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Figure 1 **New work[2] clarifies the thermodynamics of granular materials, such as sand.**

wheat, sand (Fig. 1) and all sorts of powders. The study of such materials has a long history dating back to at least the time of Coulomb[4], whose friction law was actually derived for these materials rather than for blocks moving on planes. It was Reynolds[5] who first showed that compacted materials must first expand (dilate) if they are to deform. And Faraday's observation[6] of convection in a shaken powder provided an insight into the role played by the surrounding air. More recently, investigations of granular materials have been driven by commercial applications. Vast sums of money are expended in handling these materials for applications that range from energy production or extraction to food supplies and pharmaceuticals.

In the past few years, researchers have taken up the issue of the statistical properties of granular materials. Because these materials have flow characteristics that roughly resemble those of ordinary, newtonian fluids, it is tempting to look in that direction for useful analogies. But these analogies should not be pursued too closely: granular systems dissipate energy quickly, so ordinary techniques of statistical mechanics that depend on energy conservation break down.

Undeterred, several groups have worked towards understanding the true statistical properties of granular materials. Such work includes studies of gas-like granular states[7], investigations of fluctuations and stress variability in dense systems[8], and, perhaps most importantly here, proposed new versions of statistical mechanics that would apply in a granular system where energy is not conserved[9–12].

This issue of energy conservation was addressed early on by Edwards and co-workers[9,10]. They introduced a new way of calculating the entropy (the degree of disorder) and temperature for a granular system. Entropy depends on the number of states available to a system. Edwards *et al.* counted the number of configurations possible for fixed volume and energy, and defined the 'Edwards temperature' in terms of the volume derivative of this entropy.

The problem with the Edwards approach is that it is difficult to test directly in real systems. Some experiments have achieved at least a flavour of the Edwards picture, such as studies of granular compaction[12,13] that showed very slow increases in the density of a granular column that is tapped repeatedly. But, as with many granular experiments, their interpretation is complicated because there is a non-uniform rate of energy injection and non-uniform density — the key control parameter.

In Makse and Kurchan's numerical model[2] of a granular system subject to a gentle shearing force, the rate of energy input is uniform (over a reasonable time scale), and a uniform density is maintained. The authors use a tried and tested means to extract a temperature for the system: a comparison of diffusivity and mobility, whose ratio yields the temperature in conventional fluids. They then show that, for their model granular system, this ratio is identical for different particle sizes, just as one would expect in a fluid. The temperature extracted from their observations of diffusion and mobility is also consistent with the predicted value of the Edwards temperature.

So this work shows that, at least in a model system, it is possible to relate temperatures obtained from transport measurements, such as diffusion and mobility, to the Edwards picture. If similar transport measurements are performed in real granular systems, we would have, arguably for the first time, a measurement of a key statistical property that could be matched, in principle, to a theoretical prescription.

But there is a caveat: when real granular systems are sheared or shaken, they tend to become inhomogeneous often in both space and time. Although, to a certain extent, inhomogeneities can be avoided or accounted for, the link to the theoretical picture would be broken. Nonetheless, this work[2] leads us towards a clearer understanding of the statistical properties of real dense granular materials. ■

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Daedalus

Perfect perforations

Birds have feathery porous wings, and engineers are pondering the reason, with a view to applying it to aircraft wings. One idea is to riddle aircraft wings with tiny holes. Any solid wing has a boundary layer of air. A porous wing can remove this layer by suction, or displace it by blowing. To optimize these effects, says Daedalus, we need a wing that is dense with little holes, but not at 90° to the wing surface. The wing should suck at the front, with each inlet hole pointing forwards to accept air from ahead. It should blow at the rear, with exit holes angled steeply to eject air backwards. The two effects would counterbalance each other, but need not cancel out. The ideal combination would optimize the wing as a lifting device of low drag.

Modern passenger aircraft need to provide cabin air for their passengers. The wings might draw on the plane's air budget, or alternatively might help to supply it; any supply from or drain to the wings must be taken into account. Even so, Daedalus reckons that porous wings must have good physics behind them, or rather beneath them. Nature knows her business.

Daedalus does not intend to power his aircraft from the air extracted ahead and ejected behind by its porous wings, though this should make a useful contribution. His idea is simply to make artificial porous wings as efficient as possible, and with the lowest feasible drag.

So DREADCO engineers are flying blown and sucked wings in a wind tunnel, and comparing the results with those obtained with naturally feathered wings. Both natural and artificially porous wings should have lower drag and higher lift than the standard solid variety. Further, sucking in air at the front while ejecting it at the back should improve the wings both as lifters and thrusters.

One problem will be ice, which at high altitudes grows on even the best wings. But conventional engines are only about 25% efficient, so 75% of their energy is wasted as heat. A distributed cooling system would warm the wings, helping to keep ice away. It could heat the rear-ejected air as well, increasing the thrust of blown wings by a sort of afterburner effect. A plane with cylinder engines could even release its exhaust gases through the rear-facing holes in a blown wing. This would neatly capture energy that would otherwise be lost, and raise the thrust of the wings. Sadly, it would disfigure the usual tasteless painted-on colour scheme.

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