'pre-S' sequence that precedes the 'S' sequence of HBsAg and encodes a 55 amino acid extension which is poorly represented in serum HBsAg particles and is not found in yeast HBsAg particles because only the S gene has been engineered into yeast. The irony is that the pre-S encoded extension may be too important to be ignored or disrupted according to S. Kent (California Institute of Technology). Data he presented suggest that the pre-S extension is more immunogenic than the S gene product; that it should be included in hepatitis B vaccines; that a synthetic peptide corresponding to the amino terminus of pre-S might itself be the basis of a vaccine; and that antibodies against the peptide will find diagnostic uses. Note, however, that

serum and yeast HBsAg particles have been shown to protect chimpanzees against hepatitis B virus challenge, as has vaccinia virus carrying the S gene (see J. Beale *op.cit.*)

Space forbids mention of many other diseases for which a modern (sometimes not so modern) approach to a vaccine was reported. It should, however, be recorded that a session and a half was devoted to the prospects of a malaria vaccine and to the repetitive sequences within most of the potential malaria immunogens; the bulk of what was reported has recently been discussed in these columns (27 September, p.300 and 16 August, p.541). □

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Biological aerodynamics

Flight of fancy planned for the largest pterosaur

from Kevin Padian

AT one time, pterosaurs, the 'flying reptiles' of the Mesozoic era, seemed relatively simple to understand. They were considered to be bat-like inferior prototypes of birds, incapable of flapping flight or of efficient locomotion on land, no more than an early experiment in vertebrate flight. The giant *Pteranodon*, with its 7 m wingspan, seemed to be at the upper limit of any flying creature's size. Their replacement by the 'real masters' of the air, the birds and the bats, could easily be explained by a factor as trivial as a change in the average wind speed at the end of the Cretaceous (Bramwell, G.R. & Whitfield, C.D. *Phil. Trans. R. Soc. B*267, 503; 1974).

Recent work has called for a re-evaluation of these bizarre animals; none more so than the discovery of the giant *Quetzalcoatlus northropi* (Lawson, D.A. *Science* 187, 947; 1975) which, with a wingspan currently estimated at 11 m, was 50 per cent larger than *Pteranodon*. This remarkable beast was responsible for a recent gathering* of over 30 engineers, aerodynamicists, palaeontologists and inventors in Pasadena, California, to discuss the possibility of building an accurate radio-controlled flying model of the creature. The purpose of such a venture would be not only to challenge the potential of ornithopter technology, but also to use the problems posed to the aerodynamicist to illuminate the biological limitations of the largest animal ever known to fly.

Before any accurate flying model of a pterosaur can be built, it will be necessary to have as complete a picture of these animals as possible. Much of the conference was therefore devoted to

reviewing the most recent findings.

We now know that pterosaurs' wings were attached, not bat-like to the feet, but to the pelvis, to give a much more attenuate planform (Wellnhofer, P. *Abh. Bayer. Akad. Wiss.* 141, 1; 1979); the resultant wing loading resembles closely that of modern fliers (Padian, K. *Discovery* 14, 20; 1979). All pterosaurs, except the largest ones (like the largest birds), were active fliers; their wings were fully folded when they walked on the ground, which they did bipedally: their forelimbs are functionally homologous to those of their closest relatives, the dinosaurs and birds, not to those of the bats (Padian, K. *Paleobiology* 9, 218; 1983).

Recent models have treated the wing membrane as if it billowed with no internal structure, and ignored the probability that most pterosaurs having a wingspan of less than 3 m seldom glided or soared, but flapped continually. Moreover, finely preserved specimens of *Rhamphorhynchus*, from the Late Jurassic of West Germany, show a series of fine, intercalated and stiffened striae permeating the entire wing membrane (Wellnhofer, *op. cit.*). This arrangement resembles the structural elements in the wings of birds (feather shafts) and bats (fingers), and suggests a role in maintaining the shape of the wing. The striae may have helped to determine the camber of the wing, although the details of their muscular control, including the extent to which the wing may have been collapsed without losing its aerodynamic integrity in flight, are not known.

Some idea must also be had of the dimensions and mobility of the animal to be modelled. This is complicated by the bimodal distribution of *Quetzalcoatlus* specimens. Thus there are around 20 partially-preserved 'small' individuals, with

wingspans of about 5.5 m. Taken collectively, they provide a complete three-dimensional picture of nearly every wing element (Langston, W. *Scient. Am.* 244, 122; 1981). Then there is the giant specimen, known initially from its tree-like 50 cm long humerus. Each of its incomplete skeletal elements is approximately twice the length of its homologue in the 'small' form, although its shape is much more robust. Doubling the dimensions of the smaller form is not adequate for some parts of the body, including the torso, of which there are very few remains. Body length can be extrapolated from the few dorsal vertebrae preserved, but body weight is more difficult to determine and estimates range from 50 to 100 kg; until a scale replica of the animal can be built from preserved material, a weight of about 65 kg has been provisionally accepted. The wing area must depend on the length of the body, and seems to have been about 8.13 m²; this yields a wing loading of approximately 0.8 g cm⁻². *Quetzalcoatlus* had an aspect ratio of about 15 which, although high by the standards of natural fliers, is significantly lower than that of *Pteranodon* and other smaller seagoing pterosaurs. No living or man-made flier is an exact analogy for pterosaurs, although ultralight sailcraft may serve the purpose (McMasters, J. *NASA Conf. Pap.* 2085 (II); 1979).

The practical problems of replicating the flight of such an animal in a radio-controlled soarer-ornithopter are just beginning to be addressed. The first is that *Quetzalcoatlus*, like all pterodactyloid pterosaurs, had no tail, so pitch control will be complicated. Its neck and head were, by contrast, remarkably long, each about 2 m, while its entire torso was much shorter and its legs did not trail far behind the body. How far the neck could have been retracted or bent, if at all, is an important problem for paleontologists and has implications for engineers for calculating the centre of mass. The long neck and head form a powerful lateral moment arm, but also create a large amount of inherent instability; some sort of balancing mechanism up front will be necessary to control this. There are also logistic problems in trying to construct joints that can, for example, trim the wings and adjust pitch, while also supplying power for climbing flight.

The aim of the project is to launch the model from the Air and Space Museum of the Smithsonian Institution, from where it will fly across the Mall, climbing under its own power, circle the Washington Monument and return. To add realism, it has been suggested the model might pause in its flight, swoop down to snatch a small child from the crowd, carry it aloft, and consume it. For the present, mercifully, that objective seems to be beyond the technological capabilities of the field of Robotics. □

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