within the temporal bones. If the coils were straightened out, each cochlea would be 34 mm long in humans and about one-third of that size in small mammals[2]. The basilar membrane — a collagen-fibre membrane no more than 0.5 mm wide — divides the cochlea along its length. This membrane, together with the sensory hair cells of the organ of Corti that also span the length of the cochlea, transmits information about incoming sounds into a pattern code sent to the brain via the auditory nerve. The idea is that each component sound frequency is mapped by the mechanics onto a unique pattern of displacements of the membrane.

Sound waves travelling in air are transmitted to the fluid in the cochlear duct with little loss of energy. But how is the pattern of hair-cell excitation then set up along the basilar membrane? Modelling the vibration pattern of the basilar membrane has been a problem for nearly 140 years — ever since Helmholtz[3] first tackled it but ignored the hydrodynamics. The guiding principle since then has been to treat the cochlea as a one-dimensional transmission line[4]. The hydrodynamics implied in a three-dimensional cochlea have been difficult to add in, both computationally and experimentally. Olson's work[1] indicates that three-dimensional fluid flow may have to be included in any complete and realistic description of hearing.

Sound waves propagating in cochlear fluid travel, as in water, at around 1,550 m s^{-1}. Drop a stone into a pond and the sound it creates propagates to the bottom at this speed, although the ripples travel across the surface much more slowly (a Rayleigh wave) at a velocity that depends on the depth of the pond and the surface tension of the water. The basilar membrane is a two-dimensional surface with variable stiffness along its length that separates the two fluid compartments (Fig. 1). It effectively propagates a 'surface' wave — known as the Bekesy travelling wave — with a velocity of about 15 m s^{-1} (ref. 5). This wave starts at the base of the cochlea, nearest the middle ear, and propagates with decreasing wavelength but increasing amplitude towards a position of maximum amplitude beyond which it rapidly decays. In the cochlea of a living animal, the amplitude of the travelling wave at this peak is further increased about 100 times by the action of the outer hair cells that lie along the length of the cochlea[6,7].

Olson[1] offers a rare experimental view of the dynamic pressure changes in the cochlea. It is technically very difficult to make mechanical measurements in the cochlea owing to the extremely small size and delicate nature of the structures, especially at the basal end where high frequencies are processed. This has slowed progress considerably, and there are few direct measurements of pressure waves. Olson has overcome these problems by developing a small but sensitive hydrophone that can be placed into the gerbil cochlea and measure pressure changes within the cochlear fluids.

The new data show that fluid flow perpendicular to the basilar membrane falls away within 15 μm of the membrane. This result seems paradoxical. It has been supposed (in the so-called 'long wave' limit[4]) that fluid should be carried with the basilar-membrane wave throughout the height of the cochlear duct at the basal end of the travelling wave. Because water is incompressible, conservation of mass may imply that fluid is moving in a radial rather than perpendicular direction to the long axis of the cochlea. Alternatively, this is an indication that previous models of the cochlea may have ignored subtle features of the mechanics at the basal end of the cochlea.

Olson's result is consistent with the idea that the cochlea is a three-dimensional, dynamic structure. Not only does it have length, but the cochlear duct also has width and a variable height that determines the mass of fluid moving with the basilar membrane[5]. There are also indications that the organ of Corti on the membrane must be modelled as a complex matrix that includes not only hair cells, but also other cell types with varied mechanical properties. Modern computing power allows us to show that the structure may alter the fine detail of the local vibration pattern in the basilar membrane[8]. This pattern can involve higher radial vibrational modes, implying that surrounding fluid would be both pushed and pulled across, as well as along, the membrane[9,10]. It is a huge challenge to design a small enough pressure sensor, compared with the membrane width, that could resolve the dynamic detail required for the cochlea (Olson's is 160 μm in diameter).

We have yet to construct physiologically based models of the cochlea that convincingly describe all of its real-time abilities to analyse complex sounds. Such models should now probably include local interactions between the compartment fluids and the basilar membrane. It is hard to avoid thinking that cochlear models will get more complex before they become simpler. ■

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Daedalus

Happy landings

Aircraft are notorious for not failing safe. If anything goes wrong, it can be a terrible task to keep the plane in the air until it can land at an airport. Ideally, aircraft should be fitted with parachutes for safe descent; but a chute big enough to support a plane would occupy almost its whole interior. Daedalus now has a way out.

A parachutist hauls on the webs of his canopy just before hitting the ground. As a result, the parachute descends a little faster, and the man beneath it a little slower, at the crucial moment of impact. DREADCO engineers are now taking this strategy to extremes. They are devising a small but very strong parachute, to be deployed from an aircraft in distress, from a door in the top of the fuselage. Its horizontal flight will be checked below stalling speed, and it will plummet towards the earth, suspended in a horizontal attitude beneath its chute. The chute, however, is attached to the plane not by a simple anchorage, but by a winch. As the plane falls, the winch unwinds rapidly, paying out the parachute on many hundreds of metres of cable. But just as the plane is about to hit the ground, the winch is powered in reverse, and winds the cable forcefully in again. This hauls the parachute downwards far faster than its terminal velocity. So the parachute exerts a powerful upward force on the plane, which slows at the last minute and hits the ground quite gently.

A reliable safety system must be as simple as possible. As the parachute unreels, Daedalus wants it to wind up a spring on the winch, whose tension will wind it in again when the craft is about to hit the ground. This moment will be determined by a weighted cable lowered from the craft, which will go slack when its far end touches the ground. This purely mechanical system will have no vulnerable electronics or powered units.

At last the worry of flying will be relaxed. In case of decompression, engine failure, hi-jacking or structural fatigue, a plane will be able to drop safely out of the sky onto the friendly land. By angling the plane on its tether, the pilot could even 'glide' it towards the best landing site, as human parachutists do. Even if the plane hit the sea, the gentle impact would leave it undamaged. It would float until rescue arrived.

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