Penguin Coloration Affects Skin Friction Drag

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Abstract

Why do penguins have black and white patterns? Some theories claim that it is camouflage against predators. Others believe that this helps with thermal regulation: black absorbs more heat than white does. There are even theories that suggest this coloration protects from abrasion and helps with energy balance. This study suggests that the specific color of penguins results in temperature differences on top and bottom surfaces reducing their skin drag. To prove this hypothesis, we conducted several experimental and computational studies. In experiments, an infrared camera was used to measure the penguin's temperature of the penguin's back and front. These temperatures were used to calculate energy balance and friction drag. The results show that penguin coloration affects the drag.

Introduction

There are different factors that help penguins to stay warm in the cold places; (1) They are warm-blooded birds with a normal body temperature of about 37.8 ◦C; (2) penguins have a layer of fat (blubber) under their skin; (3) penguins' feathers provide dynamic insulation in both air and water (they have fluffy "down" feathers and overtop of those they have outer feathers which help them to stay warm); and (4) penguins rub oil from a gland onto their feathers which make them windproof and waterproof.

One of the methods in drag reduction applied by warm-bloodied aquatics, such as marine mammals and birds is boundary layer heating. Recent studies have shown that colors can affect the flight and swimming performance of birds and aquatic animals[1,2]. Hassanalian et al.[1] showed that black color on the top side and white color on the bottom side of the migrating birds and aquatic animals can decrease their drag and consequently increase their efficiency[1,2]. Penguins as amphibious birds also have black backs and white fronts. Penguins generally live in the southern hemisphere. They live as far as Galapagos island. Antarctica is the main habitat of the penguins. Antarctica as the coldest place on Earth has a very short summer and a very long winter. In winter, the average temperatures range between -20 ◦C in the coastal strip and -70 ◦C in the continent, while in the summer the average temperatures range between 0 ◦C along the coast and -35 ◦C in the continent[3]. The core temperature of a penguin is about 36.9 degrees Celsius. Most of the penguins swim underwater at around 1.8 to 3.1 m/s, but the fastest penguin, Gentoo (Pygoscelis Papua), can reach top speeds of 9.8 m/s. Penguins have a layer of blubber to keep themselves warm. The thickness of the layer of blubber depends on the size of the penguin. For larger penguins, the blubber can be at least 2 to 3 centimeters thick while the smaller penguins have blubber up to 1 cm thick.

Energy Balance and Thermal Modeling

In this work, a new factor, which is the thermal effects of the body color of penguins, is investigated with respect to their swimming features and geometric and behavioral characteristics. Considering the environmental characteristics of these amphibious, a thermal analysis is performed. As indicated in Figure 1, the incoming energy from the solar and atmospheric radiations for the top part of the penguin and the core temperature of this warm-blooded bird can be balanced by convection to the freestream and radiative surface emission.

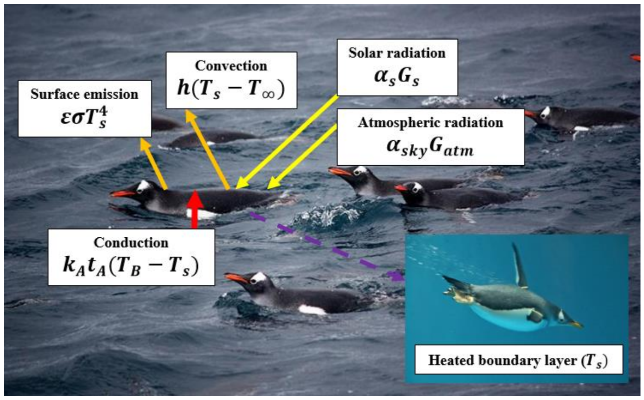

Figure 1: Heat fluxes on the penguin's body and energy balance.

In this study, it is assumed that penguins are moving over the surface of the water and receiving heat from the sun and atmosphere radiations, in order to increase their surface temperature. Then, they will continue moving under the water. An energy balance equation is written for the top side of the penguins while the backside of their bodies is outside of the water, as follows:

$$\alpha_s G_s + \alpha_{sky} G_{atm} + k_A t_A (T_B - T_s) = h(T_s - T_\infty) + \varepsilon\sigma T_s^4 \quad (1)$$

where α_s, α_{sky}, ε, σ, k_A, t_A, G_s, G_{atm}, h, T_B, T_s, and T_∞ are the solar absorptivity of surface, absorptivity of sky, emissivity of surface, Stefan–Boltzmann constant, conductivity of the blubber, blubber thickness, solar radiation, radiation at the Earth's surface due to atmospheric emission, convective heat transfer coefficient, core temperature of aquatic, upper surface temperatures, and ambient temperature, respectively.

Summary and Conclusions

The thermal effects of the black and white colors of penguins' bodies on their swimming efficiency were investigated. The surrounding fluxes, such as the sky and sun radiation as well as the core temperatures were considered in an energy balance to determine the skin surface temperatures of penguins' bodies. It will be shown that black color is heated more than white color in the same condition and there will be a drag reduction under water because of the dark color of these penguins.

References

1. Hassanalian, M., Abdelmoula, H., Mohammadi, S., Bakhtiyarov, S., Goerlich, J. and Javed, U., "Aquatic animal colors and skin temperature: Biology's selection for reducing oceanic dolphin's skin friction drag", *Journal of Thermal Biology*, 84, pp. 292-310, 2019.
2. Hassanalian, M., Pellerito, V., Sedaghat, A., Sabri, F., Borvayeh, L. and Sadeghi, S., "Aerodynamics loads variations of wings with novel heating of top surface: bioinspiration and experimental study", Experimental *Thermal and Fluid Science*, 109, p.109884, 2019
3. Balog, I., Spinelli, F., Grigioni, P., Caputo, G., Napoli, G. and De Silvestri, L., "Estimation of Direct Normal Irradiance at Antarctica for Concentrated Solar Technology" *Applied System Innovation*, 2(3), p.21, 2019.