THE ANTENNAE of Eterusia aedea, a species of moth.

NATURAL WORLD

JEWEL IN THE CROWN

TEXT & PHOTOGRAPHS BY GEETHA IYER

A MOTH belonging to the Eterusia aedea species.

The life of an insect is a saga of olfaction, with the antennae taking centre stage. For some parasitoid wasps, there is more to the antenna than just the capacity to sniff and recognise a variety of chemicals. They use them to find the silent pupae by echolocation.

"the only invention man ever made which we insects do not have is money and he gives up everything else to get money and then discovers that it is not worth what he gave up to get it..."

—From *The lives and times of Archy and Mehitabel* by Don Marquis

DON MARQUIS makes a significant statement here through the inimitable philosophical cockroach Archy. Most of our inventions have arisen from observations of the natural world. Yet in the pursuit of newer and better inventions, humans have sacrificed much of the natural world. Ironically, there is little that humans have that insects do not. Indeed, insects have frequently contributed in unexpected and implausible ways to human progress. Take the antennae, for example. While we do not sprout these feelers out of our heads like insects, some of us, especially moviemakers and sci-fi writers, seem to believe that aliens (if they exist) may have them. These wings of imagination perhaps are a result of constant proximity to insects and our comparisons with and prejudices against them. When humans want things that cannot grow out of their bodies, they do the next best thing, manufacture them. The solar cell to capture sun's energy is one such example, antenna for communication purposes is another.

Do not let the waving antennae of an insect frighten or disgust you. Quell those feelings and take a few minutes to observe the antennae more closely. You will discover in them a designer's paradise. Humans are yet to come up with antennae that match insects' in design or creation. Even in function, these feelers are unique. We presume these structures are for communication, but they are used for so much more. The secret of insects' survival has been their ability to use each of their body structures for a variety of purposes, and the antennae are no exception.

There is no documented or verifiable record of how the word antenna came to be. The earliest myths and oral tales relate its function to communication.

One story and some records by Pliny the Elder connect the word to a hamlet in ancient Rome called Ante amnem, which was surrounded by trees. The wood from these trees was used to make poles for ships. The poles were called "antemnae". In those days, messages were sent to far-off places by ships, which may have been a reason for "antemnae" to evolve over the years to "antennae". The earliest confirmable record is that of Guglielmo Marconi using the word "antenna" for the pole with wires that he used to test long-distance radio transmission. Since then the word has caught on.

In insects, antennae are also called feelers because the insects are constantly waving them as they move about. This behaviour is partly responsible for the queasy feeling humans have towards insects. For naughty young kids, out to have fun or to respond to squeals for help, antennae are the best ways to catch an insect. Much as I love insects, I find it difficult to bring myself to catch a cockroach by its antennae.

Feelers seems to imply that they are organs of touch. Are the insect antennae organs that sense touch? Are they used for hearing, or smell, or do they perform functions that are not merely sensorial? Antennae have been the subject of research not only among entomologists but across a spectrum of scientists hailing from every discipline of science and technology. Gruesome experiments have been conducted on insects to determine what the antennae are for. Research has revealed a surprising diversity of antennal functions amongst insects.

ANTENNAE DESIGN

All insects, with the exception of proturans, a primitive group whose inclusion as insects is hotly debated, possess a pair of antennae. They are made up of segments with many joints, allowing for high mobility. There are two basic designs.

The less common one is called the segmented antenna. This is made of similar-looking units, all of which have muscles, expect the last one. This type of antenna is seen in springtails and bristletails.

The more common one is called the flagellar, or annulated antenna. Over time, this has evolved into numerous shapes and lengths. But essentially, it consists of the base (called the scape), the stem (pedicel) and the tip (the flagellum). A large part of the feeler is flagellum. The muscles to move this type of antennae are located either in the head or in the scape. There are also specialised structures

located in the scape, the pedicel and the flagellum to take care of all the common and special functions performed by the antenna.

MASTERS OF ODOUR

Can you measure the difference between one kind of smell and another? It is very obvious that we have very many different kinds of smells, all the way from the odour of violets and roses up to asafoetida. But until you can measure their likenesses and differences, you can have no science of odour (Alexander Graham Bell, 1914).[1]

Measuring odour has proved to be a difficult and near-impossible task for scientists, but if insects could talk they would have volumes to share with us. The life of an insect is a saga of olfaction, with the antennae taking centre stage. It is a well-established fact that insects locate their mates through special pheromones. But there are a host of other chemicals that insects can and must recognise. Insect life and chemical signals are like hand and glove. There are specialised structures called sensilla in the antennae that are responsible for detecting odours. The antennae are the sensors for the insect to monitor its physical and chemical environment.

THE WASPISH WAY

Parasitic wasps are masters of olfaction and can detect easily the tiniest amount of chemicals in their surroundings. The wasp's relationship with humans is varied and contextual. A layman's idea of the wasp is an insect that delivers a powerful sting, so powerful that it can send some into an anaphylactic shock. Farmers have a love-hate relationship with this animal. Wasps help control populations of pests, but some of them also deliver a sting to humans. There are so many of them, with unique characteristics and behaviours, that they are for taxonomists both a delight and a night-

THE PLEASING FUNGUS BEETLE and (facing page) the net-winged beetle. The secret of insects' survival has been their ability to use each of their body structures for a variety of purposes, and the antennae are no exception.

MICROGRAPHS OF the antennae of female and (below) male Aenasius bambawalei.

POORANI JANAKIRAMAN

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mare. The way parasitic wasps (or parasitoids as entomologists call them) use their antennae is an inspiration for bioengineers constantly seeking to innovate. For military scientists, they are models for engineering new gadgets for defence.

Parasitic wasps can detect a wide assembly of smells. For Glen Rains, a biological engineer at the University of Georgia, and W. Joe Lewis, an entomologist and an expert on parasitic wasps, they are species that can be used to sniff out explosives, bombs, drugs and plant diseases. Their research has been dubbed as "wasp hound". If successful, which seems eminently possible, the wasp hounds are expected to hit the market in the next five to seven years. The police snooping around with live wasps surely boggles the imagination. But this is real. The advantage is that parasitic wasps do not sting. There are several thousands of species of parasitic wasps, some of them so tiny that their features can be distinguished only under the microscope and others as large as three centimetres long. Thanks to their antennae, insects are good sniffers.

The insect world is one of smell and touch. Insects use olfaction for a variety of purposes, which include protection from predators, searching for mates, surveying for food, hunting, and communicating. The antennae play an important role. But what drives the differences in pattern, structure and size of the antenna of a male and a female of the same species? The males of moths and parasitic wasps, in many instances, have an

PYGOSPILA tyres, another species of moth, found in the forests of India and South-East Asia.

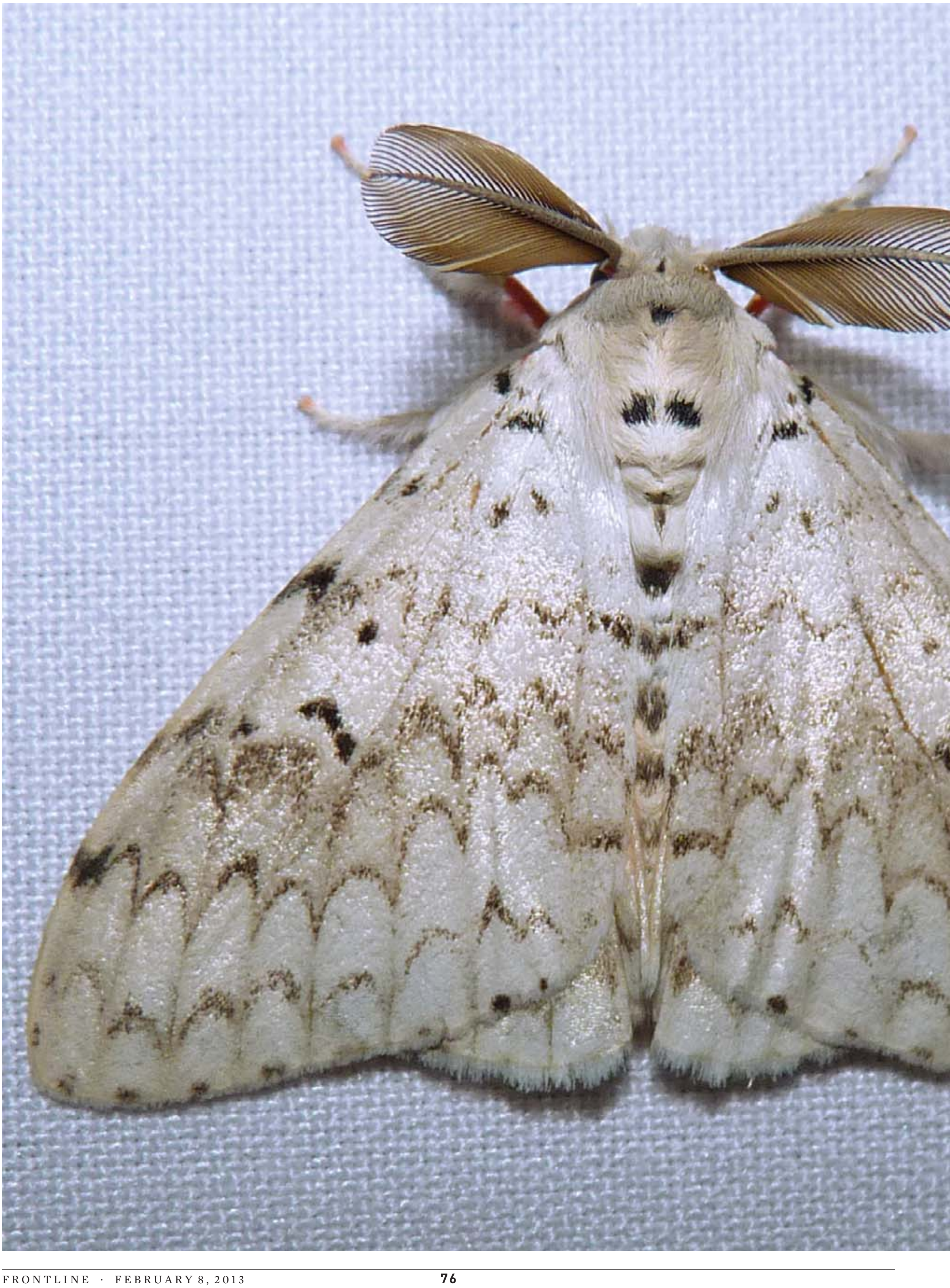
antenna that is more elaborate and ornate. Competition among males for a female is fierce; successful males are those that can locate mates, which may be far away from them. An antenna with greater surface area would allow for a greater number of receptor cells that can smell the pheromones from females separated by great distances.

For some parasitoid wasps, there is more to the antenna than just the capacity to sniff and recognise a wide variety of chemicals[2]. Some of the wasps of the sub family *Rhyssinae* are spectacular, with long ovipositors that may be three times the length of their body. These ichneumon wasps as well as their close cousins, the braconid wasps, are parasitoids of beetles, caterpillars, larvae of bugs, etc. They lay eggs on the pupae or caterpillars that serve as food for the developing wasp larva. But first they have to locate their hosts that may be deep-seated inside plants or soils in an immobile and silent state. Sniffing is no help here. The antennae are used to find these silent pupae by echolocation. The females produce sound by tapping the wood, stem or soil with their antennae. In such wasps, the tip of the female antennae is modified into a hammer-like structure. The tapping produces vibrations and the echoes produced from within are detected by certain organs present on their legs. Some wasps from the temperate regions have adapted further and can adjust the intensity of the vibration according to the ambient temperature.[3]

A braconid wasp that lays its eggs on the larvae of beetles that infect the fir tree uses a completely different mechanism to find its host. Its antennae sweep the area of the bark, but do not touch it. As they sweep the area, special structures present in the antennae detect the metabolic heat emitted by the beetle larva hidden in the interiors of the tree. In some ichneumoids too, there are sensilla in the antennae capable of detecting infrared radiation. This is indeed a unique property, which can be compared to the mechanism of heat detection of prey by pit vipers.

walk the cockroach
for you would not
think that a cockroach
had much ground for optimism
but as the fishing season
opens up I grow
cheerful at the thought
that nobody ever got
the notion of using
*cockroaches for bait**

Optimism? Not when there are



ANTENNAE SHAPES vary, and different styles within a particular shape are not uncommon. Here, feathery antennae in the moths Perina nuda (above) and Lymantria sp. (left). There are specialised structures called sensilla in the antennae that are responsible for detecting odours. The antennae are the sensors for the insect to monitor its physical and chemical environment.

wasps around. The beautiful jewel wasp *Ampulex compressa* hunts live cockroaches as food for its larvae. It injects a powerful venom first into the thorax region and then into the head of the roach. The venom can be compared to a mind-altering drug.[4] Research has shown that the stung cockroach is not paralysed but loses the will to put up any fight or attempt to escape.

The cockroach's muscles function very well, but the motivation to move or defend is completely lost because of the action of the venom. Subdued thus, the cockroach allows the wasp to hold it by the antennae and lead it to the wasp's nest. The cockroach meekly walks with the wasp, like a dog on leash. Once inside the nest, the wasp lays an egg on the cockroach, seals the nest and leaves. The cockroach remains docile all the time, waiting to be eaten by the larva that will hatch out from the egg.

The materials that make up the insect antennae have also come in for scrutiny. From a mechanical point of view insect antennae are like cantilever beams. A longer antenna, such as those seen in the long-horned beetles, in cockroaches or in field crickets, must sag if they are cantilever beams; but they do not. The insects seem to have found the trick of having just the right amount of stiffness to ensure

PARASTIC WASPS sport ornate antennae. Neocladia narendrani (above) and Eulophid sp. (top), whose features may be seen only under a microscope, are two examples of species with elaborately structured antennae.

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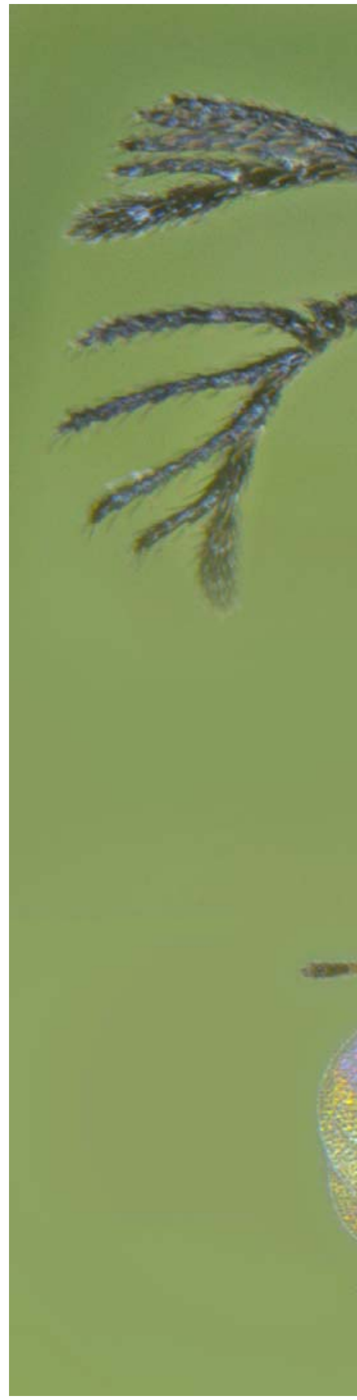

that it neither sags nor obstructs the insect from its many different functions. The material that confers this property is the chitinous cuticle. These properties are the centre of attention for robotic engineers.

COCKROACH ANTENNAE

The antennae of the cockroach are seen in an entirely different light by a team of engineers at Johns Hopkins University. To them it is a role model for the one they want to build on a robot.

Antennae in a cockroach provide both tactile and olfactory inputs, helping it to navigate complex environments. When confronted with an obstacle, the cockroach waves its antennae vigorously, then makes contact with the object, and holds them at certain angles, collectively gathering important messages to avoid bumping into the object or to decide which way to go, climb up a shelf or disappear down the small crevice.

The engineers at the university built an obstacle course to observe and study the actions of the cockroach and were amazed at the agility and

NEOCHARITOPUS ORIENTALIS, MALE, and (below) Neocharitopus orientalis, female. Males of moths and parasitic wasps, in many instances, have antennae that are more elaborate and ornate than those of females.

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speed exhibited by these creatures. They then designed a robotic cockroach antenna with relevant sensors and similar in function to that seen in a roach. It was then mounted on an existing robot. The robot could effectively manage to navigate and avoid obstacles. The team believes that emulating the principles seen in the cockroach could lead to new robots capable of moving safely in difficult situations.

COPY THE WASP

Insect philosophy is simple and straightforward, "if you can't beat them, follow them". The flies of the family *Syrphidae* (hover flies, flower flies) have short, three-segmented antennae, which are quite inconspicuous. They have evolved a protective mechanism by mimicking wasp antennae. Wasps have conspicuously long filiform antennae that are easily recognised by other insects. These flies use this feature to their advantage. In some syrphid flies, where the antennae are not long, the front legs are long and thin, held in front of the head in a way that they look like an-

ICHNEUMON WASP. Certain species of ichneumoid and braconid wasps use antennae to locate their prey.

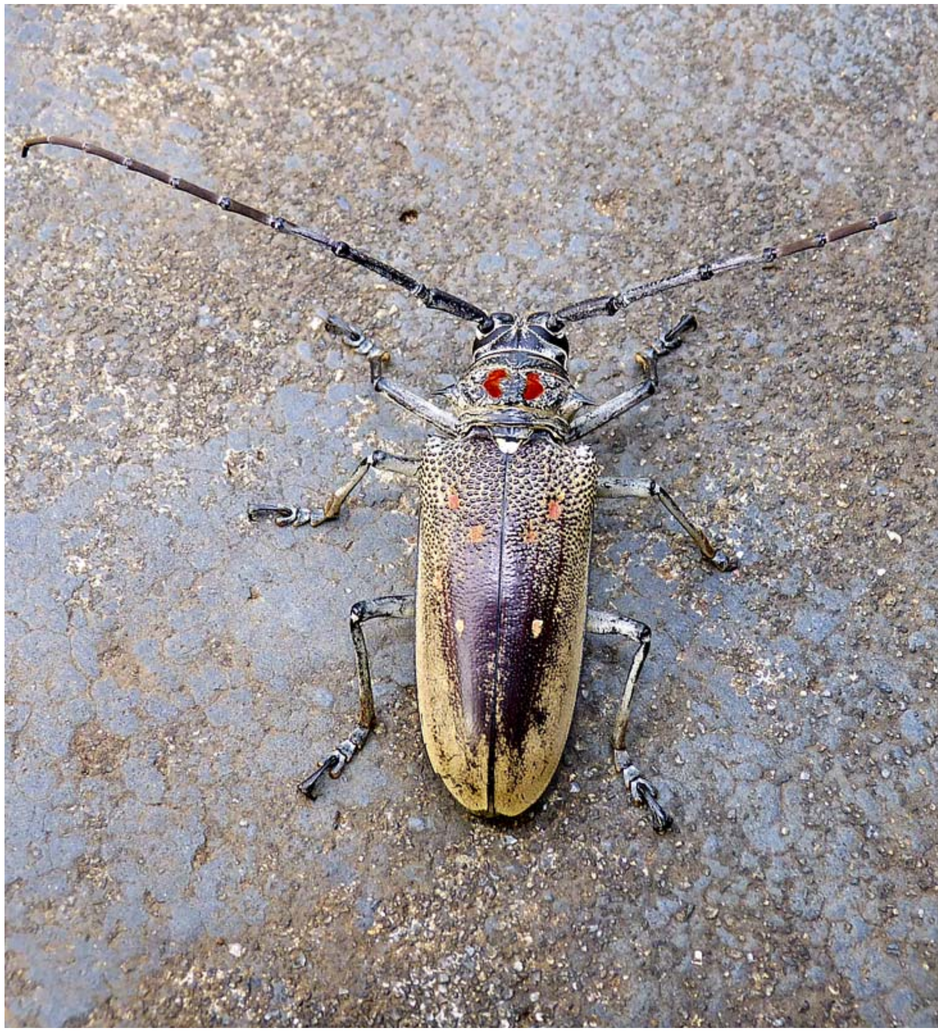
tennae. The flies in this family have evolved at least four different ways by which they are able to achieve the appearance of vespid antennae. G.P. Waldbauer of the University of Illinois believes that these may represent three to four evolutionary innovations. Males of certain species of fleas, pond skaters and springtails use their antennae to hold the females during mating. It would appear that three pairs of legs are not enough to hold them. Female pond skaters resist males when they think the latter are unfit or when they already have sperms stored from a previous mate. Males refuse to be spurned; they pin the females down by means of their

HAWK MOTH, Parum colligata. Hovering hawk moths use their antennae to collect information, especially when visual inputs are not available.

antennae specially shaped to go around the female's head. They are also fitted with hooks and spikes to prevent escape. Holding the female in captivity, the males successfully mate. Rape, in the insect world! The antennae of the male fleas have several discs on the underside with glands that secrete adhesive materials. They clasp the females from below. The male springtail holds on to his mate with his prehensile antenna and is sometimes carried around for several days by the female attached by antennae.

ANTENNAE AS GYROSCOPES

Flight requires a high level of coordination and control to maintain stability during aerial manoeuvres. Migrating insects, in addition, need cues to ensure that they are moving in the right direction. Experiments done with moths, butterflies, bees and locusts show that mechanoreceptors present on the antennae provide different types of feedback to these insects during flight. They help



LONG-HORNED BEETLE (above) and cricket nymph (left). From a mechanical point of view, insect antennae are like cantilever beams. A longer antenna, such as those seen in the long-horned beetles, in cockroaches or in field crickets, must sag if they are cantilever beams; but they do not.

maintain directions and flight speeds. The antennae in locusts are sensitive to air currents, and help control flight speed by providing inputs for selecting the right wing-stroke parameters. Inputs from antennae are used by uraniid moths to stabilise flight and assist in aerial manoeuvres. Hovering hawk moths use the antennae to gather information about unwanted movements in their vicinity, especially at low lights when visual inputs are not available. Antennae in monarch butterflies have circadian clocks that act like a time-compensated sun compass to track the sun's movements and provide vital information for navigation.

As more and more insects come to be described, several more interesting functions and designs are likely to emerge. Can the mere need for a larger surface area justify the presence of elaborately designed antennae? The sculpted antennae of some insects are a source of marvel. What drives the formation of such elaborate structures, natural selection or special creation? Does it matter?

As Eric C. Brown, editor of *Insect Poetics,* says, "I'd say they remove us (sometimes harshly) from a quotidian existence and, like other innumerable—the stars, the sands on the beach—help us see the sublime in the everyday." □

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CLUB-SHAPED ANTENNAE of Popinjay, or Stibocjiona nicea, and (below) sapphires.

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*From *The lives and times of Archy and Mehitabel*.