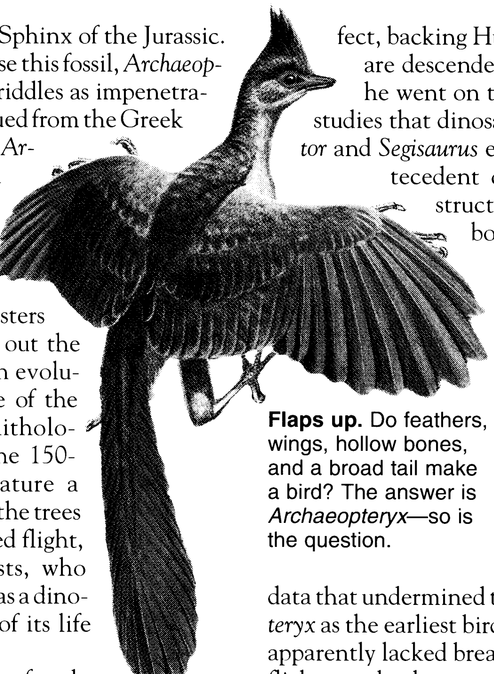
Archaeopteryx: Early Bird Catches a Can of Worms

Call it the feathered Sphinx of the Jurassic. The name is apt because this fossil, *Archaeopteryx*, is the source of riddles as impenetrable as the ones that issued from the Greek original. Since the first *Archaeopteryx* specimen was discovered in Germany in 1861, scientists have been pecking at each other like bantam roosters in an attempt to sort out the creature's true place in evolution. The latest phase of the controversy pits ornithologists, who consider the 150-million-year-old creature a bird, adapted to life in the trees and capable of powered flight, against paleontologists, who claim *Archaeopteryx* was a dinosaur that spent most of its life on the ground.



Flaps up. Do feathers, wings, hollow bones, and a broad tail make a bird? The answer is *Archaeopteryx*—so is the question.

JOHN P. O'NEILL

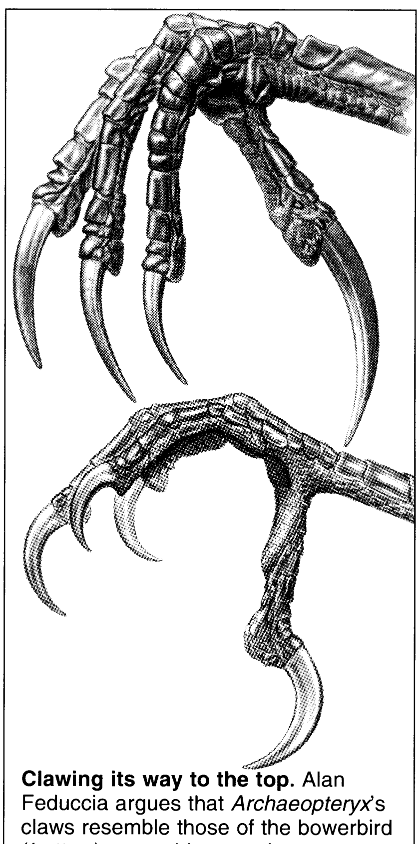
More than a century after the dispute began, the squawks keep rising in volume. In this issue of *Science*, ornithologist Alan Feduccia of the University of North Carolina at Chapel Hill argues that the claws of *Archaeopteryx* indicate that it did live in the trees and was unquestionably a bird (see page 790). "Paleontologists have tried to turn *Archaeopteryx* into an earth-bound, feathered dinosaur," Feduccia says. "But it's not. It is a bird, a perching bird. And no amount of 'paleobabble' is going to change that." Paleontologists remain far from convinced.

Partly obscured by the flying feathers are two opposing views of avian evolution. The first stems from Darwin's contemporary, Thomas Henry Huxley, who argued in the late 1860s that birds are directly descended from dinosaurs. The other view holds that both birds and dinosaurs share an earlier, crocodile-like ancestor. For much of this century, ornithologists and paleontologists were almost unanimous in accepting the second hypothesis. According to that view, rather than resulting from a single line of descent, the features shared by birds and the small running dinosaurs known as coelurosaurian theropods (including hollow bones, long hind limbs, long tails, and long necks) arose from parallel evolution.

But in 1973, John Ostrom, a paleontologist at Yale University, upset the consensus in a letter to *Nature* in which he asserted that the skeleton of *Archaeopteryx* was "that of a coelurosaurian dinosaur." Ostrom was, in effect, backing Huxley's view that birds are descended from dinosaurs, and he went on to argue in subsequent studies that dinosaurs such as *Velociraptor* and *Segisaurus* even possessed the antecedent of the most bird-like structure of all: the wishbone. By the mid-1980s, it appeared Ostrom had won; at an international conference on *Archaeopteryx*, most researchers agreed that it was directly linked to the dinosaurs.

Ostrom wasn't content to crow over his apparent victory. He kept piling up data that undermined the image of *Archaeopteryx* as the earliest bird. Since *Archaeopteryx* apparently lacked breastbones for anchoring flight muscles, he questioned whether it could fly at all and suggested that its claws resembled not those of high fliers but the feet of lowly ground dwellers such as quail and roadrunners. By the time Ostrom was finished, *Archaeopteryx* had been pushed out of the treetops and was reduced to running through the shrubs—a well-feathered but thoroughly grounded dinosaur. What is more, Ostrom claimed, if *Archaeopteryx* ran on the ground, then avian flight probably originated when creatures like *Archaeopteryx* began leaping up (after insects, say) rather than swooping down from the treetops.

Although stunned by Ostrom's apparently successful claims, the ornithologists began clawing their way back, attempting to reclaim *Archaeopteryx*, which, after all, was replete with feathers, wings, hollow bones, and a broad tail. "The paleontologists would like it to be a done deal," says Storrs Olson, curator of birds at the Smithsonian Institution. "But their terrestrial idea is almost certainly wrong, and Feduccia's paper will keep them aware that the issue has not been resolved."



Clawing its way to the top. Alan Feduccia argues that *Archaeopteryx*'s claws resemble those of the bowerbird (*bottom*), a perching specimen, not those of the lyrebird, a groundling.

BRIT GRISWOLD

Feduccia was one of the leaders in ornithologists' reclamation effort. In previous, highly regarded papers (*Science*, 9 March 1979, p. 1021), he argued that *Archaeopteryx*'s feathers and wings are identical to those of modern birds. There, at least, he's scored success, since by now even paleontologists concede *Archaeopteryx* was capable of limited flight. "Okay, in the vernacular sense, it is a bird," grouses Jacques Gauthier, a herpetologist at the California Academy of Sciences in San Francisco and a supporter of *Archaeopteryx*'s dinosaur ancestry. "If by that you mean something with feathers that sort of flies."

Those concessions don't satisfy Feduccia. In his current article, he lends additional touches to his portrait of *Archaeopteryx* as a full-fledged bird by arguing that its claws resemble those of birds that spend most of their time in the trees. To substantiate his claim, Feduccia measured the curvature of the foot claws (*Archaeopteryx* also had claws on its wings) of the three best *Archaeopteryx* specimens, then compared this arc with 500 species of modern birds. The fossils' arc fell comfortably in the range of definitive perching birds such as the South American motmots and the cuckoo-rollers of Madagascar. A further clue comes from the fossils' curved claw on the reversed first toe (the hallux), which Feduccia says is "strictly a perching adaptation; it would be a tremendous obstacle to running on the ground."

Feduccia even turns *Archaeopteryx*'s curious wing claws (or manus claws) to advantage. Other researchers, puzzled by the long claws, have suggested they were used for everything from gripping branches to aiding flight to trapping insects. To Feduccia, though, they are simply another adaptation for life in the treetops. "The claws are extremely similar" to the foot claws of modern trunk-climbing birds, he insists. "In fact, if you compared the claws of a wood creeper with the manus claws of *Archaeopteryx*, you would be hard pressed to tell them apart. They are virtually identical."

To other ornithologists, Feduccia's gripping tale clinches the case. "Feduccia's paper establishes conclusively that the claws of *Archaeopteryx* have the morphology of a perching, climbing animal," says Larry Martin, a paleo-ornithologist at the University of Kansas in Lawrence. "It was not running on the ground."

Some paleontologists, however, think Feduccia is, well, out of his tree. Paul Sereno, an evolutionary biologist at the University of Chicago, disputes whether one can use a bird's claws to draw definitive conclusions about its overall behavior. "Many so called groundbirds, for example chickens, still spend some time in the trees," he says. Sereno also questions Feduccia's claims for the wing, or hand, claws. "I think the hand claws are particularly irrelevant because he makes no comparisons to dinosaurs. In fact, *Archaeopteryx*'s hand claws are very, very similar to those of theropods." Gauthier adds, "If *Archaeopteryx* used its hand claws for climbing in trees, then all the related dinosaurs—theropods, *Velociraptor*, *T. rex*—all climbed in trees." And if that's the case says Gauthier, "You've got a problem," since *T. rex* was clearly a terrestrial creature.

But not all the clucks from paleontologists are those of disapproval. Ostrom, whom one might expect to be outraged, is preening instead. "I'm just having a ball," he said with a chuckle. "It sounds to me as if Alan [Feduccia] has presented a very good argument; I'm not sure he's absolutely right, but I'm sure he's on solid ground." Even though Ostrom acknowledges that Feduccia may be right about the shape of the claws, Ostrom is far from giving up his own, hard-won ground. Like Sereno and Gauthier, he doesn't think the case can be closed before the claws of *Archaeopteryx* have been compared with those of the theropods.

In any case, says Ostrom, his ideas have been constructive in stimulating scholars to examine assumptions. "In the early 1970s, it was a given that birds learned to fly from the trees down," Ostrom says. "I thought people hadn't looked closely enough at the evidence, so I deliberately wrote my paper to provoke people. And I'm laughing now because it has provoked people out of their hides. It's a great big controversy—which is what it should be." And a controversy in which the world hasn't heard the final peep.

–Virginia Morell

PHYSICS

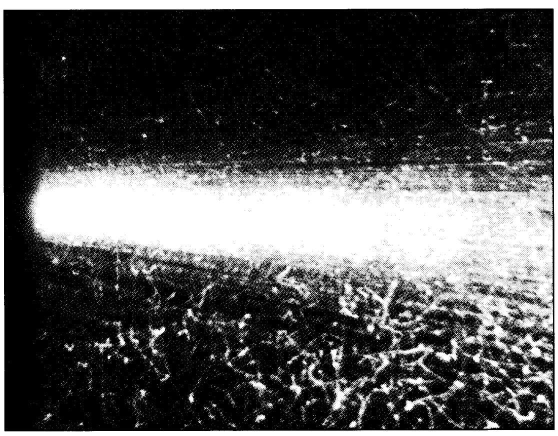
Catching the Wave of a New Accelerator

Even as heavy machinery cuts a tunnel under the Texas prairie for the Superconducting Super Collider's (SSC) 87-kilometer ring of concrete, metal, and equipment, a group of physicists and engineers at the University of California, Los Angeles, is developing a technology that has the potential of ending the era of ever more gargantuan accelerators. In a pinky-sized volume of gas heated by lasers, they created electric fields powerful enough to accelerate electrons at a rate that has physicists dreaming of doing the SSC's job in a setup only a few city blocks long.

"This is a significant step forward," says accelerator physicist Andrew Sessler of the Lawrence Berkeley Laboratory. Adds physicist Chris Clayton, chief experimentalist in the eight-member group that did the work, "The success of this experiment has suddenly made future possibilities seem a lot more real." Among those possibilities, Clayton, group leader Chan Joshi, and their colleagues suggest in the 4 January *Physical Review Letters (PRL)*, are smaller, cheaper accelerators that could not only cut high-energy physics down to size but also open the way to compact x-ray sources for medical therapies, biological studies, and materials analysis.

Conventional accelerators grow like topsy because they rely on a gauntlet of strong electric fields to accelerate charged particles. The electric fields of the high-end accelerators have approached the limit of what materials can sustain before electrons tear themselves away from atoms in the accelerator constituents. As a result, the only way to boost the energy of conventional accelerators is to lengthen the gauntlet of accelerating fields.

Plasma wave accelerators work by a different principle and therefore aren't subject to the same limits. The fields are created temporarily by blasting hydrogen gas with a pair of powerful laser beams. The result is a plasma—in this case a sea of positively charged hydrogen nuclei and negatively charged electrons. The laser beams, tuned to different wavelengths, interfere with each other, generating a pattern of light intensities that segregate the plasma's charged constituents into alternating stripes. That creates a multitude of short, but extremely strong, electric fields between the stripes. And because the interfering beams also generate ocean-like waves in the plasma that travel at the speed of light, the charge-segregated disturbances race through the plasma. Like surfers gaining speed as they move down a wave, electrons can gain energy by catching and riding these lightning-fast plasma waves.



C. JOSHI, C. CLAYTON *ET AL.*

Little big accelerator. Tracks in a cloud chamber indicate paths of electrons accelerated in a plasma wave.

That principle was proposed almost 15 years ago by John Dawson of the University of California, Los Angeles, and Tajima Toshi of the University of Texas in Austin. But not until recently had the UCLA researchers and other groups honed their understanding, machinery, and technical expertise enough to make plasma waves of sufficient quality for acceleration experiments. Now the UCLA group has gone on to harness the energy of those waves to accelerate electrons from an external source.

In the work reported in *PRL*, the group succeeded in boosting the energy of electrons injected into a laboratory plasma by at least 7 million electron volts. If the same acceleration rate could be maintained over just a few hundred meters (most likely through a series of shorter accelerating regions, within which high-quality plasmas would be easier to maintain), a plasma accelerator conceivably could match the 20 trillion electron volts of the SSC, says Dawson, who was not an author on the *PRL* paper.

Given that kind of payoff, it's not surprising that the UCLA group has company in the advanced accelerator business. Their recent work may have put them in the lead, concedes Jim Simpson, head of Argonne National Laboratory's accelerator R & D program, but researchers at Argonne and elsewhere have accelerated electrons in plasma waves generated by other methods. Notable among them is the "wa ke field" method, in which bunches of injected electrons plow through a plasma like a boat on a lake. The "wake" that results can accelerate electrons, but not yet at rates as high as the laser-based technique, says Simpson. Within the year, though, a testbed known as the Wake Field Accelerator should be up and running at Argonne. And that, Simpson adds, could inject additional energy into the "friendly competition" to shrink particle accelerators.

–Ivan Amato