Birds, Bees, and Ballistic Beasts

Air Force basic research in biology may provide clues for improving missile detection and computers.

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While the public has become increasingly informed of the use of dogs, cats, rats, and monkeys in medical research, the use of some of our lower or more exotic forms of life in biological research gives rise to comments about their significance for human or Air Force problems. It almost seems as if some of this feeling harks back to our culturally old and deep-seated dread of lowly life forms. I am reminded of the fairies in *A Midsummer Night's Dream*, who sang:

You spotted snakes with double tongue,
Thorny hedgehogs, be not seen;
Newts and blind-worms, do no wrong,
Come not near our fairy queen. . . .
Weaving spiders, come not here,
Hence, you long-legg'd spinners, hence!
Beetles black, approach not near;
Worm nor snail, do no offense.

Thus, when my scientists in the Air Force Office of Scientific Research report studies in which bats, beetles, electric fishes, octopuses, or bobolinks have been used, we are met with either tolerant amusement or slightly veiled ridicule, and in official circles, up to and including congressional levels, we seem to invoke incredulity, alarm, or special inquiry.

I am therefore reluctant to admit that our interests also extend to blind fish, waltzing mice, congenitally deaf cats, eels, ants, locusts, lizards, porpoises, crickets, scorpions, praying mantes, fighting fish, newts, spiders, and toads, to mention only a few. But one thing we can be sure of, and that is that no one will be indifferent. Animals are familiar and provoke some response, be it protectiveness, acquisitiveness, gustatory anticipation, endearment, amusement, revulsion, or fear. I sometimes envy my scientists in physics, mathematics, and chemistry, who can report with relative impunity on the inanimate objects of their studies. Their reports are usually received with solemnity and respect, if not understanding. Paramagnetic resonance, neutrinos, magnetohydrodynamics, microwaves, excited states, Boolean algebra, ergodic theory, and intergalactic dust, are, after all, nothing to joke about, even if eyebrows may be raised occasionally over such things as Lie groups, pi mesons, Love's theory, Green's function on a Brown Space, or the backside of the moon.

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Biology and Engineering

Knowledge of the fundamental workings of the life process can have far-reaching military implications, as well as civil and humanitarian values. The improvements to be achieved in human performance and tolerance to stress are closely related to medical interest in control of disease and are well known. But less well known is the potential application of biology in engineering. Our physical scientists are making slow progress in building complex computer devices that can imitate the element of judgment characteristic of animal or human behavior. So far, machines can do what they are programmed to do, but can do little learning. Engineers now look with renewed interest on the ways nature has solved her control and communication problems. Nature has served as a vast laboratory for over two billion years and has made uncountable experiments. This vast evolutionary process has resulted in a fantastic wealth of animal types, many with unique and highly developed characteristics far beyond those of man. Therefore, I think it is of great importance to engineers that we are looking at all kinds of special senses in animals, and at the kinds of nervous control exhibited by even the simpler forms of life. The comparative approach to the solutions of biological problems has been a profitable strategy in the past and will undoubtedly be expanded as biology becomes a more quantitative and analytical science. I don't see how we are going to avoid getting tangled up in all this, as additional curious forms of life are brought under scrutiny.

A better understanding of man's behavior is recognized to be critical for the broad areas of selection, training, and efficiency. Since behavior depends upon differentiation within the central nervous system, the correlation of behavior with nervous activity should be as broad as possible and should not overlook the highly developed and stereotyped behaviors of certain species which may exemplify a relatively simple correlation between nervous structure and function. It should be far simpler to analyze the nervous system of an insect with a few nervous components than to tackle the intricate and frightening networks that comprise the nervous system of a rat or a monkey or man.

There is frequent talk that the manned bomber is obsolete, and those who won't believe this are immediately dubbed perpetuators of a "cavalry of the air." Missiles are all the rage. But the missile is a stupid beast. It only goes where you tell it to go. If you don't know where to send it, it is virtually worthless. A manned bomber is infinitely more versatile than a missile. But a missile operated by a computer that works like a man's brain would indeed make the manned bomber obsolete. And this, among other things, is what we are searching for in our biology basic-research program.

A dividend that can accrue from studies of diverse species is the derivation of models that can be the basis for development of useful electronic equipment. Despite the simplicity of their structure and the tiny mass of their essential components, these animals perform complex chores beyond the capability of the most sophisticated computers available today. An understanding and utilization of these biological principles can almost certainly lead to an increase in the versatility and a decrease in the size of future instruments. This is not to say that we would want to imitate the components of nature's systems, any more than our use of aerodynamic laws employed by the birds implies that we must build airplanes out of feathers. It is the laws of organization and information processing that we are most in need of. And if we get ideas for better components, that will be an added dividend.

Animal Senses

Some of the implications and uses of animal sensing devices have already been reported elsewhere. For example, a mathematical model of the beetle's vision is the basis for the development of a ground speed indicator. The use of ultrasonic cries for echolocation by the bat is well known, if not yet fully understood. Its precision, speed, and freedom from interference make this a profitable system for study by the physicist, not only for military purposes but as an aid to the blind. The sensitivity of the moth's ear in intercepting hostile bat sounds surpasses that of our most advanced microphones. The sonar system of porpoises and whales has been little studied, but evidence indicates that they have a highly developed and accurate location sense combined with a high degree of intelligence and ability to communicate. An institute is now being formed in the Virgin Islands dedicated to the study of these animals.

Other animal sensing devices are perhaps less well known but appear to the practical-minded to have equal potentialities. Many fish have electroreceptors which they use to detect obstacles. These fish emit pulses of low voltage with frequencies characteristic for each species. The frequencies may range from 50 to 1600 cycles per second. The alteration of the pattern of the electric field as a result of objects, apertures, or other fish in the surrounding water can be detected. So sensitive is this response that the fish will respond to the movement of electrostatic charge produced by waving a comb (that has been run through one's hair) in front of the aquarium. They can differentiate between a conductor and a nonconductor or respond to the presence of a stationary magnet outside the aquarium. It has been calculated that these fish are sensitive to a change in field of the water around them of 0.003 microvolt per millimeter, a fantastically minute alteration.

The rattlesnake is equipped with exquisitely sensitive temperature receptors. These receptors will respond to an increase or decrease of 10^{-11} calorie (small) in 0.1 second, which represents a change in tissue temperature of 0.001°C. Expressed in terms of a temperature quotient of Q_{10}, the frequency of nerve impulses in a single fiber is 10^{80}. When two balls of equal size differing minutely in temperature are presented to the snake, it will invariably and unhesitatingly strike at the warmer.

Certain insects have highly developed smell receptors. The antennae of male silk moths are highly sensitive to the odorous material produced by females of the same species, which they can detect at great distances. Hairs of various flies are amazingly sensitive to certain chemicals—some to salt, some to acid, some to alcohol. Spiders and some insects have mechanoreceptors by which they can detect minute vibrations, which they use for localization of prey or enemy. The lobster has a beautifully designed equilibrium sense organ which is sensitive to movement in various directions, to maintain position in one or another plane, and to vibration. The antennae of flies contain mechanoreceptors sensitive to a wide range of frequencies. This sensitivity permits analysis of each wing beat, with a delay of only 1 millisecond. The speed of flight is controlled by this sense organ. The flies long ago modified their back pair of wings into a vibrating gyroscope, which we are now trying to imitate.

The praying mantis integrates all the information it receives on the position of a fly, strikes and captures its prey —all within the space of 50 milliseconds. Bees use polarized light in returning to a source of nectar or to the hive. The visual accomplishments of certain birds are legendary; some use clicking sounds for echolocations. In the owl the shape of the head is related to a highly developed sound-locating system which enables the animal to pick up its prey in the dark. These examples could be multipled almost indefinitely.

Some animals have receptors and sense organs which have been described anatomically but whose function is still unknown. Other animals are able to perform amazing feats—notably, the long migratory trek of birds—by mechanisms which are completely unknown to us.

I plead for patience with the Air Force biologist when he uses strange specimens of animal life. The wisdom and wonder of animal life have long attracted man. Let me remind you of the comments of the prophet Agur:

> There be four things which are little upon the earth, but they are exceeding wise;
> The ants are a people not strong, yet they prepare their meat in the summer;
> The conies are but a feeble folk, yet make they their houses in the rocks;
> The locusts have no king, yet go they forth all of them by bands;
> The spider taketh hold with her hands, and is in kings' palaces (Proverbs 30: 24–28).

Note

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