Paper from: *Design and Nature*, CA Brebbia, L Sucharov & P Pascola (Editors).
ISBN 1-85312-901-1

The physical structure, optical mechanics and aesthetics of the peacock tail feathers

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Abstract

The peacock tail feathers have no flight or thermal function but have the sole purpose of providing an attractive display. The peacock tail produces colours by thin-film interference. There is a very high level of optimum design in the peacock feathers including optimum layer thickness, multi layers, precision co-ordination and dark background colour. This paper analyses the structure and beauty of the peacock tail.

1 Introduction

Aesthetic beauty in appearance is produced by attributes such as patterns, brightness, variety, curves, blending or any combination of such attributes. Beauty is so important in engineering design that there is a whole subject called *aesthetics* which defines how beauty can be added to man-made products[1]. An object can have two types of beauty: inherent beauty and added beauty. Inherent beauty is a beauty that exists as a bi-product of mechanical design. In contrast, added beauty is a type of beauty which has the sole purpose of providing a beautiful display. These two types of beauty can be seen in man-made products like buildings and bridges. An example of inherent beauty is found in the shape of a suspension bridge. A suspension bridge has a curved cable structure because this is an efficient way of supporting a roadway. However, the end result can be a very elegant and beautiful design.

An example of added beauty can be seen in the decoration of a classical column. The classical column shown in Fig. 1(a) has an elaborate form with intricate carvings and grooves. There is no mechanical reason for a classical column to be any more than a plain cylinder, like the one shown in Fig. 1(b), yet the designers embellish the column with elaborate patterns just for the sake of adding beauty.

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Biologists agree that there are features in nature, like the peacock tail, whose only purpose is to produce an attractive display[2,3]. Attractive displays such as the peacock tail are analogous to the added beauty in man-made design where the designer adds embellishments for the sake of adding beauty. This paper analyses the structure and beauty of the peacock tail.

2 The peacock tail

Most species of bird have two types of tail feather: flight feathers and tail-coverts. The flight feathers provide stability during flight, while the tail-coverts cover and protect the tail region of the bird. In the vast majority of birds, the tail-coverts are small feathers just a few centimetres long. However, some birds like the peacock have very large tail-coverts for decorative purposes. (It should be noted that a peacock is a male peafowl whilst a peahen is a female peafowl.) During the breeding season, the peacock will often display his tail feathers in an attempt to woo a peahen. The reason why it is generally the male that has a beautiful coloration is that the female must spend long periods on the nest and therefore, must be well camouflaged.

The peacock tail feathers are sometimes called decorative or ornamental feathers but most people refer to them simply as the peacock tail feathers. An adult peacock has an average of 200 tail feathers and these are shed and re-grown annually. Of the 200 or so feathers, about 170 are 'eye' feathers and 30 are 'T' feathers. The 'eyes' are sometimes referred to as ocellations. The length of the feathers varies from a few centimetres to over 1.5 m. The peacock tail feathers are some of the longest and most brilliantly coloured feathers in nature. The unique length and structure of the peacock tail feathers is acknowledged by bird experts[4,5].

3 The beauty of the peacock display

When a peacock displays his tail feathers, a magnificent 'fan formation' of feathers forms a beautiful backdrop to the body of the peacock. The eye and T feathers have complimentary shapes because the T feathers have a profile which is the inverse of the shape on the eye feathers, as shown in Fig. 2. Each individual eye feather and T feather is an object of outstanding beauty in itself. The eye feathers contain beautiful patterns with brilliant colours, whilst the T feathers form a beautiful border to the fan.

4 The structure of the peacock tail feather

The basic structure of the peacock tail feather in the eye region is shown in Fig. 3(a). For comparison, the structure of a typical flight feather is shown in Fig. 3(b). Like the flight feather, the peacock tail feather has a central stem with an array of barbs on each side. In addition, these barbs are covered with a large number of barbules. A large peacock eye feather may contain up to 300 barbs and one million barbules.

Even though there is a basic similarity with a flight feather, the peacock tail feather has an unusual overlapping barbule structure. The barbules are like long

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segmented ribbons which overlap to form a smooth surface on top of the barbs. (Under a microscope the barbules are slightly curved and the surface has a bubbly appearance.) Each barbule contains at least 20 separate segments.

5 Optical colours in the peacock tail feathers

The colours in the peacock tail are not pigment colours but structural colours which are produced by an optical effect called thin-film interference[6]. The thin-film interference takes place in the transparent segments of the barbules and produces bright and iridescent colours. An iridescent colour is a colour that changes with the angle of view. The barbules are dark purple in the 'pupil' of the eye, blue in the 'iris' of the eye, bronze around the iris and green on the fringes. Away from the eye region, the barbules are uniformly green.

BACKGROUND TO THIN-FILM INTERFERENCE

Thin-film interference can be produced in one or more layers of a very thin and transparent material. Usually the thin film is placed on a dark surface. The thickness of the transparent material must be close to the wavelengths of visible light. Visible colours have wavelengths of between 0.4 μ and 0.8 μ and thin films typically have a thickness of between 0.3 μ and 1.5 μ. Another requirement for thin-film interference is that the thin film must have a refractive index that differs from air (so that the light is retarded when it passes through the thin film). One common example of where thin-film interference occurs is in oil slicks on a wet road. When a car spills drops of oil on a wet road, the oil will often form a thin layer on the wet surface of the road. The resulting thin film produces blue and green colours even though oil itself is nearly transparent.

THIN-FILM INTERFERENCE IN THE PEACOCK BARBULES

In the peacock tail feathers, thin-film interference takes place in three layers of keratin which surround the barbules, as shown in Fig. 4. Each barbule is about 60 μ wide and 5 μ thick[7]. The foam core is 2 μ thick and the keratin layers are extremely thin, being about 0.4–0.5 μ thick[8]. Other types of birds, such as hummingbirds, pigeons and kingfishers, have some patches of flat iridescent barbules, but the peacock has the largest iridescent barbules of any known bird[9]. The colours in the eye feather can only be seen on the front surface of the feather because this is where the barbules are positioned. The back of the feather is uniformly brown because the barbs contain a brown pigment.

The principle of thin-film interference in a single layer of keratin is shown in Fig. 4. White light is reflected off the front and back surfaces of the thin film. The light which passes through the keratin is retarded (slows down) whereas the light which reflects off the front surface is not. Therefore, some of the colour components of white light which are reflected from the back surface become out of phase with the corresponding light-waves which were reflected off the front surface. When two wave trains of the same colour are out of phase, this causes destructive interference to take place and the colour is removed. In the case of white light hitting a thin film, the result of the interference is a reflected colour due to the remaining colour components of white light. In practice, interference occurs simultaneously in all three thin films.

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OPTIMUM DESIGN IN THE BARBULES

The barbules in the peacock feather contain an amazing degree of optimum design. The thickness of the keratin layers is optimal for producing the brightest thin-film colour. The different colours in the eye pattern are the result of minute changes in the depth of thickness of the keratin layers[10]. The dark brown background colouring of the barbs is optimal because it prevents light shining through the back of the feather. The three layers add to the brilliance of the colours in the feather by adding multiple components of light. A further optimum feature in thin-film design is that the barbules are slightly curved in the longitudinal direction[11]. This curvature causes a mingling of slightly different colours and results in a softening of the colours seen in the keratin layers.

6 The aesthetic merit of the eye feather

Fig. 5 shows a picture of the top section of the peacock eye feather. There are several beautiful features to the feather:

- Bright colours
- Intricate eye pattern
- Loose barbs below the eye pattern
- Absence of stem in top half of eye pattern
- Narrow stem in bottom half of eye pattern
- Brown coating of stem near the eye pattern

The bright colours and intricate shapes of the eye pattern are the most striking aesthetic features. The loose barbs on the lower part of the feather are beautiful because they make a contrast with the neatness and precision of the barbs in the eye pattern. The last three features in the list above are usually only noticed by very careful observers. However, they represent important 'finishing touches' which make an important contribution to the beauty of the feather. The absence of a stem in the top half of the eye is an important detail because it prevents the pattern from being completely divided into two sections. The stem is able to be absent because the barbs gradually change in their angle of orientation and fan-out right around the top of the feather, as shown in Fig. 5. The narrowness of the stem in the bottom half of the eye pattern is important because this makes the stem fairly obscure. The brown coating of the stem in the area of the eye pattern is important because the stem is a natural white colour and this would be too conspicuous in the eye pattern. It is interesting to note that the stem is white everywhere except local to the eye pattern. This demonstrates that the brown coating near the eye pattern is a deliberate feature.

7 Digital patterns in the eye feather

The eye feather contains remarkably precise patterns. The eye pattern is made up of rounded shapes that have a high degree of resolution, as shown in Fig. 6. The 'pupil' of the eye is a dark purple cardioid shape and the 'iris' is a blue ellipsoid shape. These shapes are located within a pointed bronze ellipsoid which is surrounded by one or two green fringes. A very important feature of the eye pattern is that it is a 'digital' pattern which is formed by the combined effect of many thousands of individual barbule segments. Some patterns in nature are

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formed by natural growth mechanisms, as with the spiral shape of the nautilus shell. However, the eye pattern in the peacock tail requires the precise co-ordination of independent barbules and this cannot be achieved by a simple growth mechanism.

On each side of the eye pattern, every single barb has a unique sequence and spacing of colours along its length. Along the length of the barb there are abrupt and minute changes in the thickness of the keratin films so that different thin-film colours are produced. The thin-film colours change from blue to dark purple then back to blue and then to bronze. The colours on the barb match the colours of adjacent barbs so that the eye pattern is formed. The abrupt nature of the changes in thickness is important because if the changes were gradual, then there would be a gradual change in colour[12]. The abrupt change in thickness of keratin is an amazing feature because it involves a sudden and precise change in the dimensions of the barbule. Even more amazingly, along the length of the barb, the thickness of the keratin does not continually get thicker and thicker (or thinner and thinner) but it both increases and decreases in thickness. Such directional changes cannot be produced by simple growth mechanisms.

Since each barbule segment produces one colour, the resolution of the pattern is equal to the size of one segment, which is about 60 μ square. This is equivalent to a resolution of about 280 dots-per-inch which is comparable to modern printing technology. A large peacock feather contains over 100 barbs in the eye region. The number of barbules in the eye pattern is the order of one hundred thousand. Since each barb contains about 20 segments, the number of individual segments which make up the eye pattern is about 2 million.

8 Discussion

Mason, who has written the classical paper on thin-film interference in natural organisms, says the following about thin-film interference in birds: 'The theory of thin films as the cause of iridescence… cannot but inspire one to marvel at the perfection of nature's method of producing these colours with such uniformity through successive generations, especially when a slight general variation in thickness of the films of the feathers of a bird, such as a peacock, would be enough to alter its coloration completely.'[13] It is indeed amazing that the peacock tail is preserved from one generation to the next, considering that the smallest gene mutation could be enough to ruin the patterns completely. The extreme complexity of the tail, the subtle aesthetic features and the delicate nature of the structures present severe problems for the theory of evolution. For example, the mechanism of thin-films is irreducible because it requires several features to be present simultaneously such as flat surface, thin films, correct thickness and correct materials. The subtle aesthetic features such as brown coating near the eye pattern and absence of stem in eye pattern are also very challenging because it is difficult for the peahen to notice such features, yet alone have a preference gene which prefers such minute features. Another problem for evolution is that field studies have shown that creatures are losing their aesthetic features and not gaining them[14].

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In recent years, thin-film coatings have been applied to production motor vehicles in order to produce an aesthetic effect. However, these thin-films have always been a uniform colour and have not contained intricate patterns like the peacock tail. The peacock tail shows that intricate patterns and thin-films can have a stunning effect.

9 Conclusions

The peacock tail feathers have the sole purpose of providing an attractive display. Since aesthetic beauty is the sole purpose of the peacock display it can be an important source of inspiration for engineering designers who want to create an aesthetic effect in their designs. The peacock tail produces colours by thin-film interference. There is an amazing level of optimum design in the peacock feathers including the optimum layer thickness, multi layers, precision co-ordination and dark background colour.

References

1 **Pye, D.,** *The nature and aesthetics of design*, Barrie & Jenkins, Lond, 1978.
2 Cronin, H., *The ant and the peacock*, Cambridge University Press, Cambridge, Great Britain, p. 183, 1991.
3 Some of the peacock display feathers have a few centimetres of fluffy barbs at their root to perform the function of thermal insulation.
4 **King, A.S. and McLelland,** J., *Birds—Their Structure and Form*, Bailliere Tindall, p. 15, 1984.
5 **Sager, E.,** Morphologishce Analyse der Musterbildung beim Pfauenrad, *Revue Suisse de Zoologie, Geneve* **62**(2):116, 1955.
6 **Mason, C.W.,** Structural colours in feathers II, *J of Phys Ch* **27**:440, 1923.
7 **Mason, C.W.,** op. cit., p. 416.
8 **Mason, C.W.,** op. cit., p. 417.
9 **Mason, C.W.,** op. cit., p. 416.
10 **Mason, C.W.,** op. cit., p. 443.
11 **Mason, C.W.,** op. cit., p. 442.
12 **Marshall, A.J. (Ed.),** *Biology and Comparative Physiology of Birds*, Academic Press, London, p. 225, 1960.
13 **Mason, C.W.,** op. cit. p. 444.
14 **Wiens, J.J,** *Widespread loss of sexually selected traits: how the peacock lost its spots*, TRENDS in Ecology & Evolution, Vol. 16, No.9, Sept. 2001.

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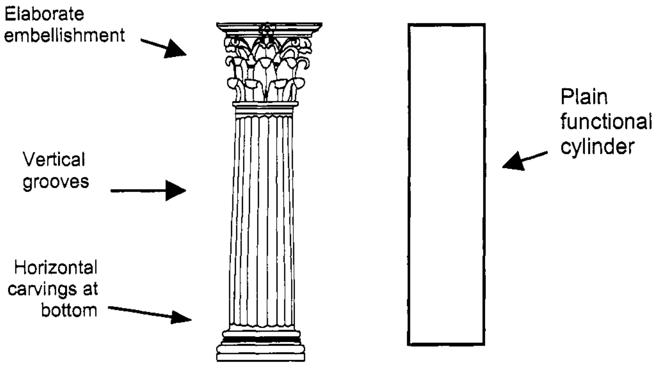

(a) Embellished column (b) Plain column

Fig. 1 Added beauty in a column

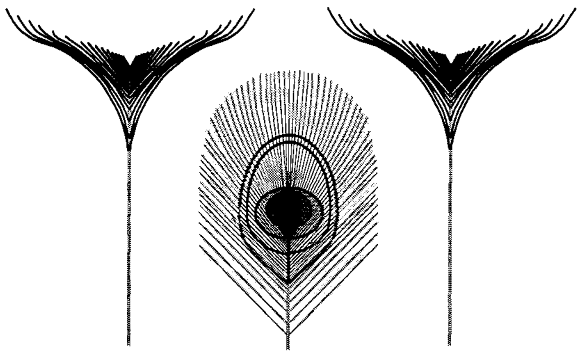

Fig. 2 Eye and T feathers in the peacock tail

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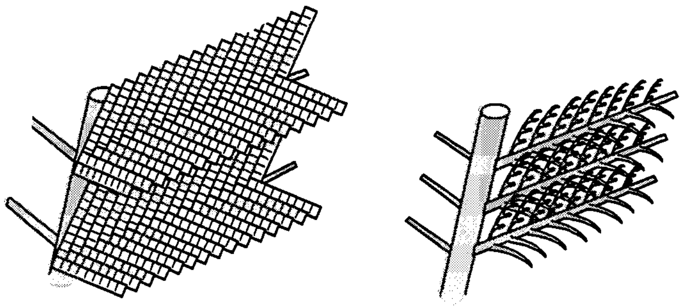

(a) Peacock tail feather (b) Flight feather

Fig. 3 Feather structure

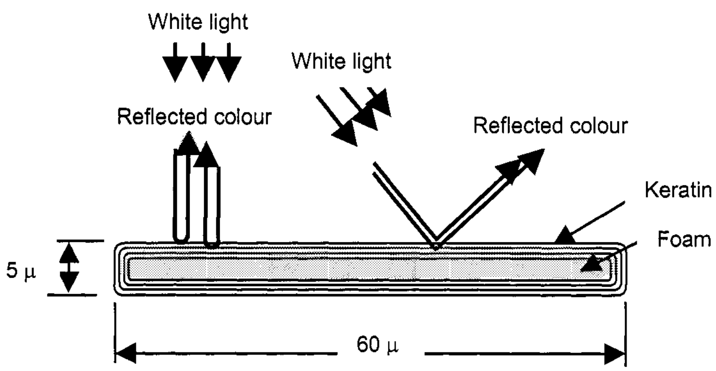

Fig. 4 Cross-section of a single tail feather barbule

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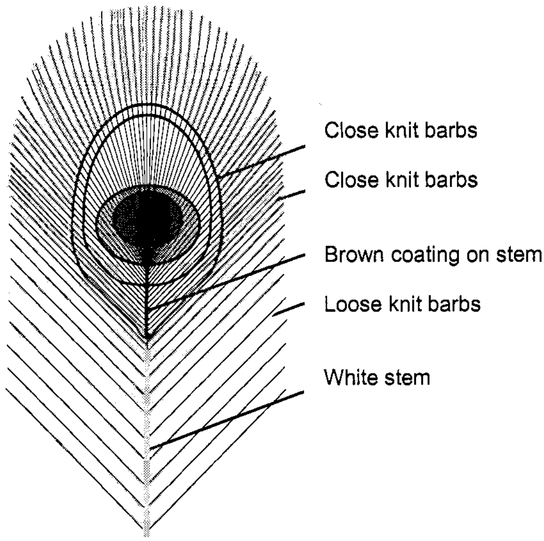

Fig. 5 Features of the eye feather

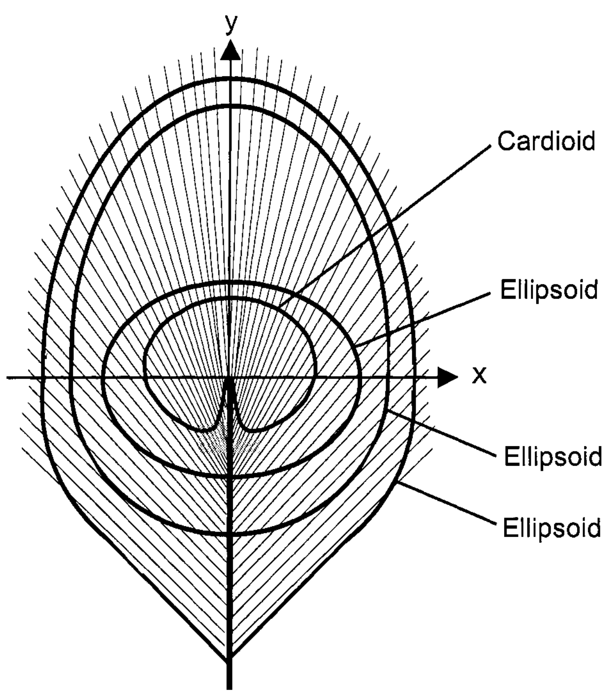

Fig. 6 Mathematical curves in the eye pattern