Travail, Dissipation et second principe de thermodynamique dans les milieux granulaires

une retombée de la physique spatiale incomprise ou .... une folie

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Film: Site web: Palais de la Découverte : un chercheur une manip/Poudres, grains et vibrations...sur terre et en apesanteur au Palais Du 27 février au 27 avril 2008
Explications en 3 temps:

• Modèles / expériences et simulations

• Une interprétation basée sur l’Eq. De Boltzmann

• Et le second principe

Remarques:

Difficulté pour écrire et parler en congrès
Difficulté pour venir ici
Test psy / comité médical (je me crois en Russie) .... Peer review
3d simulations of granular gas in a vibrating box:
Demonstration of a large boundary effect due to dissipation by collisions which is not a propagating shock wave

P. Evesque, R. Liu, Y. Chen, M. Hou

R. Liu, MSSMat, ECP, France (Oct 2008-2009), & IOP-CAS, China
M. Hou, "", & IOP-CAS, China
Y. Chen, P. Evesque, MSSMat, ECP, France & IOP 2009-2013

Thanks to ESA, CNES, CNSA

The flights: Satellite SJ8

2010: Essai de prédation (Pouliquen, Falcon, Vandewalle,...)
Why Studying Granular Matter in Micro-gravity.

Experiments on vibrated granular matter in micro-gravity

Behaviour of granular dissipative gas under vibration
- to Study gas, cluster formation?
- to Test the foundations of statistical Mechanics
- to Test the validity of the theoretical approach / approximations

More Importantly: to learn How to handle grains in 0-g to generate industrial processes…. & allow human life in space

Grains in 0g may be quite dangerous (breath - command)

Accurate comparisons lead to a series of puzzling questions for theorists of hydrodynamics and of disordered systems

P. Evesque - Travail, Dissipation et second principe dans les milieux granulaires, Ecole EGRIN; 2-4/4/2013, Chalès-Frabnace
Experimental study in 0g
Minitexus 5 (1998), Maxus 5 (2003), Maxus 7 (2006), SJ8 (2006); A300-0g

► Incompatibility of our experimental results in 0g compared to simulations
  • $n_{\text{layer}} > 1$ : particle speed $<$ wall speed $\Rightarrow$ « supersonic excitation »
  • but No Shock waves
  • bad coupling when $V_{\text{ball}} << V_{\text{wall}}$ - boundary effect

Is wall a thermostat or a velostat?? …

So we have shown that accurate study of experimental results lead to a series of puzzling questions that are not yet understood / described by theorists of hydrodynamics and of disordered systems nor by simulations.

However it requires to look in some details to what does not work

How to confirm, confort or test our results? with simulations? What to test?
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State of the art on simulations of Granular gaz and theoretical predictions

Hypotheses
- No Rotation or rotation (no matter)
- Boundary conditions (no matter)
- Restitution coefficient

Inhomogeneous collapse and clustering

1995-2009...

Conclusion: Right parameters
- Effective temperature
- Constant Pressure
- Kinetic theory works with thermal balance for dissipation

\[ T_1, T_2, \rho(z), T(z), f(v) \propto \exp\left[-(v^2/kT)^a\right] \]
with \( a \) not far from 1
Simulation results using DEM

( not in R. Liu thesis, clustering and MD)


+ Y. Chen, Thesis: 2d Paraboloic flight, 2d exp in Horizontal plane 2d simulations 2d Inclined vibration (small effective g) (2009-2013)
Simulations:

Cell: 20d*20d* 60d

Wall Motion kinds
- Bi-parabolic symmetric
- Symmetric Sawteeth
- Bi-parabolic non symmetric
- Non Symmetric Sawteeth

+ Thermal wall

Parameters:
- e = 0.7, 0.8 and 0.9
- N = 100, 500, 1200, 1600, 2000, 3000, 4000, 4500

Measurements:
- n(z)
- PDF $V_z$ at different z, PDF of $V_x$ at different z
- $<V_z>$, $\Sigma V_z$ = flow; $<V_+>, <V_->$, $F^+$ et $F^-$
- $p = \Sigma V_z^2$, $p^+ = \Sigma V_z^2^+$, $p^- = \Sigma mV_z^2^-$
- $T = \Sigma mV_z^2/\Sigma m$; $T^- = \Sigma mV_z^2^-/\Sigma m$; $T^+ = \Sigma mV_z^2^+/\Sigma m$
Simulation N=1200; PDF $V_z$, $V_x$

Figure 2.1 - $V_z$, Simulations of granular gas in 3d rectangular cell

Figure 2.2 - $V_x$, Simulations of granular gas in 3d rectangular cell
PDF $V_z$ in log

shoulder is amplified at large $z$

- The shoulder disappears at half the cell (bin ±12 over ±30)
- The maximum goes to left of $z=0$
Simulation N=1200; PDF $V_z$, $V_x$

$V_z^+ \neq V_z^- $; steady state $\Rightarrow n^+ V_z^+ + n^- V_z^- = 0$

**Figure 2.2 - a. Simulations of granular gas in 3d rectangular cell**

**Figure 15: sawtooth vibration $N = 1200$**

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Difference between $T^+$ & $T^-$; $P^+$ & $P^-$

If $V_z^+ \neq V_z^-$ and steady state $\Rightarrow$ $n^+v_z^+ + n^-v_z^- = 0$

$p_z^+ \neq p_z^-$ and $T^+ \neq T^-$

$P_z^\pm (z) = \sum_v \rho(v_z^\pm, z) V_z^\pm^2 = \sum_{at z} (V_z^\pm^2)$

$T^\pm (z) = \sum_v \rho(v_z^\pm, z) V_z^\pm^2 / \left[ \sum_v \rho(v_z^\pm, z) \right]$

$= \langle V_z^\pm^2 \rangle$

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Comparison with Simulation from others: averaging over whole cell

Most results • tell no difference with the kind of excitation (Sawtooth, sinus)
• do not give local speed distribution, define only one $T(r)$ (at best).
• look at averaged $f(v)$ as $f(v) \approx \exp[-(\beta v^2/T)^\alpha]$

$\Rightarrow$ equivalent to mean field treatment / approximation (1995-2006)

Best finding:

5.1 the pressure.

J. J. Brey et al [arXiv:0906.0747] find some stationary state pressure, like that in classical gases. But they also observe wire distribution. Their system is quite near elasticity ($c = 0.1$) strongly dissipative system, whether the constant pressure is misunderstood. And it is difficult to calculate the pressure in the local mean free path is too short. $\Sigma c_i^2$ does not give any idea of the pressure if too many collisions there.

5.2 the stability of the cluster.

E. Khain and B. Meerson [Europhys. Lett., 65 (2), pp. discussed an oscillating phenomenon of the cluster in the center. These results indicate that steady state sometimes is difficult number of particles $N$. Three states of the cluster, i.e. a static cluster (singular), steady cluster, and an oscillating cluster, may be found.

5.3 wings and double-peak structures in velocity distribution.

Morgado and Mucciolo [Physica A 311 (2002) 150-168] disc and velocity distributions in a 2D system with their DSMC r found in the longitudinal velocity distributions.

J. F. Boudet et al [PRL 101, 254503 (2008)] observed a sin structure near the shock front of an obstacle, which indicates two kinds of particles, in a granular flow.
Difference between sawtooth and sinus

But still: \( n^+ \neq n^-; P^+ \neq P^-; T^+ \neq T^- \)
Difference of PDF $V_z$ between sawtooth, sinus, thermal wall (In log scale)

PDF $V_z$ is non symmetric
+ depends on $z$
It has 2 peaks only for sawtooth
Part 1: Conclusion 1:

- **GG** is an interesting problem with a lot of **contradictions/unknown**
- Its statistics does not obey the one of a gaz with a single temperature:
  - 2 temperatures and 2 pressures everywhere, in vibration direction
- This is linked to **boundary conditions**
- This is observed in **simulations** and in **experiments**
  - and this despite the numerous publications **which deny/do not cite** this point
  - or/but which have not checked this
- 0g and 1g experiments are not equivalent
- **MD is not well understood, despite what tell the publications**

These are opened questions => SJ-10

We are still far from understanding the **structure of the universe**, with stars, galaxies, ..., dust

We do not want to **die with peas (or flour, coffee)**, preparing some **food**... (in space)

We are facing also some problem about **edition**, and **research management**
Part 1: Conclusion 2:

Complex non-linear systems need large amount of data to determine (non-mean field) analysis

And correct analysis

Number of curves studied: 6000 (3e*8N*5 boundaries*4t*12 plots(v, v²,...)

Poudres & Grains 17 (2009) (550 pages)

Generalisation

+ This may happen very often for any flow with local jump and/or hydrodynamic discontinuities.
+ i.e. Leidenfrost effect

This work uses concepts from my previous works:

- boundary = thermostat or velostat
- Problem of diffusive or/propagative Boltzmann equation
- True effect of fast boundary

physical idea: \( V_+ \neq V_- \)
Interpretation / Conclusion 3:

Impact with moving boundary  =>  \( V_+ >> V_- \) on \(-L\) &  \( V_+ << V_- \) at \(+L\)

**Steady state**  =>  \( \Sigma \rho_+ v_+ = \Sigma \rho_- v_- \)  =>  \( \rho_+/\rho_- = V_-/V_+ \)

This makes the **speed-symmetry breaking** at \( \pm L \), that propagates with decrease to 0 at \( z=0 \)

**Characteristics:**
- 2 different temperatures \( T_\pm \) in any given position (\( z \)) for \( V_{+z} \) and \( V_{-z} \).
  
  since  \( kT_\pm/m = \langle \rho_\pm V_\pm^2 \rangle/\langle \rho_\pm \rangle \propto |V_\pm^2| \)

- 2 different pressures \( P_\pm \) in any given (\( z \)) since  \( P_\pm = \langle \rho_\pm V_\pm^2 \rangle \propto |V_\pm| \)

▶ This seems to be coherent with what we observed experimentally and not coherent/described in other simulations and theoretical descriptions \((P=\text{cst})\)

Nobody tested the non random distribution in GG

I hoped this wuld allow discussion but not
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La **équation de Boltzmann** est donnée par : 

\[
\frac{\partial \rho}{\partial t} + \mathbf{v} \frac{\partial \rho}{\partial x} - g \frac{\partial \rho}{\partial v} = - \int du \, du' \, \left| u-v \right| \rho(v,x,t) \rho(u,x,t) \, d\{u'-v+\varepsilon(v-u)\} \, d\{v'-u+\varepsilon(u-v)\} \\
+ \int du \, du' \, dv' \, \left| v'-u' \right| \rho(u',x,t) \rho(v',x,t) \, d\{v-v'+\varepsilon(v'-u')\} \, d\{u-u'+\varepsilon(u'-v')\} \\
+ \text{2}\text{nd order term (thermal and particle diffusion )}
\]

En notant : 

\[
\frac{\partial \rho}{\partial t} + \mathbf{v} \frac{\partial \rho}{\partial x} - g \frac{\partial \rho}{\partial v} = \varepsilon \partial \left\{ \int du \, (v-u) \, \left| v-u \right| \rho(v,x,t) \rho(u,x,t) \right\} / \partial v
\]

(2)

Où \( \varepsilon = (1-e)/2 \) est le coefficient de dissipation lié au coefficient de restitution \( e \).

Le côté droit est non nul si la distribution n'est pas symétrique.
LAGRANGIAN POINT OF VIEW OF THE MECHANICS AND CAUCHY’S STRESS TENSOR

- **Material frame**, with point-volume like $\delta m$, $\delta v$
  - $\sigma^+ \& \sigma^- : T^+ ds \& T^- ds$
  - $\Rightarrow \rho g ds = (T^+ - T^-) ds$
  - $\Rightarrow$ pressure $p^+ = p^-$
  - $p^+ = m \sum_{v > 0} v^2 \neq p^- = m \sum_{v < 0} v^2$

The real wall moves toward the center
The real big ball moves toward the center
EULERIAN POINT OF VIEW

One starts from the continuity equation

\[ \frac{\partial \rho}{\partial t} + \rho \, \text{div}(v) + v \, \text{grad}(r) = \frac{\partial \rho}{\partial t} + \text{div}(\rho v) = 0 \]

And one defines the pressure…. $P$ so $p^+ = p^-$
Shaken sand, stress and test
(J. Villain 2012)

- Limit of 2-body collisions
  1) \[ P = P^+ + P^- = \text{constante} \]

\[
\int_0^T F_i(t) \, dt = m_i [v_i - v_i']
\]

\[
F_T = \sum_i m_i v_i - \sum_f m_f v_f
\]

\[
P^- = \rho \int_0^\infty v^2 p(v) \, dv
\]

\[
P^+ = \rho \int_0^\infty v^2 p(v) \, dv
\]

*Figure 3: Various types of collisions. The z-component of the velocities are denoted \( v_z \) and \( v_z' \) (incoming particles), \( v_i' \) and \( v_i'' \) (outgoing particles).*
The Paper says:

- With few balls (2-20) they found hydrodynamics modelling is impossible
- This comes from dissipation
- And modified the equation
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Remarques:
Difficulté à parler
Difficulté à venir
Évaluation psychiatrique/comité médical
Quelques examples

« Classic » view

\[ f(V, T) = A \left[ \frac{\pi T}{(T^{d/2})} \right] \exp\left(-\frac{V^2}{(BT)}\right) \]

Real view

Woks for 2d & 3d simulations, Airbus 0g
2d results & 2d horizontal in 1g, compatible with rockets and satellite exp.

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Few new understanding

2nd principle: no work without 2 T

Leidenfrost effect or boiling crisis
Levitating hourglass
Clustering

Paroi => force centrale