



FIG. 1.



FIG. 2.

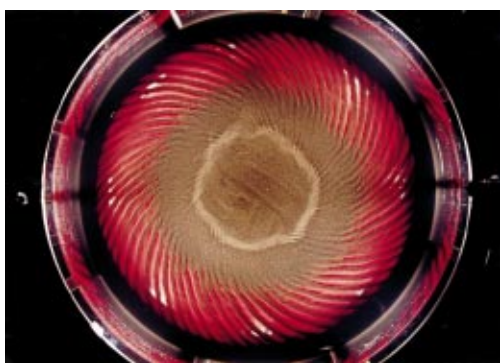


FIG. 3.

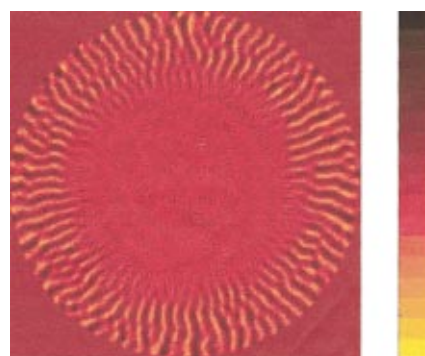


FIG. 4.

## Spiral Patterns Formed by Granular Media Underneath a Rotating Fluid. Experiment vs Computation

Submitted by

Farzam Zoueshtiagh and Peter J. Thomas, University of Warwick

Figures 1–3 show spiral patterns formed by small granules on the bottom of a circular, fluid-filled rotating tank. The granule diameter is around 200–250  $\mu\text{m}$  and the diameter of each spiral pattern corresponds approximately to the tank diameter of 1 m. Initially the granules were distributed in a uniform layer across the whole bottom of the tank. The fluid above the layer was in a state of solid-body rotation and, hence, did not move relative to the granules. Pattern formation is initiated when the rotational velocity of the tank is instantaneously increased from its original value  $\omega_0$  by a sufficiently large increment  $\Delta\omega$  to a higher rate  $\omega_1$ . The fluid mass inside the tank cannot follow the instantaneous acceleration of the tank. This establishes shear forces between the granule layer and the fluid above it. The granules are set in motion, slide across the bottom of the tank and, within a few seconds, form patterns such as those displayed in Figs. 1–3.

Depending on the experimental conditions we have observed<sup>1</sup> patterns with  $7 \leq n \leq 110$  spiral arms originating from uniform, inner granule patches with associated radii  $r_0$ . The data analysis has shown that  $n \propto \omega_1^{0.5} / \Delta\omega$  and that  $r_0 \propto 1 / \Delta\omega$ . Recently we have developed a cellular-automaton model<sup>2</sup> which succeeds in generating patterns qualitatively similar to those observed in the experiments. One computational pattern is shown in Fig. 4; the colorbar indicates the height of the granule layer. The model is a suitable generalization of a model previously used<sup>3</sup> to simulate ripple formation in wind-blown sand in a straight channel. Our model, in particular, also reproduces quantitatively the scalings for  $n$  and  $r_0$  measured in the experiments. Prompted by the inherent properties of the model, intuitive physical arguments have been advanced<sup>2</sup> which readily yield these scalings as a consequence of the existence of some critical threshold condition. It is argued that this result suggests that the spiral patterns might constitute some type of rotating analogue of sand ripples typically observed on beaches.

<sup>1</sup>P. J. Thomas, "Pattern formation of granules on the bottom of a differentially rotating tank," *J. Fluid Mech.* **274**, 23 (1994).

<sup>2</sup>F. Zoueshtiagh and P. J. Thomas, "On the wavelength scaling of spiral patterns formed by granular media underneath a rotating fluid," to appear in *Phys. Rev. E*.

<sup>3</sup>H. Nishimori and N. Ouchi, "Formation of ripple patterns and dunes by wind-blown sand," *Phys. Rev. E* **71**, 197 (1993).