

Homework 1 (chapters 1-3):

- Using Figure 2.31 on page 47 as a reference, determine the percentage increase in CO₂ concentrations in the atmosphere from 1960 to 1995.

This is a deceptively easy question. There are two parts to formulating the answer. First, you must correctly interpolate the data from the graph; next you must make the calculations. The best way to make the interpolation if you are working with a hard-copy of the graph (you could scan it into the computer) is to use a clear ruler to find the points you need to be on the line and move at a 90° angle to the y-axis to read off the value. If a value on either axis does not lie on a tick mark, then you have to estimate. You can use geometric techniques or the scale on the ruler to increase the accuracy of your estimate. Of course, in this case part of the problem is that the line itself is so thick and the changes in direction so sharp that it isn't always apparent where to read the line.

If the graph is in electronic form, you can use Photoshop or a similar program to draw in straight lines to the axes and then use the information from the cursor to estimate the value on the axes. For instance, in the example below (Figure 1) the value for 1995 on the y-axis reads off easily – 360 ppmv. The value for 1960 is more problematic. Using the cursor, I determined the y-value in pixels for 310 ppmv to be 4403 pixels. The y-value for 320 ppmv was 3810 pixels. The y-value for the line going to the graph at the intersection with 1960 is 4028 pixels (red circle in Figure 1). The difference between 310 and 320 ppmv on the graph is 4403-3810 or 593 pixels. The difference between the intercept for the 1960 data and the 310 ppmv is 4403-4028 or 375 pixels. A distance of 375 pixels is 63% of the total difference (593 pixels) between the 310 and 320 ppmv values ($375/593 = 0.63$). 63% of that 10 ppmv difference is a difference of 6.3 ppmv; therefore the interpolated value is $310 + 6.3 = 316.3$ ppmv. Given the uncertainty of the interpolation, we are safe in rounding it to 316 ppmv. Just 'eyeballing' it I would have said 316 ppmv, so I'm not sure in this case that all the math was worthwhile!

OK – now for the math. The difference between 360 ppmv and 316 ppmv is 44 ppmv; 44 ppmv is 13.9% of 316ppmv ($44/316 = 0.139$). Therefore, the answer is 14%.

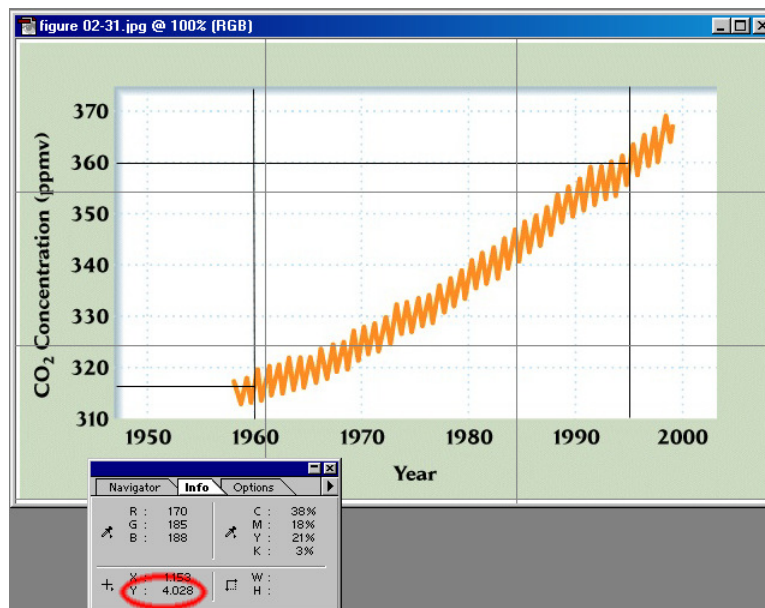


Figure 1 - Interpolation of graph data with Adobe Photoshop

2. List the main pathways of heat exchange for an organism.

1. Radiation: heat transfer occurs through the medium of infrared radiation. Organisms gain heat this way if the environment is warmer than they are; otherwise, they lose heat through this route. It's not just the sun that radiates heat, however. Our bodies radiate heat, as do plants (which are warmed by the sun) and other objects in the environment. Water holds a great deal of heat as well, and radiates it constantly. Cloudy nights are warmer than clear nights because the clouds, composed of H₂O vapor, radiate heat to the ground (and prevent heat from being radiated to space). Feathers and fur are usually barriers to radiative heat transfer.

2. Conduction occurs when heat is transferred between two surfaces in contact with each other. The more molecules in contact, the greater the heat transfer. Because of this, a vacuum transfers no heat by conduction; air transfers some, and water about 20x as much heat as air (this is why water at 25° C feels cooler than air at the same temperature). Organisms can insulate themselves to some extent against this transfer. They can also regulate heat loss or gain by this route by controlling which surfaces they come in contact with and how much of the body is allowed in contact. On a cool morning a lizard will sprawl on a rock warmed by the sun; this maximizes heat uptake and allows the lizard to become active. In the heat of the day, the lizard will hold itself off the rock to minimize the danger of overheating.

3. Convection is similar to conduction, but convection takes into account the effect of moving fluids (air or water) on the process of conduction. In convection, air or water moves away from the site of heat transfer and is replaced by cooler (or warmer) fluid. In this way, a strong gradient is always present and the stronger the gradient, the greater the rate of heat transfer. Again, feathers and fur reduce this effect by trapping and slowing the movement of air or water near the skin. In general, higher wind or water current speed will increase the rate of heat transfer (usually cooling the organism).

4. Evaporation, which requires a great deal of heat. Evaporation depends on many factors including temperature, humidity, and wind speed. The lower the humidity, and the higher the temperature and wind speed, the faster evaporation will occur. Thus, evaporation is enhanced under the precise conditions (at least in relation to temperature) where evaporation is needed to cool the organism. On the other hand, since cool air holds little water, in the winter as our body warms the cool air we breathe in, evaporation rates increase and we tend to lose more water (and heat as well). Plants also cool themselves through **transpiration**, or evaporation, of water through the **stomata**. Know figure 2.17 well.

Organisms gain most of their heat through two mechanisms; metabolic production of heat internally and through insolation, the absorption of heat from the sun. The former is not a form of heat *transfer*; the latter is a type of radiative heat transfer. To answer this question for full credit, you only needed to list the mechanisms. I have expanded on them here for your review.

3. Several species of Arctiid moths emit clicks when in the presence of bats. Bats, of course, locate their prey by sound. Several hypotheses exist as to the purpose of these clicks. Locate online (through the Dawes Library, OhioLink and the Ohiolink Electronic Journal Center) the following article:

Arctiid moths and bat echolocation: broad-band clicks interfere with neural responses to auditory stimuli in the nuclei of the lateral lemniscus of the big brown bat.

From the introduction, list 4 hypotheses for how the clicks may protect the moths. Then, read the last section "Relevance for bat/moth interactions" and determine which hypotheses are supported by the authors' work. You don't have to read the rest of the article.

Introduction

Many species of arctiid moths (Lepidoptera: Arctiidae) emit broad band clicks in response to intense ultrasound, including bat echolocation calls (Blest et al. 1963; Blest 1964; Dunning and Roeder 1965). Although it is generally agreed that clicking is a defence strategy employed by moths against echolocating bats, there are several different theories regarding the mechanism through which the clicks exert their effects. Dunning and Roeder (1965) were the first to demonstrate that moth clicks can disrupt the foraging behaviour of bats. In laboratory experiments they showed that *Myotis lucifugus* trained to catch mealworms tossed into the air turned away from the mealworm if a train of arctiid clicks was presented simultaneously with the bat's approach to the mealworm.

Blest et al. (1963) and Dunning (1968) suggested that arctiid clicks serve as aposematic signals, warning the bat that its prey is poisonous. Arctiids have been shown to contain toxins (Rothschild et al. 1970), and bats generally prefer moths of the geometrid and noctuid families to arctiids (Dunning et al. 1992). **Stoneman and Fenton (1988) suggested that arctiid clicks startle the approaching bat, providing time for the moth to escape.** Mühl and Miller (1976) showed that it is indeed possible to startle a bat with ultrasonic clicks of the peacock butterfly; these experiments, however, were performed with crawling rather than flying bats, so it is not known whether clicks can also elicit a startle response in a flying bat. Other authors have suggested that the clicks emitted by moths interfere with the bat's perception of the returning echoes from its own vocalisations. There are two suggested mechanisms for this interference. **One possibility suggested by Fullard et al. (1979, 1994) is that moth clicks, by their temporal proximity and resemblance to echoes, would create a neural response similar to that evoked by echoes.** According to this hypothesis, the neural response to the clicks would create the illusion of multiple targets.

Another possibility, raised by Miller (1991), is that the clicks disrupt the neural mechanism for encoding the time of occurrence of the echo. Two psychophysical studies have measured the interference of clicks on the ranging ability of bats (Surykke and Miller 1985; Miller 1991). Miller (1991) showed an interference in ranging ability that was only expressed when the clicks were presented in a very narrow time window immediately preceding the returning echo. Under these conditions, the range difference threshold increased from 6 mm to as much as 240 mm. This dramatic increase in the range difference threshold in the presence of clicks suggests that arctiid moth clicks may interfere with the bat's ability to process information about the distance of the moth during foraging. The fact that clicks presented after the echo had no effect supports the idea that the click somehow interferes directly with the temporal processing of the echo and is not perceived as an echo from a second target, which the bat confuses with the echo from the real target.

The present study addresses the issue of whether it is possible to identify neural correlates of the effects of clicks on echolocation performance. Our experiments focused specifically on identifying neural correlates of the click-induced deterioration of behavioural ranging ability seen in the experiments of Miller (1991). The goal of our experiments was to determine whether each click simply evokes a discrete neural response which remains separate from the response to the real echo as would be predicted by the first, multiple-target hypothesis, or whether the presence of the click somehow directly interferes with the response to the echo, as suggested by the second (interference) hypothesis.

The two hypotheses are not mutually exclusive in that a neurone could obviously respond to both a click and an echo, and thus behave in a way consistent with the multiple-target hypothesis; however, its response to the simulated echo might also be altered, meaning that this neurone also responds in a way that is consistent with the interference hypothesis.

To look for neural correlates of these hypotheses, we focused on those parts of the ascending auditory pathway that transmit information about the time relationships between sounds and are situated at a level preceding the output to motor systems. Previous studies (Covey and Casseday 1986, 1991; Covey 1993) have suggested that the nuclei of the lateral lemniscus are specialised to provide precise timing markers for the occurrence of the bat's emitted pulse and returning echoes. The target of the nuclei of the lateral lemniscus is the inferior colliculus (IC), which in turn has output to motor centres concerned with orientation in space (Covey and Casseday 1995; Casseday and Covey 1996). For these reasons, we examined the responses of neurones in the nuclei of the lateral lemniscus of the big brown bat, *Eptesicus fuscus*, a North American bat that uses a frequency-modulated (FM) echolocation call. The same species was used by Miller (1991) in range discrimination studies. We presented artificial echolocation calls together with arctiid-like clicks to the bats while recording extracellularly from individual neurones. The sound stimuli were presented passively to the ears of the bat, and the temporal position of the click relative to the artificial echolocation call was varied in a systematic manner.

The 4 hypotheses are highlighted above; they are:

1. **Arctiid clicks serve as aposematic signals, warning the bat that its prey is poisonous.**
2. **Arctiid clicks startle the approaching bat, providing time for the moth to escape.**
3. **Moth clicks, by their temporal proximity and resemblance to echoes, would create a neural response similar to that evoked by echoes (multiple targets).**
4. **Clicks disrupt the neural mechanism for encoding the time of occurrence of the echo.**

Relevance for bat/moth interactions

Although we cannot rule out the possibility that parameters other than apparent target range would be affected by clicks, we can nevertheless use our data to make some predictions about interactions between bats and arctiid moths. In order for clicks to have an effect on the bat's perceptual abilities, one or more clicks would have to occur within a narrow time window less than 2 ms wide preceding the echo or extending part way into the echo. Because of these temporal constraints, it would be impossible for a moth first to hear a sonar pulse and then emit a click that would perturb the bat's perception of the returning echo. It is probably also impossible for a moth to emit a click in response to one sonar pulse but intended to interfere with the echo of a subsequent pulse, because the interval between successive sonar pulses changes considerably during the bat's approach to the moth (see, for example, the echolocation sequence of Fullard et al. 1994). Thus, the only obviously viable strategy by which a moth could place a click immediately in front of a returning echo would be to emit large numbers of clicks to maximise the probability that some will fall within the critical time window. At least one species of

arctiid moth, *Cycnia tenera*, appears to use this strategy (Fullard et al. 1994). This species emits several clicks for each sonar pulse emitted by the bat. These clicks are emitted at a time late in the approach of the bat, a time where ranging errors could easily lead the bat to miss the moth. Although we cannot rule out the possibility that the clicks elicit a startle reflex, **it seems likely that the clicks emitted by *C. tenera* do jam the bat's biosonar system by interfering with the temporal processing of the echo.** Aposematic signaling seems unlikely in this species, since in this case one would expect that survival would be optimised by an early- warning system; the strategy of emitting clicks only when the bat is very close does not seem consistent with this theory.

Other species of moths such as *Arctia caja* emit only a few clicks relatively early during the approach of the bat. For these species, it is unlikely that the clicks would perturb the ranging of the bat, so it seems reasonable to conclude that the clicks of these species serve some other function such as aposematic signaling or startle.

The two sections in boldface above are the ones relevant to the hypotheses. The first such section is the conclusion of the authors and supports the 4th hypothesis, namely that the clicks interfere with the processing of the aural data. The last paragraph supports the first 2 hypotheses, but it is not based on the authors' own work. I don't see anything here that addresses the 3rd hypothesis that the clicks might confuse the bat with multiple targets.

4. Locate a distribution map for the paddlefish, *Polyodon spathula*, and determine which are the westernmost and easternmost states in its distribution. Incorporate a copy of the map.

The westernmost state to have paddlefish is Montana; the easternmost is Pennsylvania. Your map may differ; see Figure 4, below.

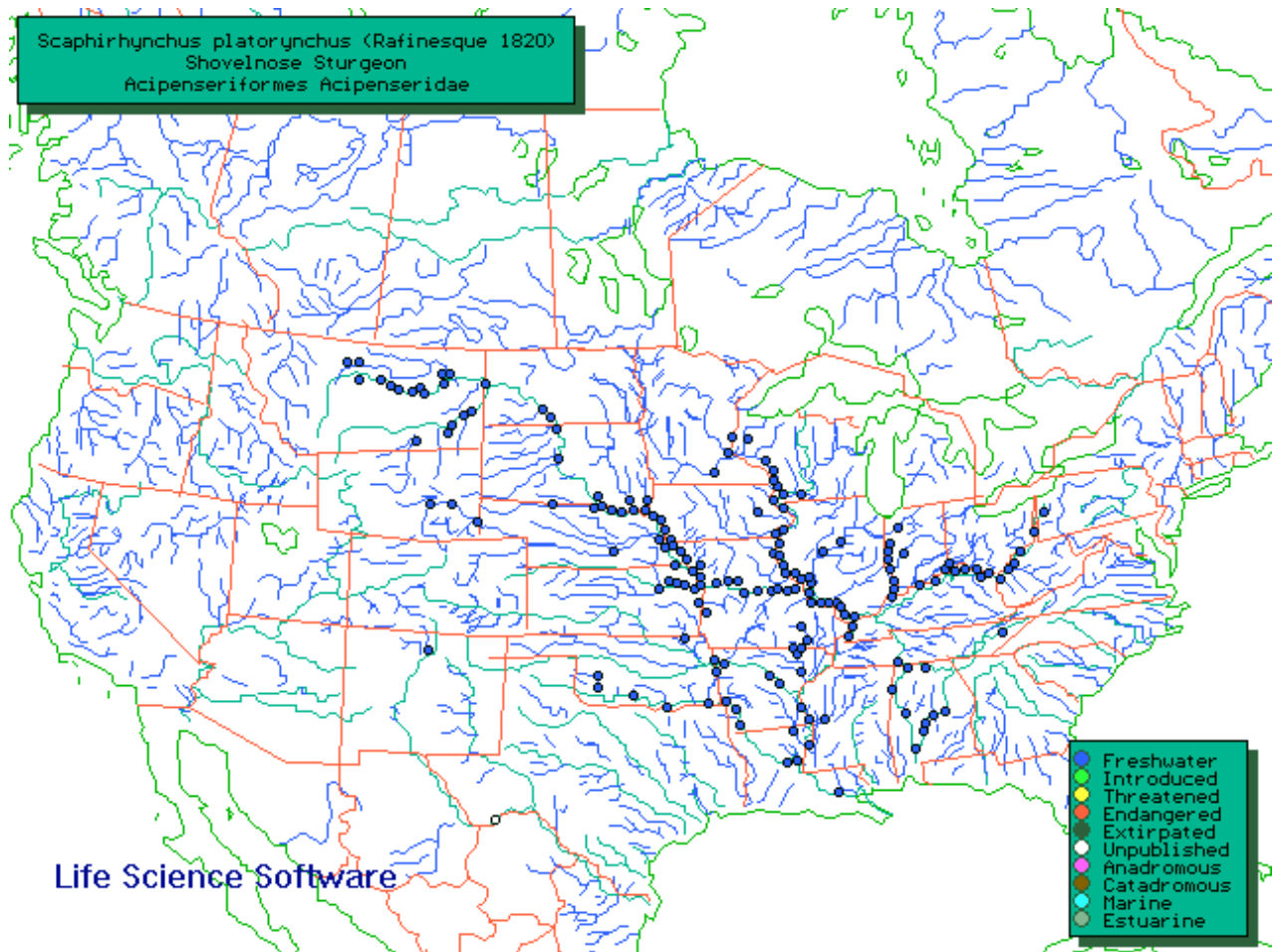


Figure 4 - Distribution of the Shovelnose Sturgeon in the USA

Source: Texas Natural History Collections.

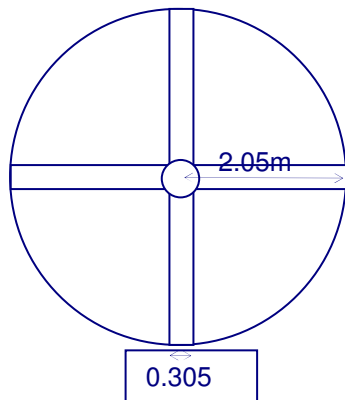
<http://www.tmm.utexas.edu/tnhc/fish/maps/huggmaps/scapplat.gif>

5. A flight of 199 Canada Geese averaging 1m long approaches a Vestas V-80-2.0 MW wind turbine in Kansas. The birds are flying in a typical "V" formation. The wind is blowing from 172° at 15 m/s. The birds are flying at (towards) a bearing of 172° at an airspeed of 65 km/hr. Assuming the birds fly within the arc of the turbine blades:
- What is the chance that all of the birds will pass through the blades unscathed?
 - How many birds would you expect to be struck?

This is going to be a long answer. First, let us go back to and examine the original goose question from 2003:

A military C-130 aircraft used for civilian relief flights has 4 turboprop engines. The engines have 4 propeller blades, each about 1 foot wide with a diameter of about 4.1 meters. The engines turn at 13,820 RPM and the plane cruises at 595 km/hour.

- a. If the plane is approached by a 1 meter long goose flying into one of the propeller arcs at 20 km/hour, what are the odds that there will be goose pâté on the side of the plane?



$$\begin{aligned} \text{Circumference of prop arc at blade tips} &= \pi D = 4.1\text{m} \times 3.14 = 12.9\text{m} \\ \text{Circumference of prop arc at mid point} &= \pi D = 2.01\text{m} \times 3.14 = 6.45\text{m} \end{aligned}$$

First, get the basic facts in order, and all the units converted:

The combined speed of the goose and the plane is $595+20\text{km/hr} = 615\text{ km/hr}$

Converting to m/s:

$$\frac{615\text{km}}{1\text{ hr}} \times \frac{1000\text{m}}{1\text{km}} \times \frac{1\text{hr}}{60\text{ min}} \times \frac{1\text{ min}}{60\text{s}} = \frac{615\text{ km}}{1\text{hr}} \times \frac{1000\text{m}}{1\text{km}} \times \frac{1\text{hr}}{60\text{min}} \times \frac{1\text{ min}}{60\text{ s}} = 170\text{m/s}$$

If the goose and the plane are closing each other at 170 m/s, then it takes 0.0059 seconds for the 1m long goose to pass the prop.

$$\frac{1\text{ m}}{170\text{ m/s}} = \frac{1\text{ m}}{170\text{ m/s}} = 0.0059\text{s}$$

During this time, what does the prop do? It revolves 13,820 times. This means that at the tip the blade must travel the 12.9m 13,820 times for a total distance of 178,278m each minute:

$$\frac{178,278\text{m}}{1\text{ min}} \times \frac{1\text{ min}}{60\text{s}} = 2,971\text{m/s}$$

Now, in the 0.0059s it takes the goose to clear the prop arc each of the prop tips will travel $0.0059\text{s} \times 2,971\text{m/s}$ or 17.53m. This is equivalent to more than one revolution. A single revolution would be a distance of 12.9m. Thus, in 0.059s the blade travels:

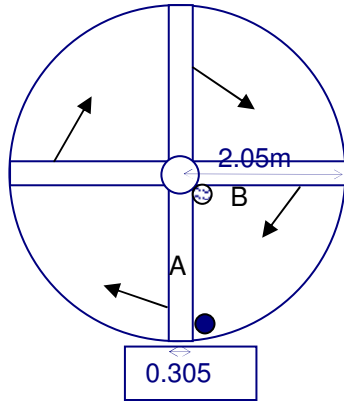
$$17.53\text{m}/12.9\text{m} = 1.36\text{ revolutions.}$$

This means that any single blade would pass once through the goose and have a 36% chance of hitting it again – and this is assuming an infinitely thin goose!

If the bird flies into the prop at the mid-point of the blade the speed is 1,485 m/s but the arc is only 6.45 meters. In 0.0059 seconds the midpoint of the blade travels 8.76 meters; again 135% of the arc, so the chance is the same.

- b. What is the largest bird that would have a chance of getting through the prop?

You can simplify this problem enormously by considering only one part of the propeller arc. Consider again the diagram:



Circumference of prop arc at blade tips = $\pi D = 4.1m * 3.14 = 12.9m$
 Circumference of prop arc at mid point = $\pi D = 2.01m * 3.14 = 6.45m$

If we consider only a 90 degree arc, and figure out how small a bird would have to be to get through there, the same length would work in any of the other four quadrants. In the diagram above, the bird is represented by a small solid circle. If it flies through just as the trailing edge of prop blade "A" clears the space, it has a period of time until the next blade ("B") gets there. How long? The blade tip is traveling at 2,971 m/s. The entire arc is 12.9m, but we are only looking at 1/4 or 3.23m. From that we have to subtract the 1 foot (0.305m) of space actually occupied by the blade. This means there is a gap of 3.23-0.305 or 2.93m for the leading edge of blade "B" to cover. At 2,971m/s this will take:

$$2.93m \quad \times \quad \frac{1 \text{ s}}{2,971m} = \quad 0.001s$$

So, the bird has 0.001 second to get through the space. At 170m/s a bird would travel this far in 0.001 second:

$$\frac{170m}{1 \text{ s}} \quad \times \quad \frac{0.001 \text{ s}}{1} = \quad 0.17m$$

This is about 6.5 inches long, a sparrow-sized bird. Of course, this also assumes a bird with no girth – the girth of the bird would have to be subtracted from the gap size above. I measured several sparrows in our collection and came up with an average width (diameter) of about 30mm or 0.03 meters. This would make the gap 2.9 meters and plugged into the equations above it doesn't change the rounded value for the 0.001 second. Thus, it is mathematically possible for a bird this size to make it through.

c. What is that chance?

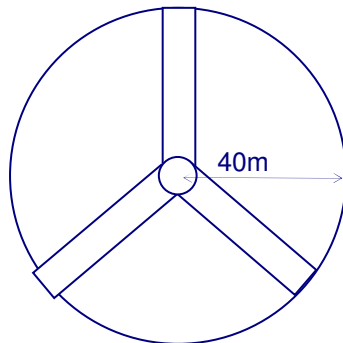
You can only estimate the chance. The area covered by the prop is πr^2 ; in this case $3.14 \times 2.05\text{m}^2$ or 13.2m^2 . The area occupied by the bird is $3.14 \times 0.03\text{m}^2 = 0.003\text{m}^2$. For the above calculation to work, the bird must come in just behind the tip of the prop. Any closer to the center of the prop means a shorter gap for the prop to close; although the blade will be traveling more slowly at that point the prop takes up just as much space – at some point the bird will get pinched between the prop blades as is happening to the bird represented by the small patterned circle in the diagram above. Thus, there are 4 places at any one time where the bird could enter the prop arc with a chance of getting through. Together, these 4 places represent $4 \times 0.003\text{m}^2$ or 0.012m^2 of the entire 13.2m^2 area within the prop arc. $0.0003/0.012 = 0.025$ or a 2.5% chance of getting through.

Now – the answer to our new question:

A flight of 199 Canada Geese averaging 1m long approaches a Vestas V-80-2.0 MW wind turbine in Kansas. The birds are flying in a typical “V” formation. The wind is blowing *from* 172° at 15 m/s. The birds are flying at (towards) a bearing of 172° at an airspeed of 65 km/hr. Assuming the birds fly within the arc of the turbine blades:

- What is the chance that all of the birds will pass through the blades unscathed?
- How many birds would you expect to be struck?

First, we need some specs on the turbine. A simple Google search gives us the technical specs for the Vestas; the rotor is 80m in diameter and sweeps an area of $5,027\text{m}^2$. At a wind speed of 15 m/s it revolves at 16.7 rpm. Next, let's make a new drawing:



$$\begin{aligned} \text{Circumference of prop arc at blade tips} &= \pi D = 40\text{m} \times 3.14 = 125.6\text{m} \\ \text{Circumference of prop arc at mid point} &= \pi D = 20\text{m} \times 3.14 = 62.8\text{m} \end{aligned}$$

Next, get the basic facts in order, and all the units converted:

We need to know the ground speed of the geese, not the air speed. To get ground speed we need to add the vectors of air speed and wind speed. If the bird flies directly into the wind, we give the wind speed a negative vector; if the wind is directly behind the bird it is a positive vector, if it is from any other direction it gets complicated. The homework gods have smiled upon us and it is an easy subtraction, but we also need to convert km/hr to m/s:

Converting to m/s:

$$\frac{65\text{km}}{1\text{hr}} \times \frac{1000\text{m}}{1\text{km}} \times \frac{1\text{hr}}{60\text{min}} \times \frac{1\text{min}}{60\text{s}} = \frac{65\text{km}}{1\text{hr}} \times \frac{1000\text{m}}{1\text{km}} \times \frac{1\text{hr}}{60\text{min}} \times \frac{1\text{min}}{60\text{s}} = 18\text{m/s}$$

Now we add the vectors.

$$\frac{18\text{m}}{1\text{s}} - \frac{15\text{m}}{1\text{s}} = \frac{3\text{m}}{1\text{s}}$$

So, it takes a goose 1 second to go 3 meters. Another way of looking at it is that if a goose is 1 meter long, it will take 1/3s for its body to pass any stationary point.

During this time, what does the blade do? The blade revolves 16.7 times per minute; This means that at the tip the blade must travel the 125.6m 16.7 times for a total distance of 2,098m each minute, in a second:

$$\frac{2098m}{1 \cancel{min}} \times \frac{1 \cancel{min}}{60s} = 35m/s$$

Now, in the 0.33s it takes the goose to clear the prop arc each of the prop tips will travel $0.33s \times 35m/s$ or 11.6m. This is equivalent to less than one revolution. A single revolution would be a distance of 125.6m. Thus, in 0.33s the blade travels:

$$11.6m/125.6m = 0.09 \text{ revolutions.}$$

This means that any single blade (of the 3) would move 0.09 revolutions, but since the bird has to pass between two blades the relevant number is 1/3rd of a revolution (see the picture). 1/3 revolution is 125.6m/3 = 41.9m; 11.6m/41.9m = 0.277 (27.8%) of the distance between 2 blades. Thus, a 1 meter long goose has a 100%-27.8% = 72.2% chance of getting through the blade.

As in the plane example, if the bird is closer to the hub the blade will be moving more slowly, but it will have proportionately less distance to travel, so the chance is the same. Note that in this analysis I have ignored the thickness of the blade either in terms of frontal area or side area (the blade is assumed to be infinitely thin when viewed from the front or side).

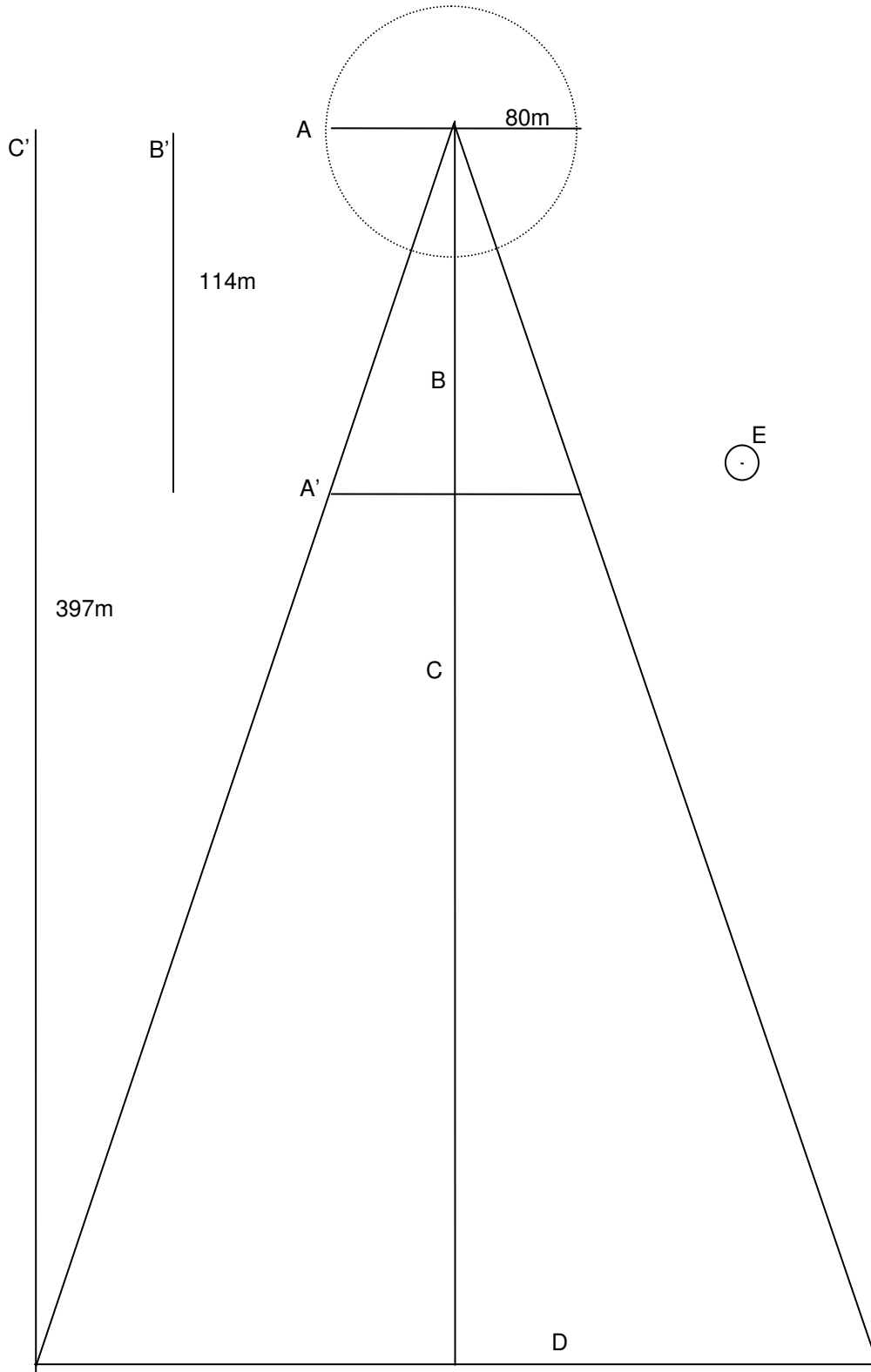
That is one bird – what about the whole flock? Smith Telek and Hackenburg provide this analysis:

Birds: <ul style="list-style-type: none"> • Avg. Body length: 1m • Avg. Wingspan: 1.5m • Depth between birds: 3m • Avg. wingspan overlap: -20cm 	<ol style="list-style-type: none"> 1. Determine depth of V of geese Per side: 100 geese x 1m = 100m (length of geese) 99geese x 3m = 297m (length of space between geese) 297m + 100m = 397m depth 2. Determine width of V of geese Per side: 1.5m x 100geese = 150 total bird wingspan Subtract overlap: 150m – (.02m x 99 geese) = 148.02m 148.02 x 2 = 296.04m total width
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As we'll see, the depth of the formation is not as important as the width. Look at the diagram on the next page (drawn to scale).

This is a plan view (looking down) of the flock as it approaches the turbine. The dashed circle represents the rotor; of course from above we would not see a circle, only the span of the rotor blades (line A). This line is 80m long. The triangle formed by the wedge-shaped formation of geese is 397m long (line C) and 269m wide (line D). For scale, a single 1m long goose is shown in the small circle (E). Now, if we make a replica of line a (line A') and place it so that it reaches from one side of the wedge to the other it will mark a position past which the geese are flying outside of the blade arc; thus they will have no chance of getting whacked. A new line, B, can be drawn to determine the distance to this point. For convenience, I have redrawn lines B and C to the left as lines B' and C'. We know Line C is 397m long. On my drawing, I did a right-click on the line and asked Word to format the autoshape. On the size tab, I found this line to be 7.46 inches long. We now know that 7.46" on the screen = 397m in real life. That means that 7.46 inches/397m = 0.0188 inches/meter. Line B' is 2.15" long, 2.15 inches / 0.0188 inches/meter = 114m. Note that we assume the birds fly through the arc dead center; higher or lower and the blade reach is less than 80m.

So, any birds further back than 114 meters will not hit the rotors no matter what. I could continue to draw in and position the tiny geese in my model (drawing) to determine how many geese could hit the fan, but there is an easier way. 114/397 = 0.29, so only about 29% of the geese pairs will fly within the rotor span. If there are 100 pairs of geese this translates to 29 pairs or 57 geese (the first "pair" is a single goose) that are at risk. We can ignore the rest. Since the geese go through in pairs (after the first one) we can make the assumption that if one of the pair gets hit so will the other (this isn't true, but the math works out the same with the simplification).



Can we answer the questions yet?

- What is the chance that all of the birds will pass through the blades unscathed?
- How many birds would you expect to be struck?

In terms of the first question the chance of a pair of birds flying through without getting hit is 0.722; the chance of all 29 pairs getting through is $0.722^{29} = 0.000079$ or **0.0079%** (the chance of flipping heads 4 times in a row is $0.5 \times 0.5 \times 0.5 \times 0.5 = 0.5^4 = 0.0625$ or 6.25%).

The number that get hit is more difficult. If 29 pairs of birds have less than a 1% chance of getting through unscathed then it follows that there is a 99% chance that at least one pair will get hit. Assuming it's the first pair, we could then calculate the chance of the next 28 pairs getting through. It would look like this:

Chance of single pair getting through	Pairs remaining	Chance of all getting through	Chance of all getting hit
0.722	29	7.89912E-05	7.53875E-17
	28	0.000109406	2.71178E-16
	27	0.000151532	9.7546E-16
	26	0.000209878	3.50885E-15
	25	0.00029069	1.26218E-14
	24	0.000402618	4.5402E-14
	23	0.000557642	1.63317E-13
	22	0.000772357	5.8747E-13
	21	0.001069747	2.1132E-12
	20	0.001481644	7.60144E-12
	19	0.002052139	2.73433E-11
	18	0.002842298	9.83572E-11
	17	0.0039367	3.53803E-10
	16	0.005452494	1.27267E-09
	15	0.00755193	4.57796E-09
	14	0.010459737	1.64675E-08
	13	0.01448717	5.92355E-08
	12	0.020065333	2.13077E-07
	11	0.02779132	7.66466E-07
	10	0.038492133	2.75707E-06
	9	0.053313203	9.91752E-06
	8	0.073841002	3.56745E-05
	7	0.102272856	0.000128326
	6	0.141652155	0.000461603
	5	0.19619412	0.001660443
	4	0.271737009	0.005972817
	3	0.376367048	0.021484952
	2	0.521284	0.077284
	1	0.722	0.278
	0	1	1

I put the chance of all of the birds getting hit (always a smaller number) in just as a check of my calculations. Sure enough, by the time we get to 1 pair of birds we are back to the probabilities we had calculated earlier.

This analysis does not do us much good in terms of figuring out how many birds will likely be hit. Fortunately, the geese are not approaching the turbine randomly. They are in a fixed formation. What happens if we assume a worst case scenario – the second row (the first real pair as the first row of the flock is a single bird) gets hit? If it does, we can calculate when the next row will be in line with the blade. If there are a total of 4 meters between birds (1 meter of bird + 3 meters of space) and the birds are flying 3m/s then the next row will have their necks on the

chopping block in $4\text{m}/3\text{m/s} = 1.33\text{s}$. The blade is advancing at 35m/s so in 1.33s the blade will advance $35\text{m/s} \times 1.33\text{s} = 46.7\text{m}$. Recall that the distance for $1/3$ of a revolution is 41.9 meters. It looks like the next row will pass just behind the blade. But what about the future rows? Back to the spreadsheet....

Time	Pair	Pair time	Blade Movement (m)	Blade Revolutions x 3
	1			
0	2	0	0	0
1.33	3	1	46.550	1.1
2.66	4	2	93.100	2.2
3.99	5	3	139.650	3.3
5.32	6	4	186.200	4.4
6.65	7	5	232.750	5.6
7.98	8	6	279.300	6.7
9.31	9	7	325.850	7.8
10.64	10	8	372.400	8.9
11.97	11	9	418.950	10.0
13.3	12	10	465.500	11.1
14.63	13	11	512.050	12.2
15.96	14	12	558.600	13.3
17.29	15	13	605.150	14.4
18.62	16	14	651.700	15.6
19.95	17	15	698.250	16.7
21.28	18	16	744.800	17.8
22.61	19	17	791.350	18.9
23.94	20	18	837.900	20.0
25.27	21	19	884.450	21.1
26.6	22	20	931.000	22.2
27.93	23	21	977.550	23.3
29.26	24	22	1024.100	24.4
30.59	25	23	1070.650	25.6
31.92	26	24	1117.200	26.7
33.25	27	25	1163.750	27.8
34.58	28	26	1210.300	28.9
35.91	29	27	1256.850	30.0
37.24		28	1303.400	31.1

The first column shows the time, incremented by 1.33 seconds, the time it takes each row to pass the blade. The second column shows the pairs. The third column shows the pair time, an increment arbitrarily started as the second pair gets hit in our worst-case scenario. The next column shows how far the 35m/s blade has advanced cumulatively with each additional 1.33 seconds. The last column shows the blade movement in terms of numbers of revolutions. To get this, we divide the number in the previous column by 41.9m , the distance the tip travels in $1/3$ revolution (alternately we could divide by 125.6 and multiply by 3). Now, here is the secret: I set the number of decimal places to 1 . If the decimal digit is 0 then the blade is back where the birds are crossing it. So, any of these rows will be hit, and so will the row 9 rows later. The birds in the intervening rows pass between the blades. In this example 4 rows get hit; each of these rows had 2 birds so a total of 8 birds out of 199 get hit.

Is our worst case really worst case? If the first bird had been hit we would have ended up with a total of 7 dead birds. If a later row got hit we would have even less:

Time	Pair	Pair time	Blade Movement (m)	Blade Revolutions x 3
	1			
	2		0	0
	3		46.550	1.1
	4		93.100	2.2
	5		139.650	3.3
	6		186.200	4.4
	7		232.750	5.6
0	8	0	0.000	0.0
1.33	9	1	46.550	1.1
2.66	10	2	93.100	2.2
3.99	11	3	139.650	3.3
5.32	12	4	186.200	4.4
6.65	13	5	232.750	5.6
7.98	14	6	279.300	6.7
9.31	15	7	325.850	7.8
10.64	16	8	372.400	8.9
11.97	17	9	418.950	10.0
13.3	18	10	465.500	11.1
14.63	19	11	512.050	12.2
15.96	20	12	558.600	13.3
17.29	21	13	605.150	14.4
18.62	22	14	651.700	15.6
19.95	23	15	698.250	16.7
21.28	24	16	744.800	17.8
22.61	25	17	791.350	18.9
23.94	26	18	837.900	20.0
25.27	27	19	884.450	21.1
26.6	28	20	931.000	22.2
27.93	29	21	977.550	23.3

In this case, a total of 6 dead birds.

There are other ways to answer the question; for instance you could calculate the frontal area of a goose and the frontal area of the 3 blades (we don't have good data on the blades and the fact that they twist makes calculating their area impossible without using calculus). The proportion of the circle occupied by the sum of the blades and the birds is the chance of the birds getting hit at any one time.

Study questions (these might appear on a test; do not turn them in as part of your homework):

1. For each chemical, list the primary uses in organisms: C, N, O, P, K, S, Mg, Fe, Na, Cu.

Table 2 - Primary uses of selected elements by organisms.

Chemical	Uses
C (carbon)	sugars, proteins, polysaccharides, DNA, ATP, etc.
N (nitrogen)	proteins
O (oxygen)	carbohydrates, respiration (oxygen acceptor)
P (phosphorous)	ATP, NADP, phospholipids
K (potassium)	ionic balance
S (sulfur)	proteins
Mg (magnesium)	chlorophyll
Fe (iron)	cytochromes, hemoglobin
Na (sodium)	ionic balance
Cu (copper)	respiratory pigments

2. Prepare a table comparing ammonia, urea, and uric acid in terms of the amount of water used in excretion, the toxicity, and the amount of energy used to synthesize each. Use ratings of low medium, and high.

Table 1. Comparison of ammonia, urea and uric acid as excretory molecules.

Compound	Water used in excretion	Toxicity	Energy required for synthesis
ammonia	high	high	low
urea	medium	medium	medium
uric acid	low	low	high

3. Describe the ecological differences in a mouse's and a frog's approach to life.

There are many ways you could have answered this question, and I won't try to elaborate on all of them. Basically, a mouse, with a large surface area-to-volume ratio, must spend a good portion of its time eating, since it loses a lot of heat. An elephant, on the other hand, has a huge volume of cells producing heat, and relatively little surface area to lose it through. It is concerned with overheating. Mice reproduce quickly and often; individuals have high death rates due to disease. Elephants reproduce more slowly, and lose fewer of their numbers to predators. Elephants live a long life at a slow pace; mice live a short life at a fast pace, with a high metabolic rate. An environment can support more mice (numerically) than elephants; but in terms of overall biomass, a given area can support more weight in elephants than mice because the elephants are more efficient.

4. Why is the electrical sense only found in aquatic organisms?

The answer to this question is based on the fact that water is much more conductive of electrons than air is. It would take a lot of current to generate a detectable effect in air; it's just not worth the

energy to produce that kind of “juice”. In addition, water, because it supports much of the weight of any particles, allows particles to stay in suspension for a longer period of time - the water is murky (by contrast, dust and other particles settle out of air very quickly). In murky water, sight is useless, and thus there is strong evolutionary pressure for a replacement for sight as a distance sense. In the conductive world of water, an electrical sense is an ideal replacement for sight. In addition, the electrical sense takes advantage of the weak electrical currents set up by living organisms.

5. Graph the density of water from 0°C to 30°C .

The graph below (Figure 2) answers the question as stated, but it is not a very pretty graph. The problem is that the major change in density comes as the ice is formed. That is the relationship I wanted you to see. By the way, note that the graph below is an *xy* graph, not an *Excel* line graph. This important distinction prevents *Excel* from putting 2 “0” points on the x-axis.

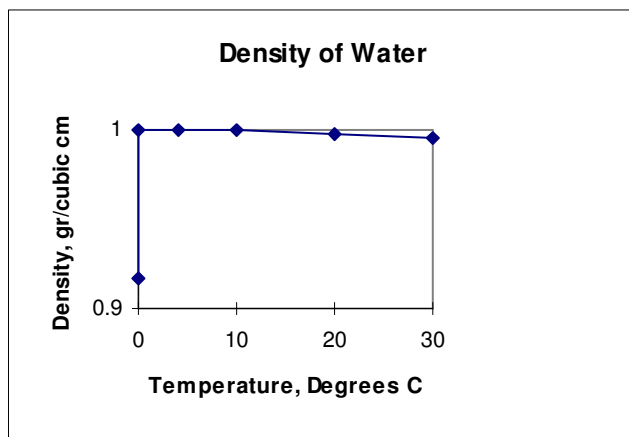


Figure 2

In Figure 3, below, I took data from the Handbook of Chemistry and Physics¹. Omitting the 0° data for ice and increasing the number of intermediate data points makes for a “prettier” graph that illustrates another important point - water is at its densest at 4° C.

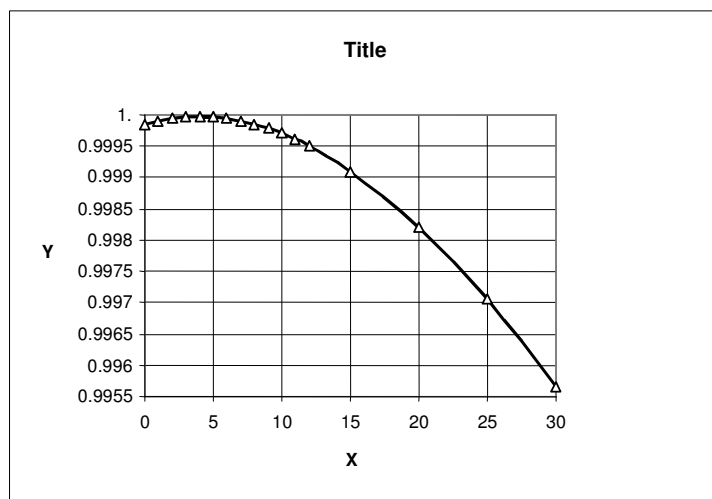


Figure 3

The moral: A graph, even of the same data, will show certain things best depending on how you set it up. Be careful about how you plan and present graphs. The goal is to show the trend you think is important without being misleading or without fabricating or changing the data. Also remember to title your graph and its axes!

¹ Weast, R.C., Ed. 1978. CRC Handbook of Chemistry and Physics. 59th edition. CRC Press, Inc. West Palm Beach. Page F-5