Abstract Submitted
for the DFD06 Meeting of
The American Physical Society

The self-ergodicity of granular contact forces PHILIP METZGER, NASA Kennedy Space Center — A formal mathematical proof of ergodicity has been accomplished for granular contact forces. It is a special type ergodicity having unique characteristics compared to thermal systems, because (for one thing) it operates across multiple spatial dimensions with orthogonal conservation laws, whereas in thermodynamics the ergodicity and the conservation laws all operate across one single dimension (namely, the time dimension). This higher-dimensional ergodicity causes the concept of temperature to become a rank-2 tensor instead of a scalar, with the dimensionality of the tensor equal to the number of ergodic dimensions (three for 3D packings). Furthermore, symmetries in the granular packing ensemble ensure that certain types of packings will always exist at maximum contact force entropy without first having to explore phase space. Thus, the ergodicity is an inherent "self-ergodicity," which explains why the granular contact force distribution is so immediate and repeatable and why it has an exponential tail. The theory predicts the distribution of contact forces and other statistics of the stress state of the individual grains. These predictions have been tested via discrete element modeling and have been overwhelmingly validated. The theory has a number of practical ramifications that are important to developing a full theory of rheology.

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Date submitted: 03 Aug 2006 Electronic form version 1.4