Wishbones on Display

X-ray movies made of European starlings as they flew in a wind tunnel uncovered some surprising details on how their skeletons move during flight

THE WISHBONE, AS EVERYONE KNOWS, plays an essential role in a Thanksgiving turkey. When the last bite of turkey is tasted and the last bit of stuffing is gone, two people tug on the U-shaped bone until it breaks, and the one with the bigger part gets his wish. No Thanksgiving dinner is complete without it.

Seriously, though, the wishbone in birds seems to play a more important role than just a bit part in holiday meal entertainment. The wishbone is an integral part of a bird's shoulder girdle, which is specialized for flying, and scientists are quite interested in discovering how the demands of flight have shaped the peculiar structures of the shoulder. Now for the first time, researchers have watched directly the movements of a bird's shoulder girdle as it flew, and their observations provide some surprising information on the role the wishbone may play in bird flight.

On page 1495, Farish Jenkins of Harvard University, Kenneth Dial, now at the University of Montana, and Ted Goslow of Northern Arizona University describe the motion of the European starling's shoulder girdle during flight. By taking high-speed x-ray movies of the birds as they flew inside a wind tunnel, the researchers were able to track the movements of the wishbone (or furcula), the sternum, and surrounding bones. What they found surprised them—the wishbone is much more dynamic than anyone expected.

The researchers report that as the bird's wings move up and down, its wishbone bends and recoils, expanding its width by almost 50%. "The wishbone in starlings is a spring," as Jenkins puts it.

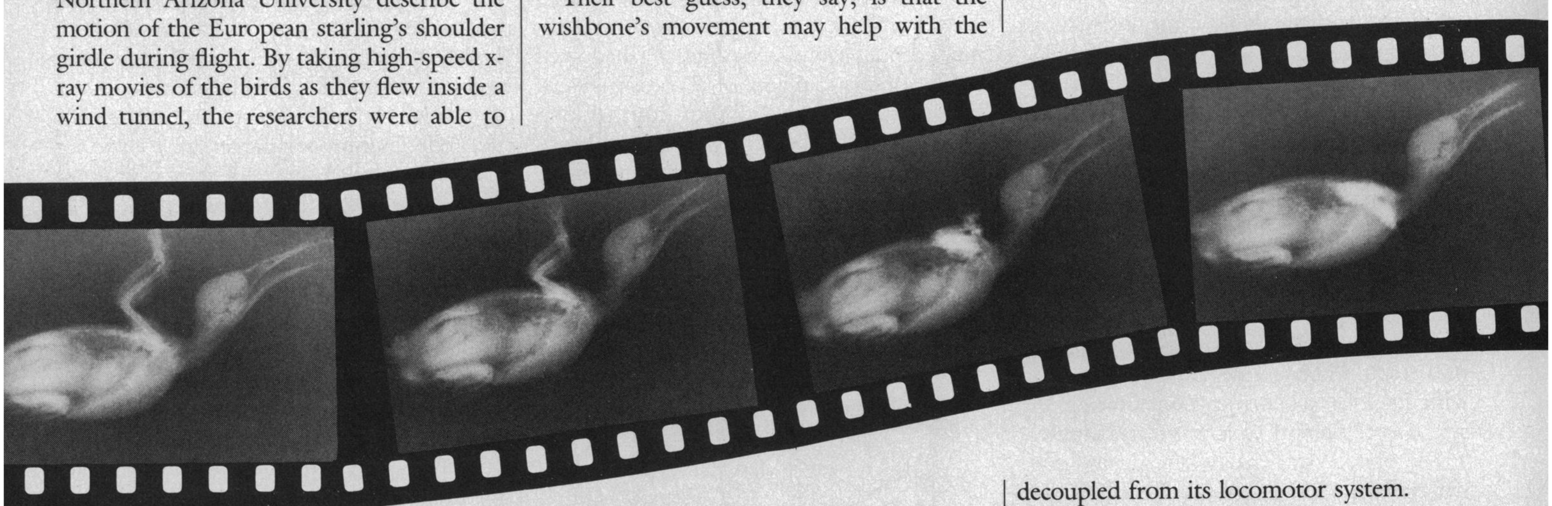
Each of the upper ends of the U-shaped wishbone in a starling is attached to one of the bird's shoulders, while the lower end is not directly attached to any other part of the skeleton. As the wings press down, the ends of the starling's wishbone are pulled apart much as two Thanksgiving celebrants might pull on a turkey's wishbone. The difference is that the starling does it 14 to 16 times a second, bending the bone to nearly 1.5 times its resting width with each beat of the wings, which is truly amazing flexibility for a bone. "This may be one of the most dynamic skeletal units in the vertebrate world," Dial says.

The obvious question is: Why? Since the skeletal structure of the European starling is typical of many birds, it is reasonable to assume this spring-like behavior of the wishbone is fairly common among birds. What function does such an in-and-out movement perform? The three researchers can offer only educated guesses.

Their best guess, they say, is that the wishbone's movement may help with the bird's breathing. "It may be related to the air sac between the two halves of the furcula," Jenkins says. The bird has air sacs throughout its body and the precise mechanisms that control them are not well understood, although it is known the air sacs play a role in the bird's respiratory system and probably also in cooling the bird and making it lighter for its size.

The starling has air sacs between the halves of its wishbone and more sacs behind the wishbone. The three researchers hypothesize that as the wings go down, the bending wishbone may cause expansion of the first set of air sacs, while at the same time the sternum presses up against the second set of sacs, causing them to compress. On the upstroke this is reversed, with the first group of sacs being compressed and the second expanding.

One intriguing possibility is that this squeezing and expanding of air sacs helps to recycle air through the bird's respiratory system in between breaths. A European starling breathes about 3 times a second during flight, while its wings beat 12 to 16 times per second, and the researchers suggest that pumping the air sacs may push air back and forth between the lungs and the air sacs, helping the bird meet the increased metabolic demands of flight. However, Jenkins warns, "Some avian physiologists we know don't like this idea much," because the bird's breathing is generally believed to be decoupled from its locomotor system.



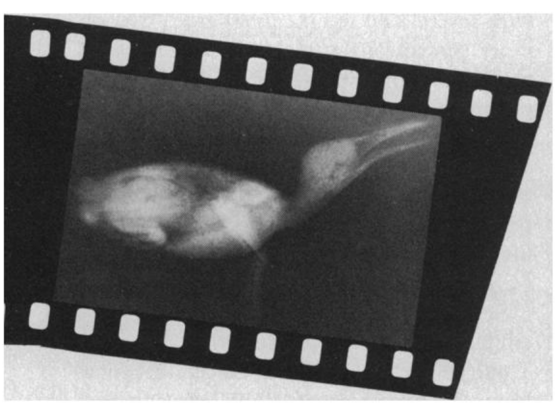
Whatever the wishbone's exact relation to the air sacs, the x-ray study should provide scientists with valuable information on the workings of the sacs, which are very difficult to study. As Goslow points out, the valving among the lungs, air sacs, and windpipe is not done with physical structures but instead depends on airflow. Since most work on birds' respiratory systems has been done on stationary birds and even anesthetized birds, it has been hard to get good information on the dynamic behavior of the respiratory system.

The three researchers cite various things they hope to learn by studying the European starling's shoulder girdle during flight. The basic goal is to understand exactly how a bird's skeleton moves as it flies. Previous studies of birds in flight had used normal photography, so that researchers could only infer the exact movements of the bones. The x-ray studies provide a detailed record of the motions of the shoulder girdle.

For Goslow, the work is part of a much bigger project: to study the similarities and differences in the shoulder mechanisms of various vertebrates. Goslow, who describes himself as a neuromuscular physiologist, wants to understand how the nervous system controls the shoulder in vertebrates, including mammals, reptiles, and birds.

Jenkins, a paleontologist, hopes that by understanding how the bird's structures reflect its function, he will gain insight into the evolution of these structures. One problem with interpreting fossils of the ancestors of birds is that no one had any hard facts about the skeletal movements of modern birds in flight. "To assess the changes [of evolution], you have to know the end point," Jenkins says.

According to this study, the wishbone-sternum system in the European starling seems to have evolved in part to link the flight and respiratory functions of the bird.



Although the researchers expect that wishbones in many other birds will perform similarly to the starling's, they point out that many birds have very different structures. Some, such as soaring birds, have seemingly stiff strong wishbones; the wishbones of others are almost vestigial. Goslow says the field is wide open for studying other birds. In particular, no one has looked at turkeys, where a close examination might show the wishbone evolved to provide a perfect postscript to a turkey dinner. ■ ROBERT POOL

A Heresy in Evolutionary Biology

As anyone with even a passing knowledge of evolutionary biology knows, natural selection is a twofold process: the generation of genetic mutation followed by the fixation of variants that are favored by prevailing conditions. And in the world of evolutionary biology, one thing has seemed certain: the generation of genetic mutations is a continuous and random process, uninfluenced by external circumstances. However, if John Cairns, Julie Overbaugh, and Stephen Miller of the Harvard School of Public Health are correct in their interpretation of certain experiments with the bacterium *Escherichia coli*, that certainty may be on shaky ground.

In a paper published in the current issue of *Nature*, Cairns and his colleagues aim "to show how insecure is our belief in the spontaneity (randomness) of most mutations." The Harvard researchers describe the results of a handful of experiments which, they suggest, demonstrate that "bacteria can choose which mutations they should produce." Anything more heretical can hardly be imagined. They do add, however, that "this is too important an issue to be settled by three or four rather ambiguous experiments."

One of the experiments involves taking colonies of *E. coli* that are incapable of metabolizing lactose and exposing them to the sugar. If the lactose-utilizing mutants simply arise spontaneously in the population and are then favored by prevailing conditions, then this would lead to one pattern of new colony growth. A distinctly different pattern is produced if, under the new conditions, the rate of production of lactose-utilizing mutants is enhanced. The observation is something of a mixture of patterns, indicating that directed mutation appears to be occurring. "This experiment suggests that populations of bacteria . . . have some way of producing (or selectively retaining) only the most appropriate mutations," note Cairns and his colleagues. They cite two other types of experiment that can also be interpreted in this way. In addition, Barry Hall of the University of Connecticut is soon to publish a fourth experimental observation, this one involving a two-step change, that carries the same heretical message. All these experiments are in *E. coli*.

Because the randomness of mutation has been so fundamental to evolutionary biology since the 1940s, few researchers have cared to test the notion directly. There are therefore no data beyond those from this handful of experiments that might indicate how general a phenomenon directed mutation might be. Nevertheless, Cairns suspects that it might well turn out to be rather widespread, at least in bacteria. Kent Holsinger, a theoretical population geneticist at the University of Connecticut, says that "if it is general and is not just confined to *E. coli* and other bacteria, it could have major implications for evolutionary biology. At the very least, he notes, "there is something going on here that we haven't considered."

Cairns and his colleague speculate on a mechanism by which mutation might be directed by external circumstances. Suppose, as a result of sloppy transcription, an organism makes a variable set of messenger RNAs from any one of its genes; and suppose the organism is equipped to test the efficacy of the different protein variants produced; it then selects the best messenger for continued translation and at the same time, using reverse transcriptase, makes a DNA copy, which is slotted into the genome. The result would be a mutant produced as a consequence of the environment to which the organism was exposed. If such a system were to exist "you would expect it to become widespread, because the organisms carrying it would be so successful," says Hall.

But would it operate in multicellular organisms, thus underpinning the notion of inheritance of acquired characteristics? Probably not, guesses Hall, at least not beyond a very limited extent. The reason is because in bacteria there can be very rapid feedback between exposure to a new environment, expression of a favorable protein, and permanent genetic change: it is a feedback between chemicals in the environment and enzymes required to process them. In multicellular organisms, where the process of embryological development interposes itself between expression of the genetic blueprint and the mature, anatomically complex organism, the potential for feedback is snapped, except perhaps for the simplest of physiological systems. In addition, of course, the germline is effectively isolated from the cells in the rest of the organism. Nevertheless, cautions Cairns, "we shouldn't be thinking about multicellular organisms until we know something about the mechanism in bacteria." ■ ROGER LEWIN