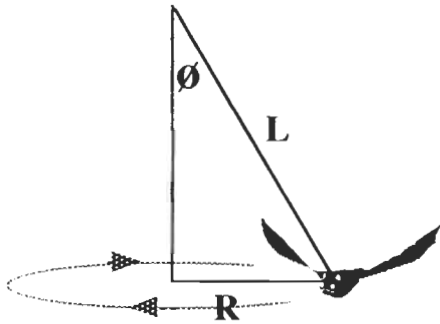


FLYING IN CIRCLES #2: FINDING THE TENSION FORCE AND THE CENTRIPETAL FORCE

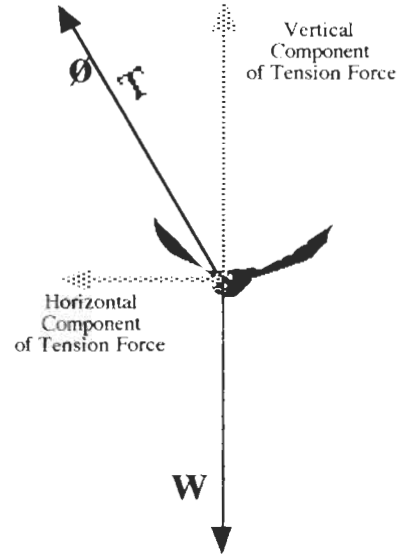
This is a continuation of *Flying in Circles #1: What Determines the Angle, ϕ , the Tethering String Makes With Vertical?* You will need the measurements you made and the triangle that you constructed for Flying in Circle #1 in order to continue with this investigation.

GEOMETRY: CIRCULAR FLIGHT (Diagram 1)



These diagrams were introduced in Flying in Circles #1.

FORCE DIAGRAM: BAT IN CIRCULAR MOTION (Diagram 3)



1. Using a small spring scale, a postal scale, or a kitchen scale, measure the weight of the bat with its batteries. Be sure to record the units of measure of the scale that you use, as well as the value for the weight. _____

One scale the authors used gave the weight as 4.4 ounces. On another scale, they got 125 grams. No matter what the units of measure, we will convert all of our force measurements to SI metric units, which are *Newtons*. Here is a chart that tells what to do in order to convert the weight measurement to *Newtons*, (abbreviated *N*) depending on the units of measure for your scale.

SCALE	UNITS	CONVERSION
Ounces		Multiply by 0.278
Grams (on Earth)		Multiply by 0.0098

The 4.4 *ounce* measurement converts to $4.4 \times 0.278 = 1.22 \text{ N}$. The 125 *gram* measurement converts to $125 \times 0.0098 = 1.22 \text{ N}$. The two results agree.

Show *your* calculation and results for the weight of the bat and batteries in Newtons. _____

From Flying in circles #1, we recall that the weight is the same size force as the *vertical component of the tension force* (See Diagram 3). So, the size of the vertical component of the tension force from your measurements is (in Newtons) _____

2. Measure the length of the vertical leg of the right triangle from Flying in Circles #1. That is the leg that goes along the left side of the page. It goes from the lower left corner of the page to where the hypotenuse

(piece of spaghetti) meets the left side of the page and forms the angle ϕ . Record the length (in centimeters) you got for the vertical leg of your right triangle. _____

3. Now you have the information you need to find the *tension force* and the *centripetal force*. Your value for the vertical component of the tension force will allow you to relate the scale of Diagram 1 to the scale of Diagram 3.

The number that relates the two diagrams is obtained by doing the following computation:

$$\frac{\text{Size of vertical component of tension force}}{\text{Length of the vertical leg of the right triangle}} = \text{Conversion factor from lengths to forces}$$

For illustration, we recall the authors' triangle from *Flying in Circles #1*. The triangle had a hypotenuse (the long slanted side) of 6.60 cm and a horizontal base of 5.86 cm. When the authors measured the vertical side, they got 3.04 cm. In step 1, their value for the vertical component of the tension force was 1.22 Newtons.

Using these values, we calculate their conversion factor from lengths to forces:

$$\frac{1.22 \text{ N}}{3.04 \text{ cm}} = 0.401 \text{ N per cm.}$$

Retrieve the measurement of the length of the vertical leg of your triangle, and write it down here. _____

Show the calculation set up and result from your triangle and weight measurements:

$$\text{_____} = \text{_____ N/cm.}$$

Again, we illustrate with the author's results. The value for the tension force is found by multiplying the conversion factor by the corresponding side of the length triangle (in this case, the hypotenuse of the triangle): $0.401 \text{ (N/cm)} \times 6.60 \text{ (cm)} = 2.65 \text{ (N)}$.

Similarly, using the horizontal base of their triangle, the authors found the centripetal force to be 2.35 N.

The author's results are summarized in the table below, where space is also provided for your results.

FORCE (Corresponding side of triangle)	TENSION (hypotenuse)	CENTRIPETAL (horizontal base)
Author's length of triangle side (cm)	6.60	5.86
Authors' calculated FORCE value (N)	2.65	2.35
Your length of triangle side (cm)		
Your calculated FORCE value (N)		

4. Another thing you can do is to find the amount of force the flapping wings apply to keep the bat moving along in its circle. If you have not already done so on your own, you should put the bat into circular motion without the wings flapping. The bat coasts along pretty well, but the size of the circle keeps decreasing. That tells us that the wings are more than decoration. Their flapping actually affects the motion of the bat.

When the battery switch was on, the bat pulled itself along, with the speed increasing, until the drag forces (air resistance being a major culprit) canceled out the forward force generated by the flapping wings.

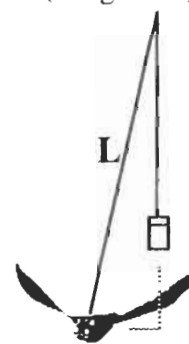
Thereafter, it flew with constant speed. However, the direction was ever-changing due to the centripetal force (horizontal component of the tension force) perpendicular to the direction of motion.

5. From the pivot at the top of the tether, suspend a string with a weight on it (we used a film canister with some coins in it). See Diagram 4. Adjust the length of this string until the weight is above the bat, where it will not interfere with the wings. The string and weight will be used for a vertical reference. Keep the string with the weight from getting tangled with the tether. It may be a two-person job.

Turn on the bat, but do not give it any sort of start. Soon, it will fly out a little way to a maximum distance so that its tether makes a measurable angle with the freely-suspended string and weight. Use a protractor to measure this angle.

This measurement is made at the point where the tether and the reference string meet at the top. The angle will probably be less than 5.0 degrees. Record the angle measurement. _____

GEOMETRY:
BAT FORCE
(Diagram 4)



It's time for another scale triangle. We hope you kept your piece of spaghetti. (Of course, you did.) Make a right triangle using the bottom right corner of the paper. Adjust the spaghetti so that it goes from the right side of the page to the bottom. Adjust the angle to be the same as the one you measured above. The triangle should then look like the one suggested in Diagram 4, with the spaghetti playing the role of L.

As before, the vertical side of the triangle goes with the vertical component of the tension force, which is equal to the weight of the bat and batteries. The horizontal side goes with the bat flying force. Measure the lengths of these sides. Calculate the new conversion factor. Use it to find the bat wing force. The authors got 0.05 N for the force.

Your result? _____