Why do Elephants have Big Ear Flaps?

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In this essay we shall try to answer the question in the title with some geometry and heat transfer thrown in for effect. For doing so, as the joke goes, allow me to assume the elephant as a sphere. The reason will be apparent soon.

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Sphere, being a much simpler geometrical shape when compared to the deformed volume shape of the elephant, can be used to understand an interesting property. As the length scale (diameter for the sphere) doubles, its surface area increases four times and the volume increases by eight times. See *Figure* 1 to verify this. Bottom curve is area increase and top curve is volume increase.

For instance, an orange is about double the diameter of a lemon, but could in principle hold eight times more juice in volume. Same goes for humans, if allowed to be assumed as a cylinder, an adult twice as much height and girth (width) as that of a kid would hold eight times more blood and flesh. Let this rest. We shall turn now into another issue.

A major difference between warm and cold-blooded creatures is that warm-blooded ones can generate by metabolism (cell-scale exothermic chemical reactions), the required heat energy to

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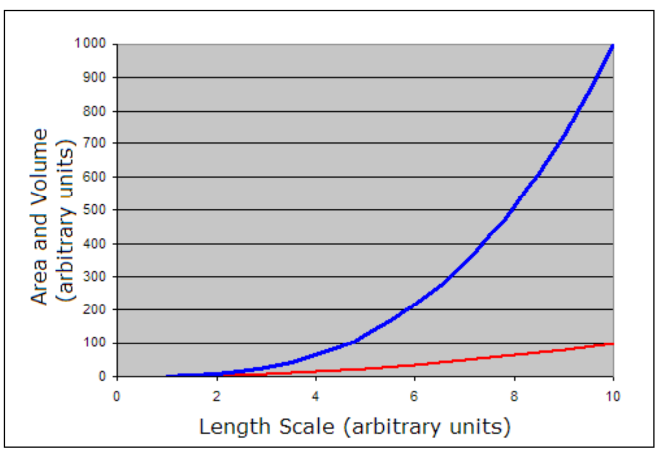

Figure 1. Length, area, volume – relative increase.

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maintain their body temperature while the cold-blooded ones require external heat sources like the Sun, to maintain their body temperature.

Mammals and birds are warm-blooded (there are exceptions), while fishes and lizards are cold-blooded (were dinosaurs cold-blooded?). Elephants are warm-blooded tetrapods.

Warm-blooded animals desire to remain at an isothermal body temperature of 35 to 42 ^{o}C (varies between animals, for humans it is about 37 ^{o}C – the core body temperature). In mammals and birds a highly active metabolism generates the required exothermic heat energy in their cells and feeds to the internal energy of the body, which results in the desired body temperature. The body temperature is maintained at the desired value with a built-in thermo-regulatory mechanism. This mechanism either releases the excess heat produced in the metabolism or triggers the body to generate higher metabolic rate at times, when the body temperature falls below the desired value.

For instance, when the outside temperature is very low, warm-blooded animals regulate their blood flow and stop most of the flow from reaching the outer surface (just below the skin) so as not to release the energy as heat transfer across a favorable thermal gradient to the environment. This is one reason why we have white finger tips (very less blood flow) during cold conditions.

Warm-blooded animals when faced with the need to release the excess metabolism generated heat energy, seek cool environment and divert their blood flow to the surface of their skin.

When this direct sensible heat release is not sufficient and the body temperature continues to fall, humans and birds shiver in cold environment to increase their metabolic rate. Shivering exercises the muscles to generate metabolic energy as much as five times that of normal conditions [1]. This release of more exothermic heat energy from the cells compensates for the heat loss to maintain the core body temperature a required constant. On the other hand, warm-blooded animals when faced with the need to release the excess metabolism generated heat energy, seek cool environment and divert their blood flow to the surface of their skin. This ensures higher heat transfer rate to the cooler environment from their body and maintains the body temperature at a constant value.

When such a direct sensible cooling is not sufficient to remove the excess heat, an evaporative cooling mechanism aids in case of mammals with large quantities of reservoir fluids. In other words, under such conditions, humans sweat. One gram of sweat (mostly water) evaporates by absorbing (carrying away from the body) about 2.26 kiloJoules of energy. Birds seldom sweat but, like dogs, they pant to release the excess heat.

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Further, warm-blooded animals retain their heat by insulating their body against the environment by growing hair and feathers. The hair traps a small layer of air around it as thermal insulation (air is a very poor heat conductor – k ~ 0.02 W/m.K). This is one reason polar bears are furry. This is also possible reason why we humans go bald.

Now let us connect the geometry part that we saw earlier with the above discussion. In light of the above features, a bigger warm-blooded animal should in principle generate more metabolic heat energy simply because it has more volume hence more flesh and cells. This metabolic heat release has to be regulated if it is excess only through the heat transfer across the skin surface area. As we saw earlier, the volume to area increase is not linear and hence large warm-blooded animals, like elephants, have more excess heat to be released than it is possible only through its skin as sensible heat and by sweating.

But elephants don't sweat [1]. And they certainly are twice as much in size as any of their savannah colleagues leading to a definitive volume (metabolic excess heat) to surface area (regulatory skin surface sensible heat release) unfavorable mismatch.

One way is to reduce the metabolic heat release itself and this indeed has happened, it seems, for large warm blooded animals in their evolutionary history – their metabolic rate is lower than that of their smaller counterparts. For elephants the standard metabolic rate (SMR) is about 0.82 W/kg [3], while for an average man it is about 1.2 W/kg. Even doing this doesn't seem to have regulated the body temperature of elephants, which would increase, unless another mechanism compensates and takes away the excess heat generated.

Firstly, in such a situation, having a fur coat of a hair structure is the least desired thing and hence elephants are mostly bald. The hotter the climate in which they live, the balder they are. Secondly, elephants have large ears which are packed with capillary structure through which sizable quantity of blood flows. Whenever there is excess heat that needs to be released, warm blood flows through these capillaries, while the elephant chooses a cold spot (like that of a shade) and uses the favorable thermal gradient to release the excess heat. In other words, the ear flaps of the elephant serve as an enormous convection plate – a flapping one at that – to enhance heat transfer from the elephant body to the environment [1].

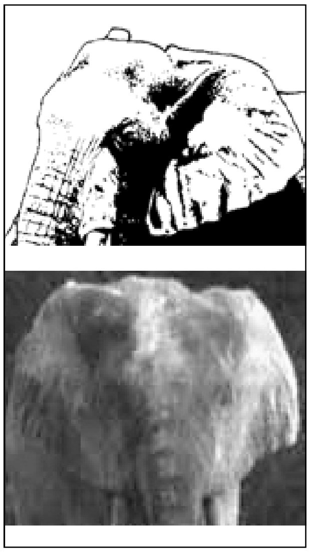

Figure 2. African Bush (or Savanna) Elephant (top) and Forest Elephant. (bottom).
Image adapted from pictures at http://www.elephantcountryweb.com/Elliefacts.html

Figure 3. Indian Elephant.
Image adapted from pictures at http://www.elephantcountryweb.com/Elliefacts.html

Elephants are classified as the African and the Indian, with the African one divided further into the bush elephant and the forest elephant. And based on this theory one could reason why the ear flaps of the African Bush Elephant (*Figure* 2) is larger than the Indian one *(Figure* 3). Assuming comparable sizes, the African bush elephant living in a hotter climate than the Indian one requires more blood vessels hence larger ear flap surfaces to release their excess heat to the environment which is relatively hotter. Lesser the thermal gradient, more the surface area required to transfer heat by convection. The hotness of the African climate can be inferred from the fact that the savannahs, where these African bush elephants live in majority, have their temperatures ranging in day time between 40 and 50 ^{o}C and can peak to even 53 ^{o}C. The hotness of the climate leading to the migration behavior of these elephants has been studied recently [2] in detail. You might wonder how much of this provocative idea is true. We shall detail now the quantitative validation procedure with experimental data support from the research literature [1].

A big African elephant weighs anywhere between 2000 kg to

4000 kg. A 4000 kg elephant needs to maintain a heat loss of 4.65 kW or more while moving and feeding (taken from [3]). This indicates that the elephant not only generates much energy but also must have an effective means of thermo-regulation to allow this excess energy to escape out as heat. Assuming most of this excess heat needs to be released from the pinna (ear region) of the elephant, this can happen through radiation and convection heat transfer to the surrounding air. The convection can either be natural or forced depending on whether the elephant ear flaps are stationary or swinging. Further, the flapping rate determines the forced convection to be laminar or turbulent. Let us analyze in detail.

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The radiation heat transfer (loss) can be calculated as

$$Q_R = \sigma \varepsilon A(T_s^4 - T_a^4) \quad (1)$$

where, $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4 is the Stefan–Boltzmann constant and e is the emissivity of the elephant ear surface taken to be equal to 0.96, the standard value for biological tissue (from [4]). The average surface area of the elephant ear, A, can be found once the average length and breadth of the elephant ear are measured. Further the average surface temperature of the elephant ear, T_s (^{o}C) and the ambient air temperature T_a (^{o}C) also should be measured before one can arrive at the radiation heat loss.

The convection heat loss can be calculated as

$$Q_c = hA(T_s - T_a), \quad (2)$$

where h is the combined natural and forced convection heat transfer coefficient of the configuration, which needs to be determined. The rest of the symbols are as defined earlier.

In the case of natural convection heat transfer from the elephant ear, it can be calculated using the correlation

$$Nu_{NC} = \frac{h_{NC} L}{k} = 0.15 Ra^{1/3} = 0.15\left(\frac{g\beta(T_S - T_a)L^3}{v\alpha}\right)^{1/3}. \quad (3)$$

where Nu_{NC} is the non-dimensional form of the natural convection heat transfer coefficient and Ra is Rayleigh number, which controls the magnitude and strength of natural convection. The above correlation is for turbulent natural convection (p.372, [5]), an assumption made due to the flapping of the elephant ear.

Other symbols are: k is the thermal conductivity of the elephant ear tissue (W/m.K); L is the characteristic length along which natural convection prevails (equal to $4A/p$, where p is the perimeter of the elephant ear); g is the acceleration due to gravity (m/s^2); β is the coefficient of volumetric thermal expansion ($1/K$); α is the thermal diffusivity (m^2/s) and ν the kinematic viscosity or momentum diffusivity (m^2/s) of the surrounding air. The temperatures are as defined earlier and observe as before, they are the only required measurements. The rest of the properties are obtained at film temperature (simple average of the surface and ambient temperature) from standard data books.

The turbulent forced convection heat loss can be calculated by assuming the elephant ear as a heated flat plate undergoing turbulent forced convection cooling in the surrounding air. The forced convection heat transfer coefficient can be calculated using the correlation (p.357, [5])

$$Nu_{NC} = \frac{h_{FC}L}{k} = 0.037 Re_L^{4/5} Pr^{1/3} = 0.037\left(\frac{UL}{\nu}\right)^{4/5}\left(\frac{\nu}{\alpha}\right)^{1/3} \tag{4}$$

where Re_L is the characteristic length based Reynolds number, a parameter that determines the flow to be laminar or turbulent and Pr is the Prandtl number, the ratio of the diffusivities defined earlier. Here only the average velocity of the flow, U (m/s), near the elephant ear needs to be measured. The rest of the properties are obtained as before at the film temperature of the configuration.

It is worthwhile to keep in mind that the correlations presented in (3) and (4) are valid for calculating the heat transfer from a flat plate surface, which is how the elephant ear is modeled in our analysis. We find the heat transfer from the front ear surface and assume it to be the same on the back side of the ear. A better and more rigorous analysis would be to model the elephant ear as a fin or extended surface with a cross section that is thick at the base (where the ear is attached to the elephant head) and thin at the tip. Also, since the ear is a biological surface (tissue and skin), it may possess a different surface roughness and more wrinkles, all of which when accounted for in the fin analysis, could lead to a different heat transfer value. In this light, we could treat our present results as a conservative estimate.

In summary, to determine the heat loss from the elephant ear, one requires measurement of the ear surface temperature, the ambient temperature and the velocity of air flow around the ear, while it is flapping. For instance, upon simplification the resulting heat transfer coefficients from (3) and (4) are $h_{NC} = 1.8\ (T_s - T_a)^{-3}$ for natural convection and $h_{FC} = 5.76\ V^{0.8}\ D^{-0.2}$ for forced convection, where D is the characteristic forced convection length. The velocity V can be calculated using $V = L(N/60)$ where L is the arc length of the ear flapping and N is the number of flapping made in 1 minute. Using these relations we can find $Q_{C,}$ the heat loss by convection given in (2), which when summed with $Q_{R,}$ the heat loss by radiation given in (1), results in the total heat loss from the elephant ear flaps.

Experiments that measure the above required temperatures and velocity were conducted and reported in a research paper by Polly Phillips and Edward Heath in 1992 [1]. For four African elephants (*Loxodonta Africana*), they measured the ear (*pinna*) surface temperature using infrared thermography under ambient conditions varying between 18 ^oC and 32 ^oC. They also measured the velocities of turbulent air flow around the ears for each case. From reference [1], for Mame, an elephant weighing 2000 kg, height = 2.31 m, ear surface area = 3.485 m^2 (21.9 percent of 15.9 m^2, the total surface area of elephant Mame) and having a standard metabolic rate of 0.8 W/kg, one set of the reported measured values of the parameters are as follows: $V = 5$ m/sec, $T_s = 33.97$ °C and $T_a = 27.2$ °C.

The convection correlations used in [3] have been improved in the last decade, as presented in (3) and (4). However the major conclusions remain aligned with that of the original paper. So, using the experimental values from [1] in the procedure detailed above from (1) to (4), results in a total heat loss of $Q = 76.21$W from one side of one ear of Mame. For all the four sides of the two ears, this translates to about 325 W, twenty five percentage of the standard metabolic rate of 1643 W of Mame. Further, Polly Phillips and Edward Heath report in their paper [1] that using the flat plate model of the ear flap, for a wind velocity of 5 m/sec around the ear, when $T_s = 36$ °C and the temperature gradient is 20 °C, the heat loss raises to 1500 W, about 91 percentage of 1643 W, the standard metabolic rate of Mame.

For an Asiatic elephant of the same size and metabolic rate but with only one third the ear size of the African elephant, the paper reports, loses only 544 W in similar situation, amounting to only 33 percentage of the standard metabolic rate. Based on our above analysis, the ambient temperature (thereby, the total temperature gradient) effect and the effect of relative velocity of ear flapping on the total heat loss from the ears of an African elephant and a corresponding Indian elephant having one third the ear size can be observed from the set of calculated results given in *Table* 1.

The elephant ear adapts its temperature to the surrounding temperature by vaso-dilation, a thermo regulatory body mechanism by which the organism dilates the blood vessels to increase or decrease blood flow in a localized region.

In their subsequent research [6], the same authors show that the elephant ear adapts its temperature to the surrounding temperature by vaso-dilation, a thermo regulatory body mechanism by which the organism dilates the blood vessels to increase or decrease blood flow in a localized region. This ensures the favorable temperature gradient for the elephants to maintain their ear heat loss. In another 2001 paper [7], on a lighter vein, these authors use the simple flat plate convection heat transfer model of the elephant ear to analyze the usefulness of the ear size of Dumbo, the Disney elephant character. Additional research material discussing the hotness of the savannah climate and the

Ambient Temp.	Ear Surface Temp.	Ear Surface Area (one side)	Ear flap relative velocity	Total Heat loss from ear (Eq. (1) + (2))	% of SMR (=1643 W)
African Elephant (Mame) with 2000 kg Weight and Standard Metabolic Rate (SMR) = 1643 W					
T_a (°C)	T_S (°C)	A (m^2)	V (m/sec)	Q (W)	% SMR
27.2	33.09	0.8712	1.03	320	20
23	33.09	0.8712	1.03	551	34
18	33.09	0.8712	1.03	846	51
27.2	33.09	0.8712	5	616	38
23	33.09	0.8712	5	1072	65
18	33.09	0.8712	5	1625	99
Indian Elephant with 1/3 rd ear size and other data identical to Mame					
27.2	33.09	0.2614	5	201	12
23	33.09	0.2614	5	350	22
18	33.09	0.2614	5	530	33

Table 1. Sample calculations using (1) to (4) with measured and specimen data.

elephant adaptation and thermoregulation in other animals are provided in [2] and [6]. These research literature, [1] [2] and [6], provide quantitative support and substantiate well that the elephant ears serve as a thermo-regulatory mechanism, capable of transferring up to 100 percent of the heat loss requirement.

The theory of elephant thermo-regulation using their pinna also explains reasonably why the now extinct Mammoths (*Figure* 4), living in a cold tundra region, have fur coats and small hairy ears. Similarly, from the discussion above, one could conjecture with confidence on why elephants seem to be always flapping their ears, even when they are relatively at one position (say, in Temples). Further, as one might have noticed, elephants spray water on to their ears to improve this convection. When water is not around, using their trunks, they suck out from their mouth, the stored saliva/water mixture and pour it onto the ears. All done possibly to enhance their thermo-regulation requirement.

Figure 4. Mammoth.
Image adapted from drawing at http://www.mammoths.info/

Before we close it is apparent that the warning from our grandmothers not to touch the elephant's ears for they would get angry and the observation that the *mahoots* do touch the elephant's ears to exercise better control on them can now be perceived in different light. For more information on this and similar topics, the book by Chris Lavers [8], which served as an inspiration for this essay, is an interesting source.

Suggested Reading

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