall at all, I stick to it!

*Bobby:* See, I told you you'd get it! Just try to think about it a little more like a physicist. Your body isn't moving towards the center of the circle, but the net acceleration is towards the center—if you think about it, you're not moving, you're stuck to the wall. The wall is exerting an action force on your body, and your body is exerting a reaction force against the wall. Essentially just what you said, but phrased the way a physics teacher would say it.

## Questions

1. What is a vector quantity?
2. What are displacement, velocity, and acceleration, and what are their relationships to each other in terms of motion?
3. What are Newton's three laws of motion? Give an example of how the first two laws of motion describe the motion of an object.
4. Why is there always acceleration when an object travels in a circular path at a constant velocity?
5. What is centripetal force? (Use Newton's second law to explain.)
6. What is the force that causes an object to remain on a wall while the wall is spinning? (Use Newton's third law to explain.)
7. Explain why an object will stick to the wall with a greater force as the wall spins faster.



# *Escape* from Colditz Castle

*by*
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## Introduction

Colditz Castle was a German prison camp during the Second World War. The castle was an ideal prison because it was located on a rocky outcrop, and had walls up to seven feet thick. Because of this, the prison was home to many prisoners who had previously attempted escapes from other POW camps. In 1945, a group of British prisoners led by Bill Goldfinch and Jack Best hatched a plan to escape by building and launching a glider off of the roof of the castle. The photo above (Figure 1) depicts the castle during World War II. The roof where the glider was to be launched is circled in red.

Goldfinch and Best found a book on aircraft design in the prison library, which they used to help them design the glider. The glider was constructed in a hidden attic room from materials they could find in the castle—bed sheets, floorboards, even porridge stolen from the mess hall (Figure 2). The plan was to use a pulley system to launch the glider off of the roof of the castle, and land in a nearby field.

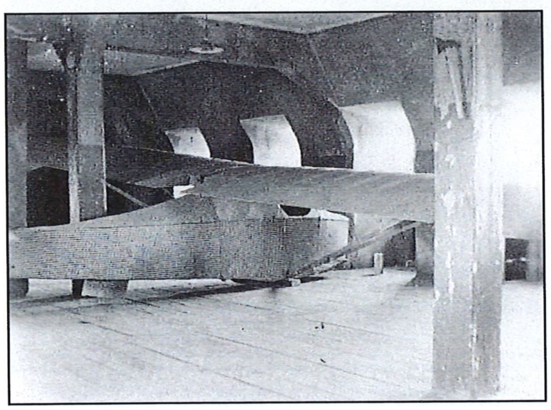


*Figure 2.* The only known photograph of original glider.

On April 16, 1945, American troops invaded the castle and freed the prisoners; they never had a chance to test their glider. Recently, a group of engineers decided to build a glider using materials that would have been available to the prisoners. Fortunately, Goldfinch had kept the plans, so they were able to reconstruct the glider with the same dimensions as the original. The goal was to test whether or not the prisoner's escape plan was possible.

The prisoner's original plan was to use a pulley system, with a bathtub as a counterweight to accelerate the glider along the roof (Figure 3). The bathtub would then release when it hit the ground, and the glider would continue off the roof, launched horizontally into the air. The prisoners would land in a field on the other side of a stream that ran around the castle grounds.

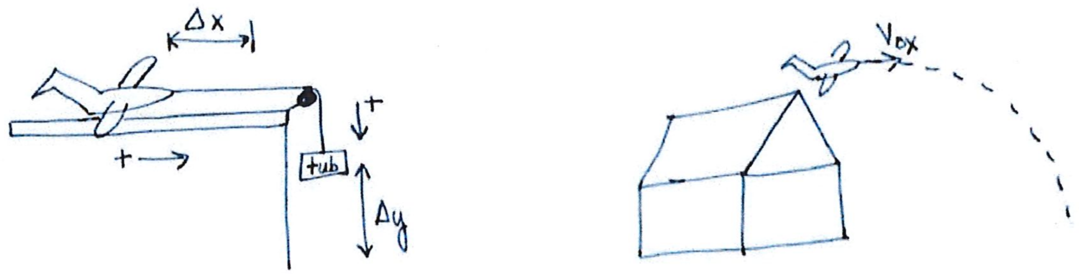



*Figure 3.* A schematic diagram of the escape plan. The tub would act as a counterweight to drag the glider to the edge of the castle roof (left), and then launch it into the air (right).

## Part I – Planning for the Escape

Imagine you are part of the team of engineers who wants to recreate this escape attempt. The first thing the team does is to build a mathematical model to predict the motion of the glider. This includes both the motion before the launch of the glider (when the bathtub is dragging it along the roof), and the motion after the glider has launched in order to predict where it will land.

### *Questions*

1. Look again at the schematic diagram of the escape plan (Figure 3). We want to convert this visual representation into a mathematical model. What fundamental principles of physics will you use to build your model?

2. What additional information do you need to begin building your mathematical model?

3. What assumptions are made in using these mathematical models?

## Part II – Is It Even Possible?

One way that mathematical models are used by scientists and engineers is to make predictions about how a system will behave. In the video, the engineers use a simple kinematics model to predict how much the glider would need to accelerate as it is pulled along the runway in order to launch. Based on the aerodynamics of the glider, the engineers calculated it would need to reach a speed of 40 mph to successfully launch into the air.

The roof is 160 feet above the ground, and the runway (built from tables on top of the peak of the roof) was about 60 feet long. The first question the engineers need to figure out is if it is theoretically possible to reach the desired launch speed given the length of the runway and the height of the tower.

### *Questions*

1. Given this information, what must the acceleration of the glider be to reach the launch velocity by the end of the runway? (Convert all values to SI units.)

2. The engineer wants the glider to accelerate at a rate of 1.2g (11.6 $m/s^2$). How does this compare to your result? Why would the engineer over-estimate the acceleration?

To see if this acceleration can be reached by the actual system, the engineers in the video conduct an experiment using a scale model of the glider system. In the scale model, they launch a piece of wood covered in fabric from a height of about 30 feet, using a bathtub full of water as the counterweight.

The result of this test shows that they did not reach the acceleration they had hoped for. Now the engineers are faced with a problem: they must find a new way to launch the glider so that they can reach the desired speed and acceleration. They are forced to revise both the parameters of the experiment and their mathematical models.

## *Questions*

3. Is it possible for the bathtub to accelerate at $1.2g$? Explain why or why not. If it is not possible, how could you modify the system to generate this acceleration?

4. Why would they use a scaled-down model to test their ideas? What are the benefits of this approach? What are the limitations of this model?

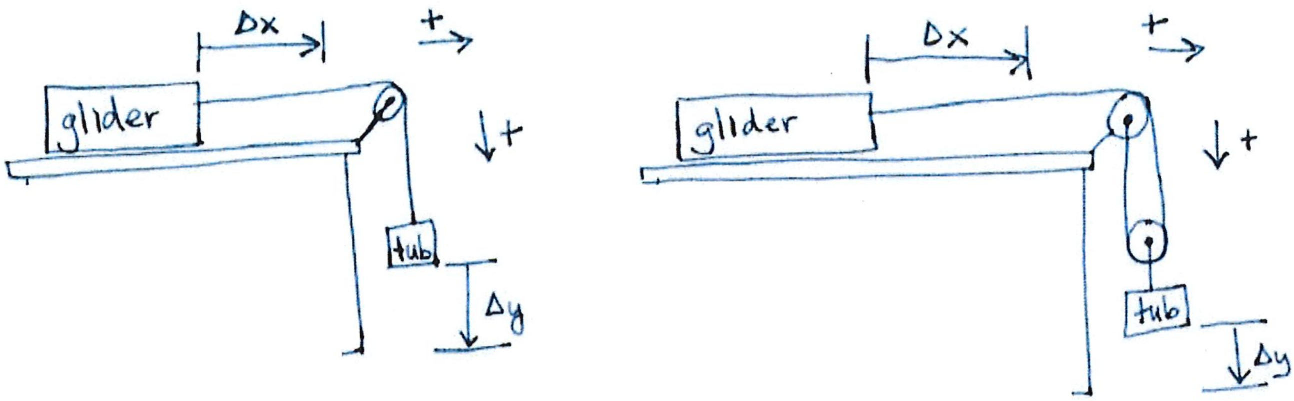



*Figure 4:* Diagrams of the single and double pulley systems. Note that the distance traveled by the glider and the tub is the same in the single pulley system (left), but in the double pulley system (right) the glider moves twice as far as the tub.

## Questions

5. The engineers' solution to this problem was to use a double pulley system (see Figure 4). Using this system, the distance traveled by the bathtub is half the distance traveled by the glider. What does this tell us about the acceleration of the glider relative to the tub?

6. What is the height that the bathtub must fall in order for the glider to reach the desired launch velocity? How does this compare to the height of the castle roof? Will the glider reach 40 mph before launch?

## Part III – We Need More Speed!

The engineers find that even with the double pulley system, the glider is not reaching the desired acceleration. Their solution is to reduce the friction on the runway.

### *Questions*

1. What effect will reducing the friction have on the speed and acceleration of the glider? Explain your answer using a free body diagram.

2. Assume that the coefficient of static friction for the glider sliding on wood is 0.4. What tension force must be applied to overcome the static friction?

3. Once the glider starts moving, the coefficient of friction drops to 0.2. What tension force must be applied to the wood to reach the desired acceleration?

4. What mass of bathtub does this correspond to? (Hint: first draw a free body diagram of the tub and write Newton's Second Law.)

5. A typical bathtub has a volume of 0.16 $m^3$. The density of water is 1000 $kg/m^3$ and for concrete can range from 2400 $kg/m^3$ to 3500 $kg/m^3$. Assume the mass of the empty tub is 100 kg. Can the tub filled with water produce the required tension? Use the above information to justify your answer.

6. The engineer then reduces the amount of friction in the system by covering the runway with sheets of metal. Wood on metal has a coefficient of static friction of about 0.2, and a coefficient of kinetic friction that is close to zero. Will this solve the problem? Justify your answer using calculations and/or free body diagrams.

## Part IV – Success?

After revising their launch plan several times, the engineers are read for launch! Due to safety reasons, they do not fly the glider themselves, but decide to test the glider with a radio control system and a dummy which simulates the weight of a person. The launch day is quite windy, and it looks like a storm is rolling in. They are delayed by a problem with a motor in the radio control system, but finally they are ready for launch. In the end, the glider launches with a speed of 36 mph, which is less than they had hoped for, likely due to the windy day. Will the glider make it across the river to safety? We will now model the glider as a projectile in two-dimensional motion.

### *Questions*

1. Assuming the glider acts like a simple projectile in free fall, how long will it take to reach the ground? Recall that the tower is 160 feet above the ground.

2. Assuming the glider acts like a simple projectile in free fall, where will it land?

3. In the real test, the glider landed in a field about 984 feet (300 m) from the castle wall. How does that compare to the distance you just calculated? What could account for any difference? How can you modify your model to account for these differences?

The glider does not act like a simple projectile in free fall because there are other forces acting on the system: drag, lift, and the force of the wind, in addition to gravity. These other forces will impact the acceleration of the glider in both the horizontal and vertical directions.

### *Questions*

4. Draw a free body diagram of the glider while it is in flight.

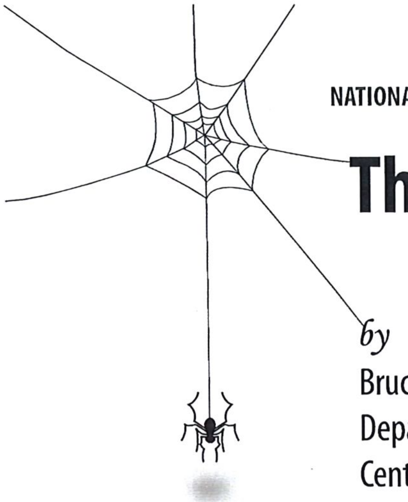
5. If we assume the glider is actually in the air for 20 seconds, calculate the horizontal and vertical components of the acceleration.

6. Based on the acceleration you just calculated, find the magnitude of the lift force.

7. This glider has a lift-to-drag ratio of 12:1. Use this fact to calculate the magnitude of the drag force.

8. Finally, calculate the force of the wind acting on the glider. Did you draw it in the correct direction in your free body diagram?

9. What are the limitations of this mathematical model? How could we improve the model to better describe the path of the glider?



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# The Itsy-Bitsy Spider: An Analysis of Spider Locomotion

*by*
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## Part I – Introduction

Understanding the relationship between form and function in organisms can increase our knowledge about natural processes, especially when it comes to investigating how physical laws apply to the adaptive design of organisms. The mode of locomotion plays a major role in the evolution of many body traits. Most terrestrial organisms walk or run upright on horizontal surfaces. Organisms that climb on vertical surfaces or hang from objects most likely evolved, through natural selection, specialized modes of locomotion to optimize ease and rate of movement.

In order to move, animals need to "build up" energy and then use that energy in a controlled way. One way to do that is through the interchange of kinetic and gravitational potential energy. One method to do this is an animal moving forward over a stiffened leg. In the initial part of the cycle, some of the kinetic energy used to propel the animal forward also raises its center of mass, increasing its gravitational potential energy. As the center of mass falls, gravitational potential energy is converted back into kinetic energy which facilitates the next step. This is called the *inverted pendulum model* (Figure 1).

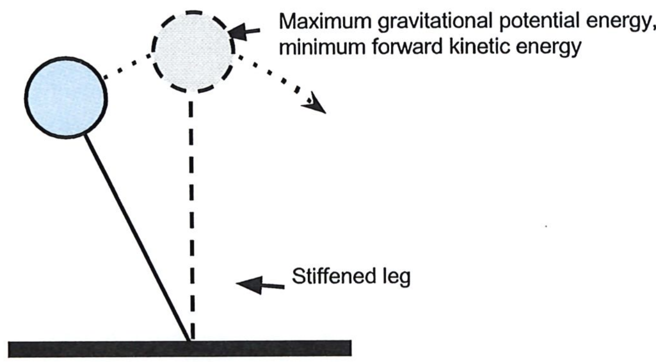


*Figure 1. Inverted pendulum model.* Body center of mass moving, supported by a stiffened leg.

Another model is the *spring-loaded inverted pendulum model* (Figure 2) in which the elastic elements in the leg store energy. As the center of mass moves downward under the force of gravity, the elastic elements in the leg (muscles, tendons, skeletal structure) are compressed. When these elements return to equilibrium, the center of mass is propelled upward and forward. Studies of "daddy longlegs" of the species *Leibunum vittatum* seem to follow this mode of locomotion (Sensenig and Schultz, 2007).

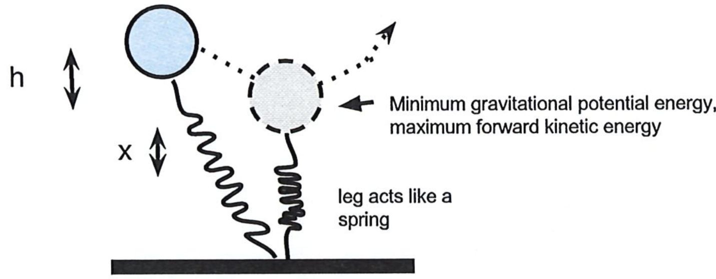


*Figure 2. Spring-loaded inverted pendulum model.* As a body moving forward brakes, it stores energy in the leg.

The third model is a *regular pendulum model,* which gains kinetic energy by swinging from a position of relatively high gravitational potential energy to a low position where kinetic energy is maximized (Figure 3). Hanging spiders most closely match this mechanical model (Moya-Laraño, Vinković, de Mas, Corcobado, & Moreno, 2008).

Spiders are a highly diverse group of terrestrial predators that are exceptional organisms to test evolutionary hypotheses about pendulum mechanics because there are many species that move primarily upright on a horizontal surface (picture a tarantula) and many that live hanging upside down (picture the spider that startles you by dropping from the ceiling).

Natural selection is the gradual, non-random process by which biological traits become more or less common in a population due to differential reproduction. For example, a spider group with a body type that lets it move quickly to avoid predators will live longer and have a greater opportunity to pass that favorable trait on to its offspring.

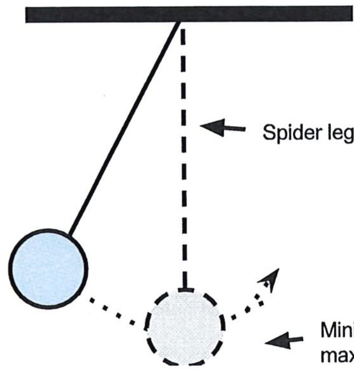


*Figure 3. Regular pendulum model.* Body center of mass swinging like a regular pendulum.

## Some Other Information

Here are some physics concepts to help you analyze the case:

- A pendulum at the endpoint of its trajectory has energy $PE_g$ = mgh where mg is the weight of the pendulum and h is the distance the pendulum is above or below the equilibrium position. A pendulum at the equilibrium point of its trajectory has energy KE = $(1/2)mv_{max}^2$ where m is the mass and $v_{max}$ is the maximum speed of the pendulum.
- The energy stored in a compressed spring is given by $PE_s = (1/2)kx^2$ where k is a measure of the stiffness of the elastic medium (called the spring constant) and x is the amount the elastic material is displaced from equilibrium.

## Questions

1. If you designed an animal that could walk on flat horizontal surfaces and move upside down on suspended surfaces, describe three body characteristics you would give that animal. Be specific. Don't just say something generic like "legs that can walk and grip."
2. What is the basic question of this study and why might it be an interesting and relevant topic for scientists to study?
3. What specific and measurable hypotheses (at least two) can you develop that are supported by the information presented and that address the basic question of this study?

## Part II – Hypotheses

If the evolution of body shape matches simple pendulum mechanics, animals that move suspending their bodies should evolve relatively longer legs, which must confer high moving capabilities (Moya-Laraño *et al.*, 2008).

### *Leg Length Hypothesis*

If leg length is the target of natural selection, hanging animals must have evolved disproportionately longer legs relative to their body size when compared with animals that walk standing on their legs.

### *Running Hypothesis*

As spider size increases, running speed should increase with a greater increase for standing rather than hanging spiders.

### *Questions*

1. Rewrite the leg length and running hypotheses of this study in your own words using the "If, then, because" format. This hypothesis must be something you can measure and observe in a short-term study.
2. Describe how you could use the concepts of kinetic and potential energy to analyze the motion of a spider.
3. Which of the two models of upright locomotion described in the introduction (inverted pendulum or spring loaded inverted pendulum) would benefit a long-legged spider running upright? Why?
4. Does the regular pendulum model favor a long-legged or short-legged spider? Why?
5. Design an experiment to test the leg length hypothesis. Describe the basic procedure, number of trials, equipment needed, and method of analysis.
6. Design an experiment to test the running hypothesis. Describe the basic procedure, number of trials, equipment needed, and method of analysis.

## Part III – Experiments and Observations

### *Leg Length Experiment*

Moya-Laraño *et al.* (2008) measured morphological leg characteristics on adult females from 105 spider species belonging to 25 spider families based on drawings from the book *The Spiders of Great Britain and Ireland*, Vol. 1 and 2 by M. J. Roberts. In order to focus on the body traits size and pendulum issues discussed in the introduction section, they measured carapace width (CW), right foreleg tibia length (FTL), and right foreleg tibia diameter (FTD). Forelegs are important for pulling the body during bridging on a silk thread, and if the pendulum hypothesis is correct they should be the most modified according to living posture. The length of the tibia is the best characteristic of leg length because it is the easiest leg segment to measure in Roberts' drawings. Tibia diameters were measured in the center of the tibias. Spider traits were directly measured to the nearest 0.1 mm from the drawings in Roberts' book by using a caliper. To validate the accuracy of the drawings, the authors measured actual spiders from 10 different families and found the CW, FTL and FTD to be highly correlated to Roberts' drawings (R=0.95-0.97).

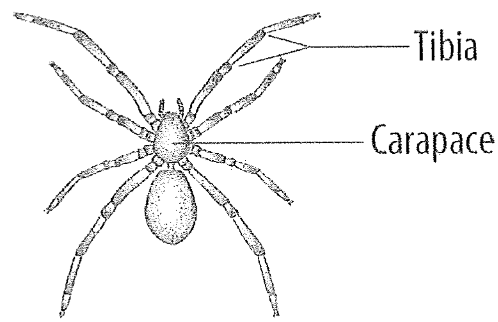


*Figure 4.* Spider body parts that were measured for the leg length hypothesis.

### *General Running Experiment*

To study the performance of spiders on flat surfaces, Moya-Laraño *et al.* (2008) ran spiders on a race track (50-cm length, 15-cm width) that had a layer of fine sand as substrate. Spiders were released from the jar and chased until they moved in a straight running trajectory. Since spider mass ranged from 0.65 mg to 1,242 mg the length of the run varied accordingly (i.e., 1.8–38 cm).

All spiders, collected in southern Spain, were kept in jars of variable size according to their own size and all were used within 48 hours after collection. Trials were conducted at room temperature (range 19.7–22.7°C) and recorded with a digital video camera for later calculating speed at 30 frames/s. After trials were finished, individuals were killed by freezing and preserved for body measurements.

### *Questions*

*Explain your reasoning for each of the following questions. It will be helpful to sketch and include a graph for each.*

Given the observations made as part of this study, what would the data look like:

1. If the leg length hypothesis in Part II is true?
2. If the leg length hypothesis in Part II is false?
3. If the running hypothesis in Part II is true?
4. If the running hypothesis in Part II is false?

## Part IV – Results

### *Leg length Hypothesis*

The authors observed a definite trend relating relative body size to relative leg length. This trend differed for standing and handing spiders.

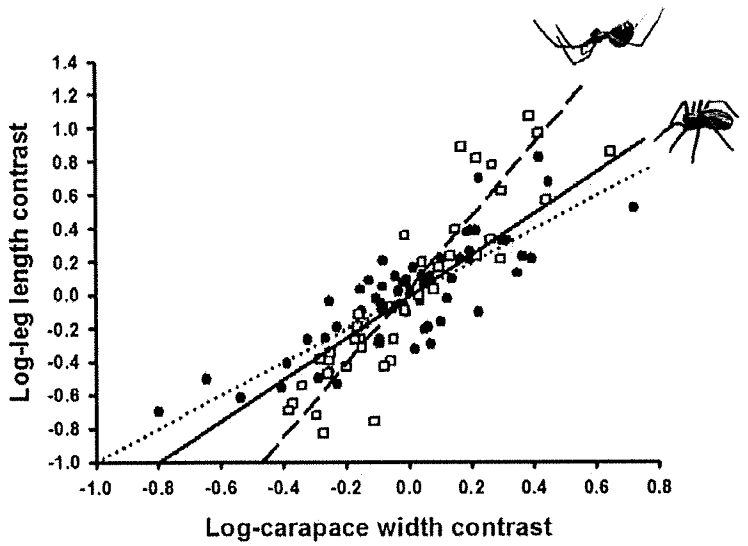


*Figure 5.* Body size is represented on the x-axis and leg length is represented on the y-axis. The larger the value on the axis, the greater the body size (carapace) or leg length compared to a standard linear growth model of organism size increase. For example, a value of 0.4 means the body part is larger/longer than a linear model would predict. A value of 0.8 means the body part is much larger/longer than a linear model would predict. A value of -0.4 means the body part is smaller than a linear growth model would indicate. Filled circles and solid line: standing spiders. Open squares and dashed line: hanging spiders. The logarithms were used to flatten the data. (Moya-Laraño *et al.,* 2008, Creative Commons Attribution License.)

### *Running Hypothesis*

Species of walking and species of hanging spiders were put through the same running test. The graph below shows their speed results.

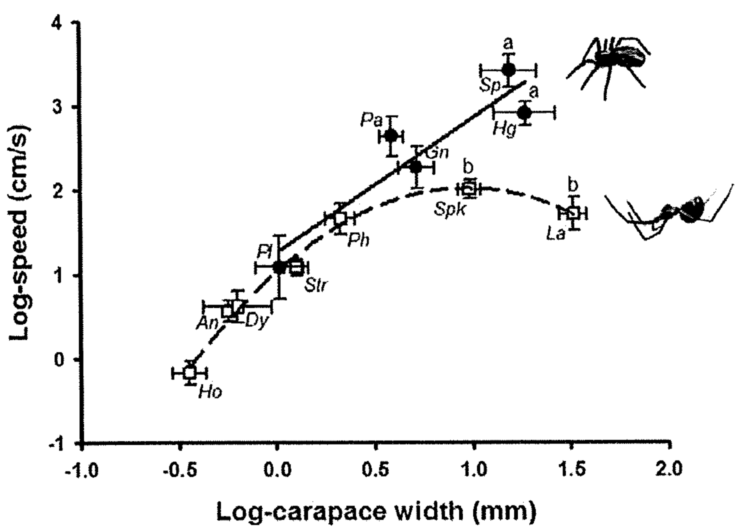


*Figure 6:* Body size is represented on the x-axis and spider speed is represented on the y-axis. Filled circles and solid line: standing spiders. Open squares and dashed line: hanging spiders. The letters represent the spider species used. The logarithms were used to flatten the data. (Moya-Laraño *et al.*, 2008, Creative Commons Attribution License.)

## Questions

1. Summarize what Figure 5 tells you about the answer to the leg length hypothesis.
2. Summarize what Figure 6 tells you about the answer to the running hypothesis.
3. Use the principles of energy conservation to explain the results of Figure 5.
4. Use the principles of energy conservation to explain the results of Figure 6.
5. Do the data "support" the research hypotheses?
6. What general conclusions can you make from the results of this study?

## References

Moya-Laraño, J., Vinković, D., de Mas, E., Corcobado, G., & Moreno, E. 2008. Morphological Evolution of Spiders Predicted by Pendulum Mechanics. *Plos ONE*, 3(3), 1–6. doi:10.1371/journal.pone.0001841. Also found at http://www.plosone.org/article/info:doi/10.1371/journal.pone.0001841.

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