The Multi Intruder “Brazil Nut” Problem

Supervisors:

Heinrich M. Jaeger
Sidney R. Nagel
Matthias E. Möbius
Detlef Lohse

Internship Chicago, Summer 2002

Peter Eshuis

Overview

- Intro to Granular Material (GM)
- “Brazil Nut” Problem
- Experiment
- Results
  - Density dependence
  - Size dependence (single & multi)
  - Miscellaneous
- Conclusions & Discussion
- Recommendations

Intro to Granular Material (GM)

- Examples of GM: sand, salt, sugar etc…
- GM can act as solid, fluid and gas

  ↳ "Fourth state of matter"

Applications:

- – Pharmaceutical industry
- – Mining
- – Agriculture
- – Food processing industry
- – many more!

“Brazil Nut” Problem

Larger (heavier) particles segregate to the surface of a shaken container with different granular materials

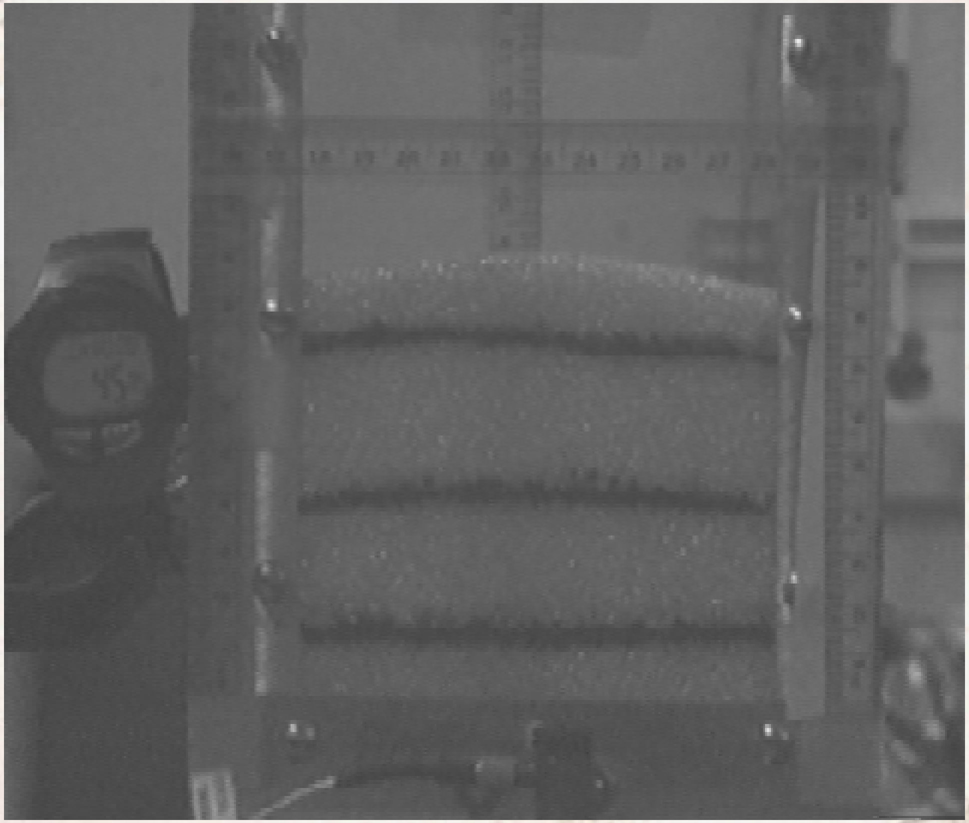
Mixed Nuts

Brazil Nut

“Brazil Nut” Problem

- Percolation: smaller particles slip through holes created by the larger ones *(Hong et al, 2001)*
- Reorganization: during shake neighboring smaller particles fill up gaps left behind by the larger ones *(Duran et al, 1993 & Jullien et al, 1992)*
- Convection: flow going up in center capturing all particles, going down in very thin layer near wall trapping the largest particles *(Knight et al, 1993)*
- Condensation (MD-Sim): binary granular system can condense either the larger or smaller particles → “Reverse Brazil Nut Problem”! *(Hong et al, 2000)*

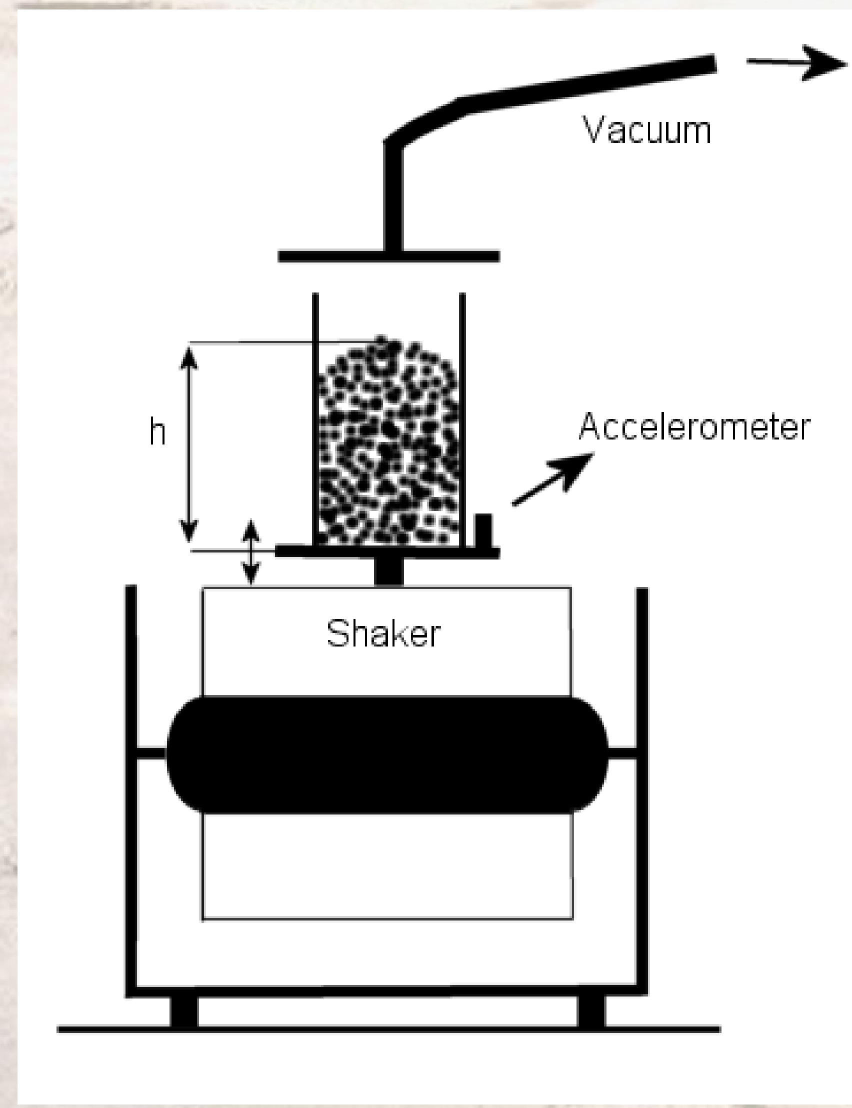
“Brazil Nut” Problem



2D-Movie: Convection without intruders

(Niemuth et al, unpublished)

Experiment

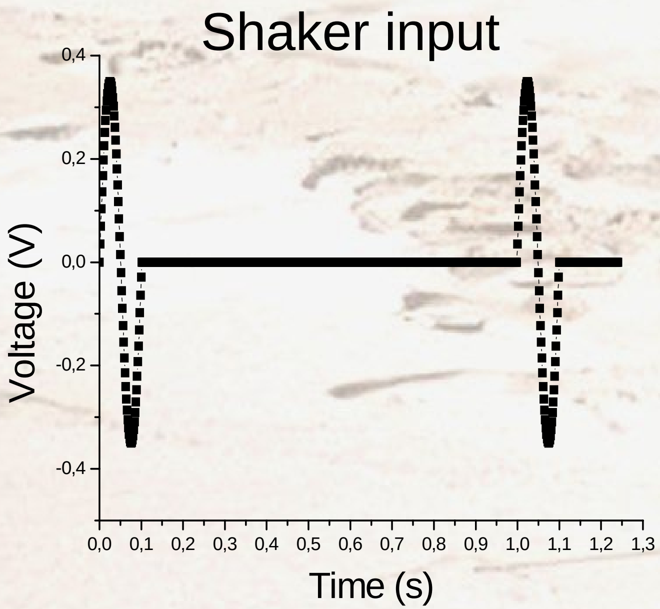


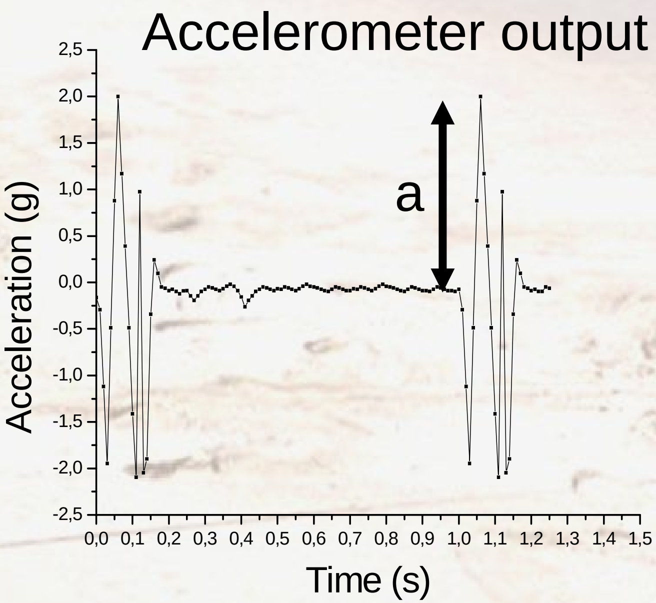
Cylinder (12cm diameter) filled up to filling height ‘h’ with glass beads:

- d=1mm & ρ_m=2.4 g/ml
- d=0.5mm & ρ_m=2.5 g/ml

Glass beads (d=1mm) glued to cylinder wall for stable convection & reproducibility

Experiment



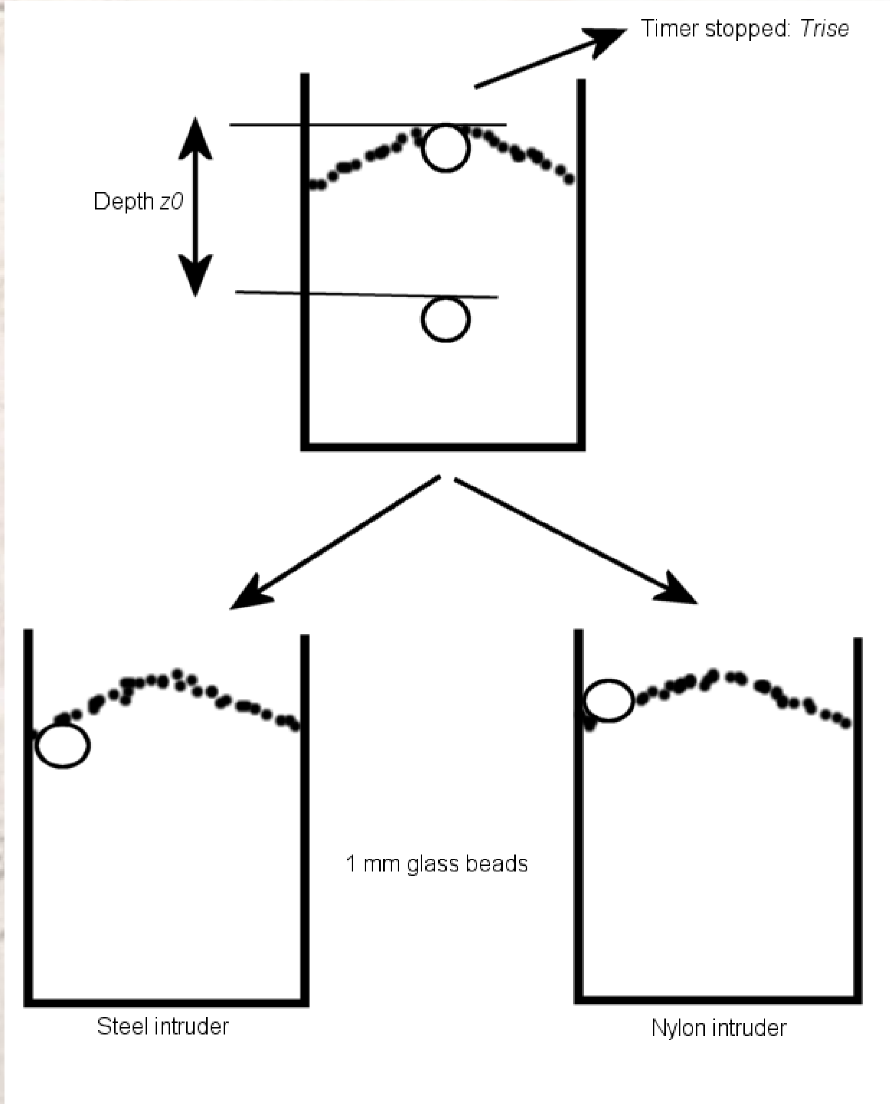


Once every second a 10Hz sine wave ('tap') is applied to the system

Acceleration parameter: $\Gamma = \frac{a}{g}$ (typical $\Gamma \approx 2.3$)

Γ adjusted to remain constant during all experiments

Experiment

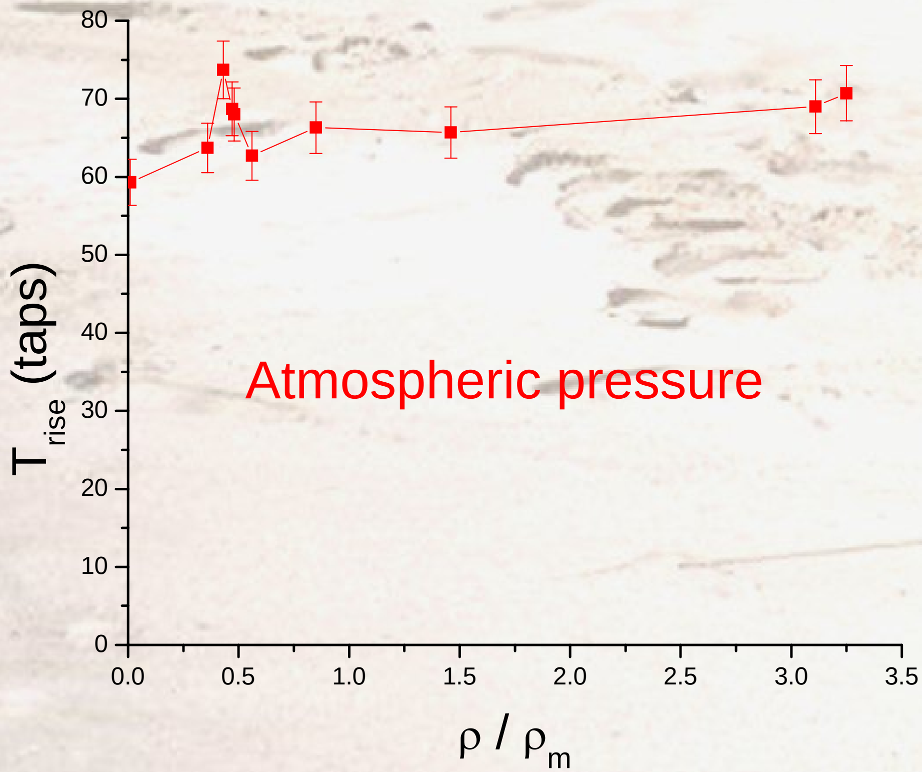


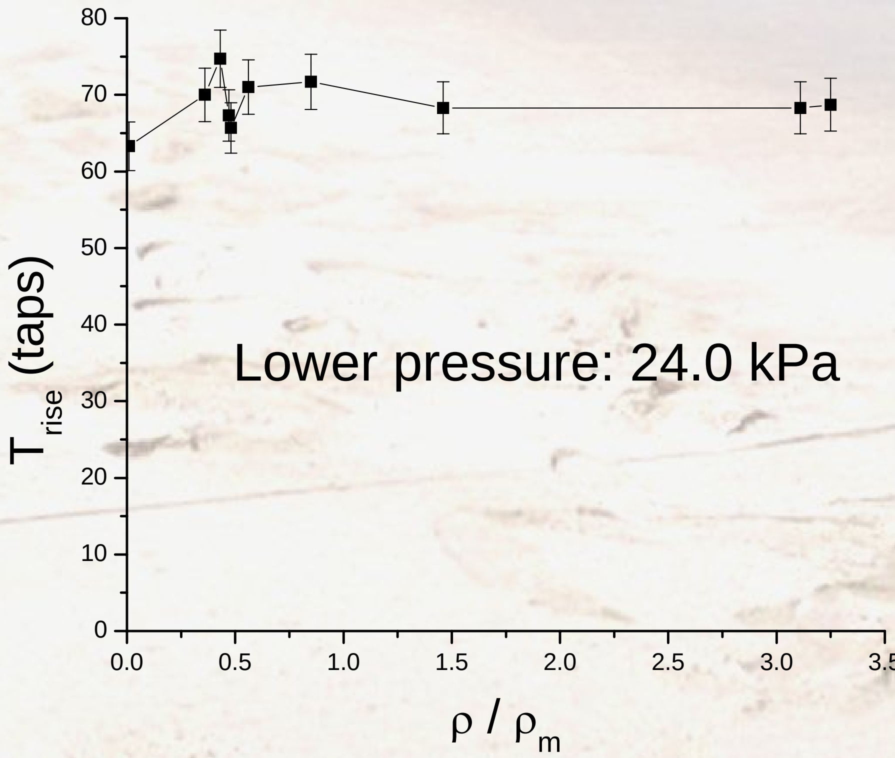
Spherical intruder (diameter D & density ρ) is carefully placed at depth z_0

Rise time (T_{rise}): determined when intruder is emerging at surface

Problems with surfacing occurred in 1mm glass beads

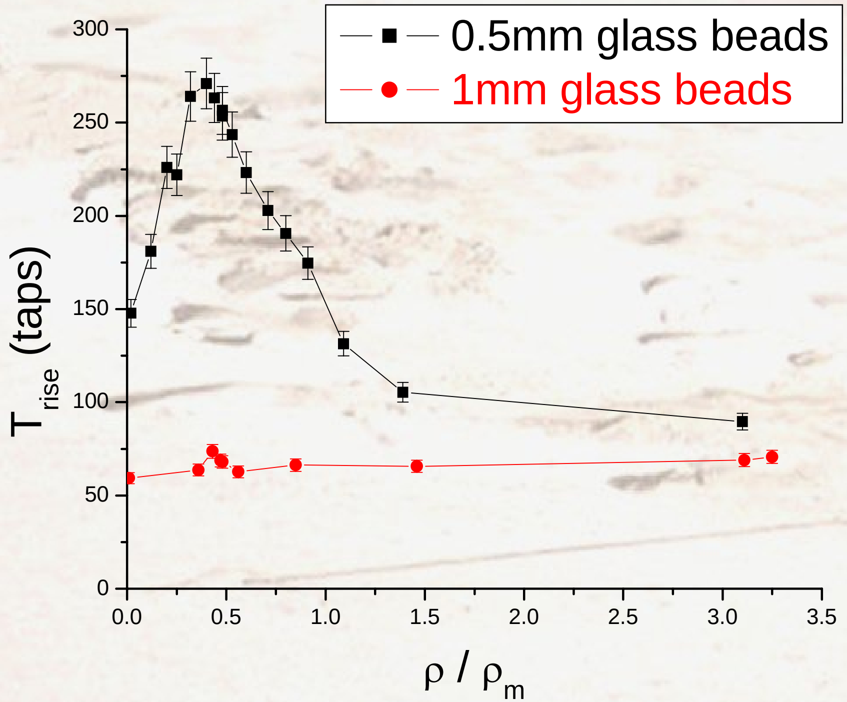
Results – Density (d=1mm)





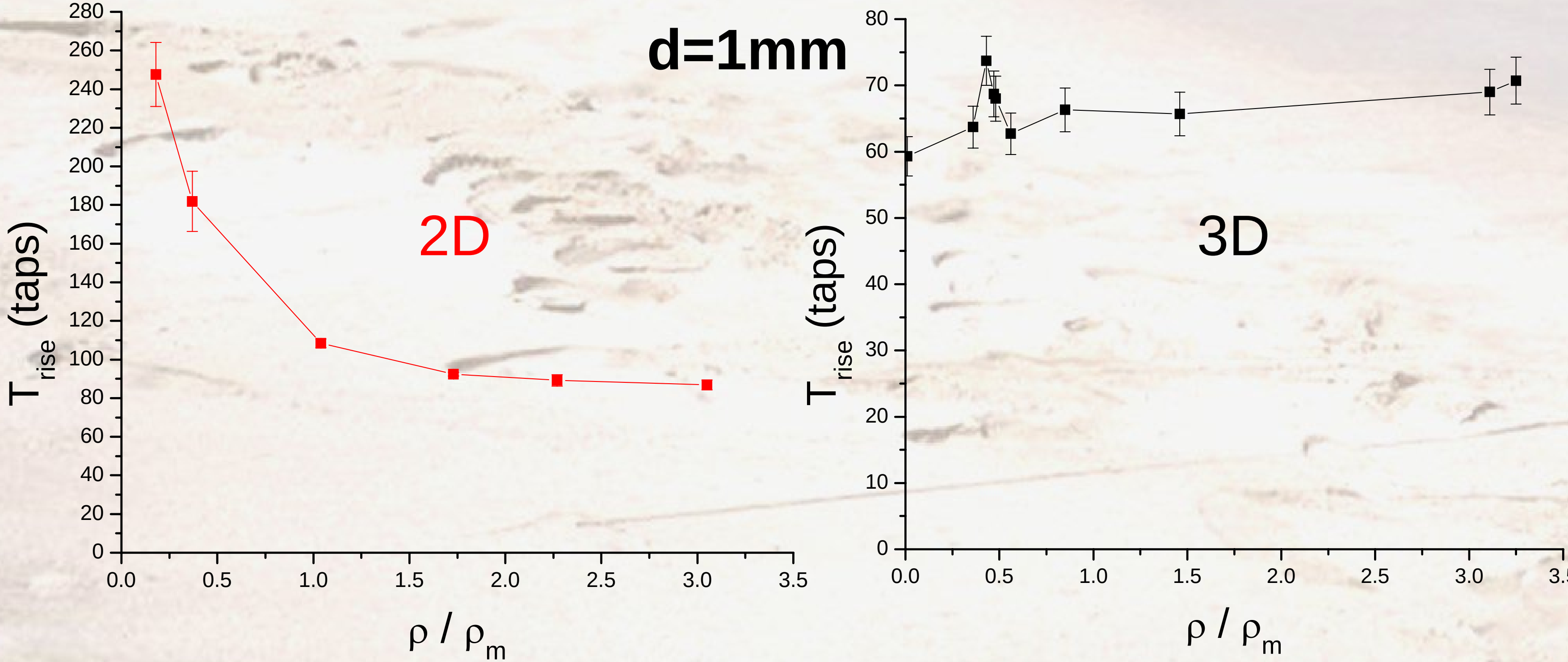
- 'Peak' around $\rho/\rho_m \approx 0.5$ less clear at lower pressure
- Overall trend for T_{rise} is slightly increasing

Results – Density (d=0.5mm)



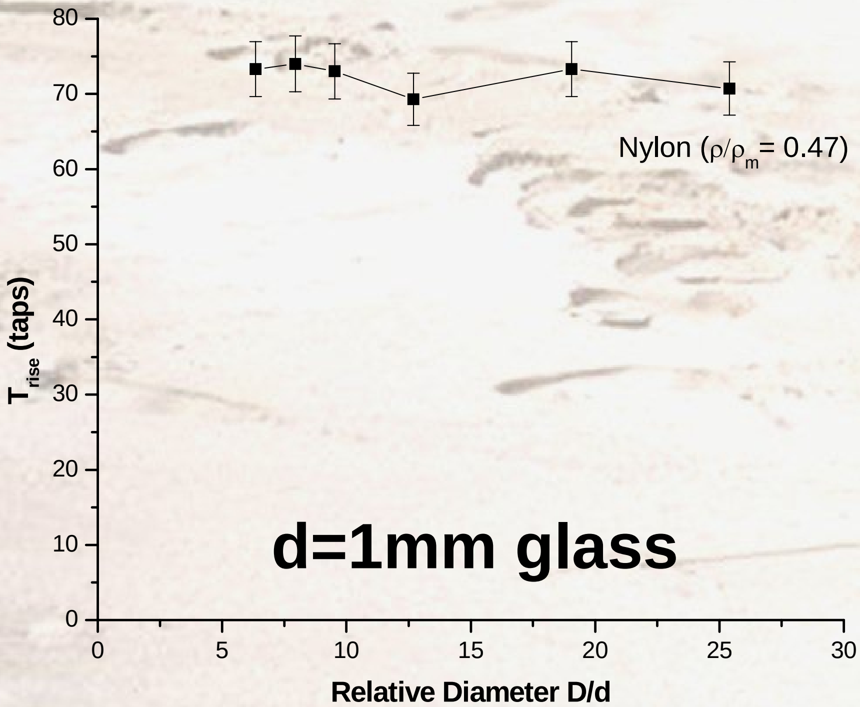
- Peak around $\rho/\rho_m \approx 0.5$ far more pronounced for 0.5mm glass beads
- This peak vanishes for low pressures *(Möbius et al, 2001)*
- No dependence on intruder surface or restitution coefficient

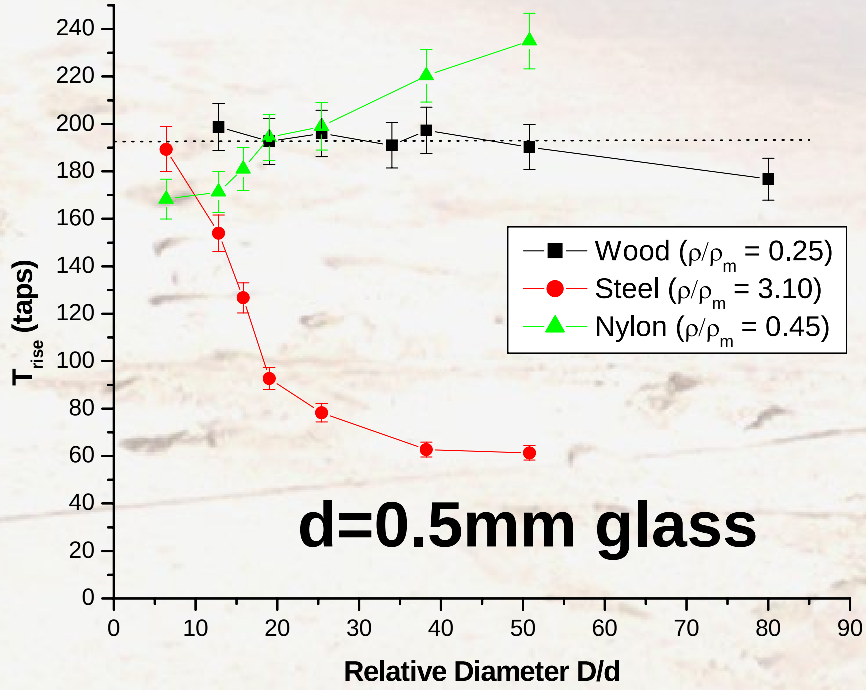
Results – Density (2D vs 3D)



- No peak in 2D situation *(Niemuth et al, unpublished)* and also a clear decrease of T_{rise} for denser intruders instead of a slight increase as in 3D
- 2D in agreement with *Liffman et al, 2001*

Results – Size (single)

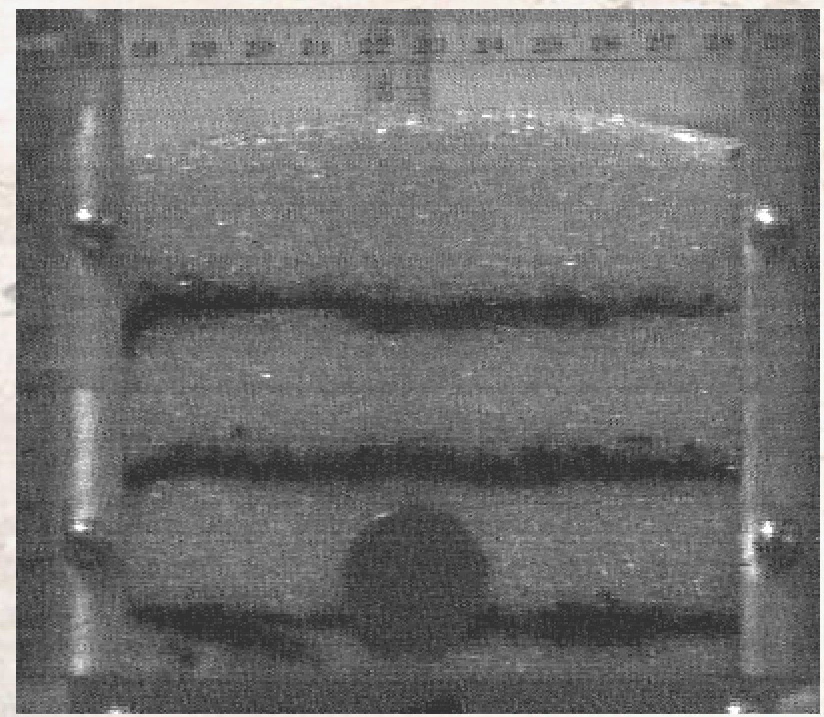




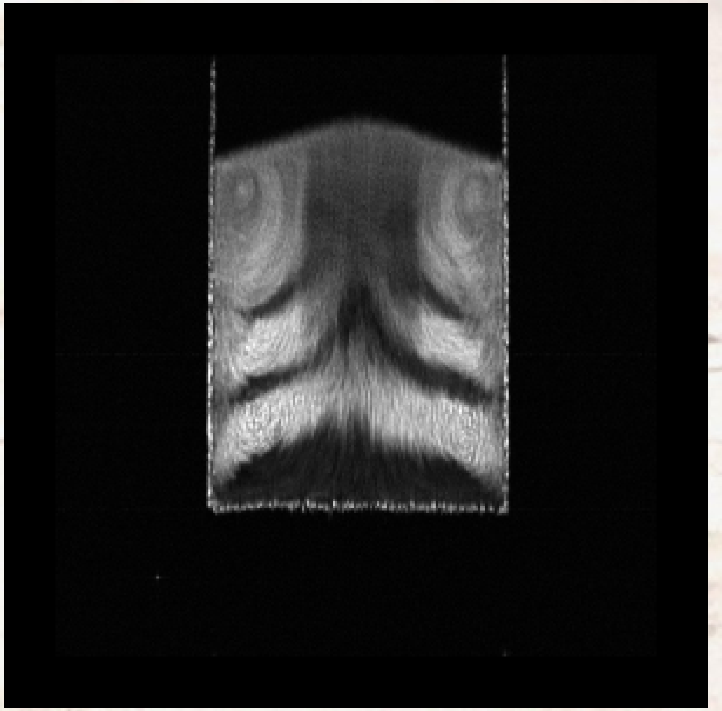
- T_{rise} constant for nylon

- T_{rise} increasing for nylon
- T_{rise} decreasing if ρ/ρ_m far enough from density peak

Results – Size (single)



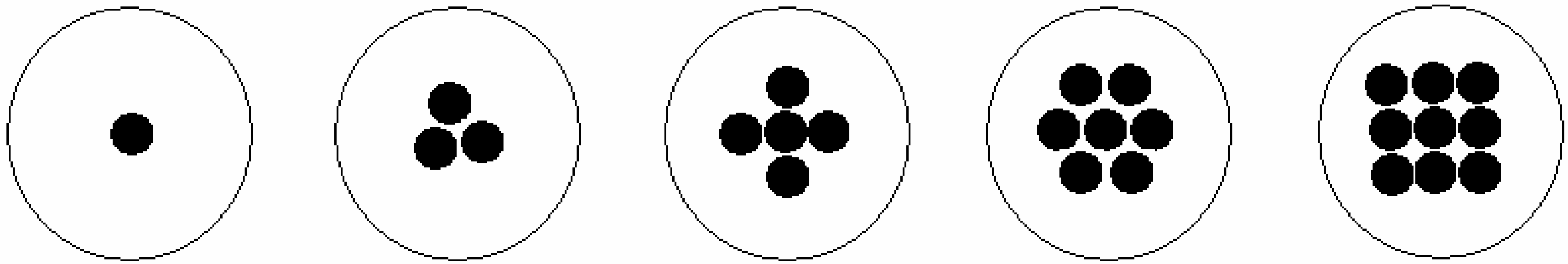
2D Movie: single disk
(Niemuth, unpublished)



MRI Movie (3D cylinder): Glass intruder in poppy seeds *(Möbius, unpublished)*

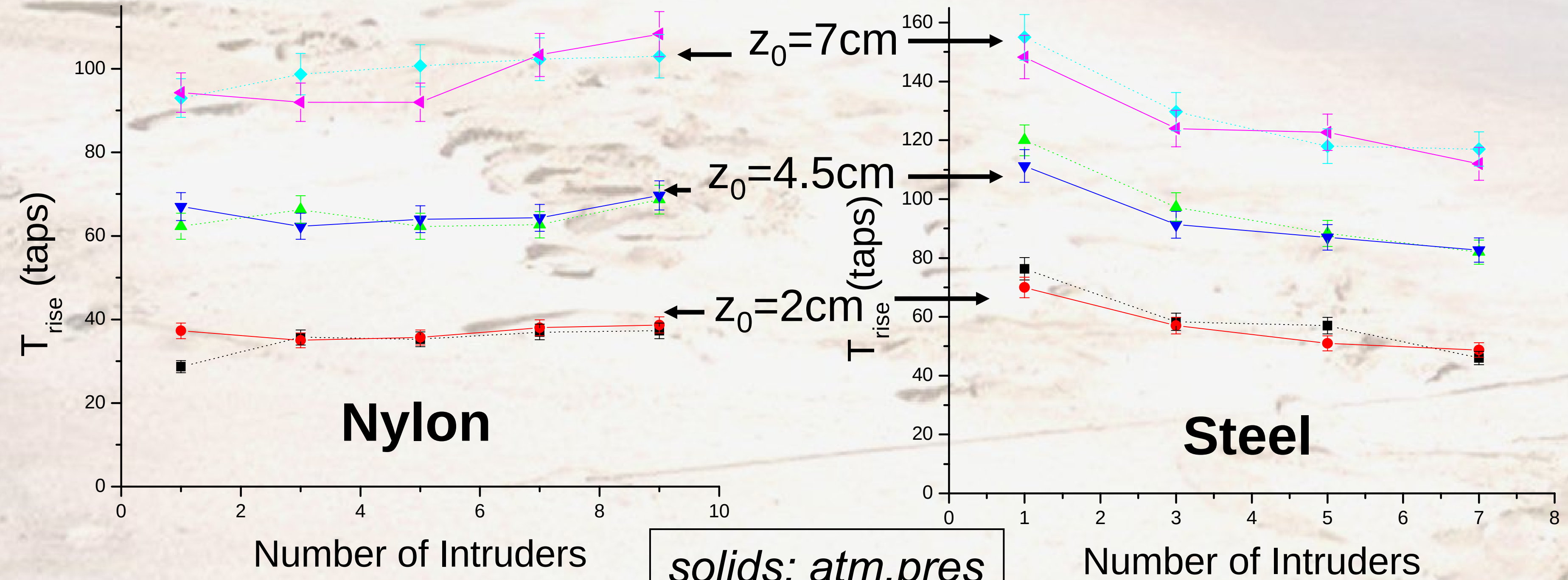
Results – Size (multi)

Default intruder configurations



- Nylon intruder configurations (on ρ/ρ_m peak) were more unstable than the steel ones, especially for 0.5mm glass beads
- Steel intruder configurations (far from ρ/ρ_m peak) were always surfacing in the configuration they were put in and they are regarded to act as a ‘compound’

Results – Size (multi, d=1mm)



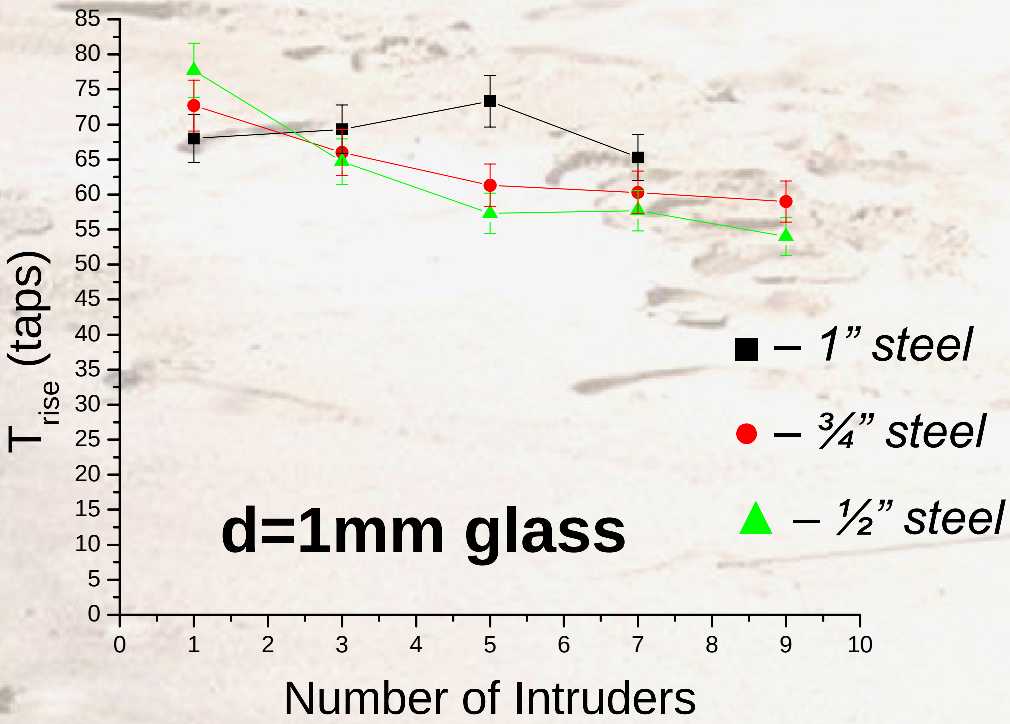
solids: atm.pres

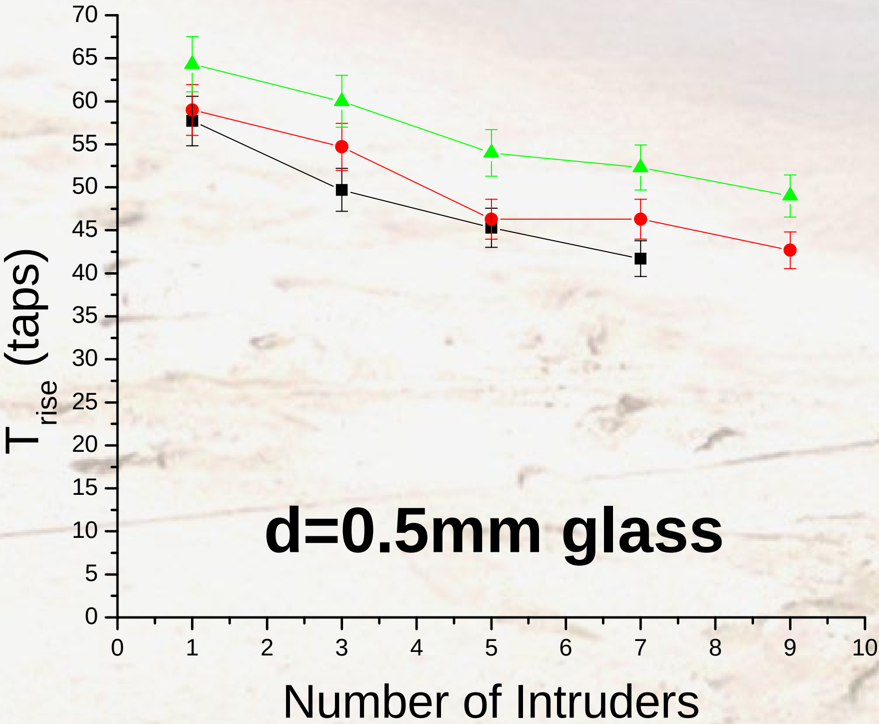
dotted: low.pres

0.053 kPa ← → 22.7 kPa

- Like in single size dependence graph: T_{rise} constant for nylon
- For steel intruders T_{rise} is decreasing if the size of the compound is increased (atmospheric and lower pressure)

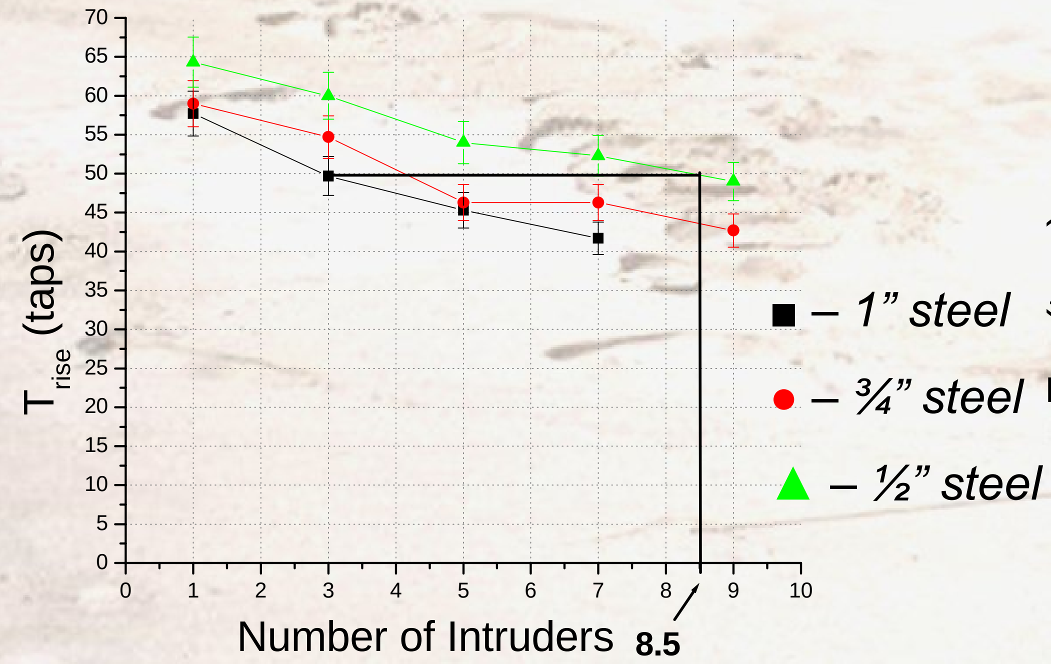
Results – Size (multi)

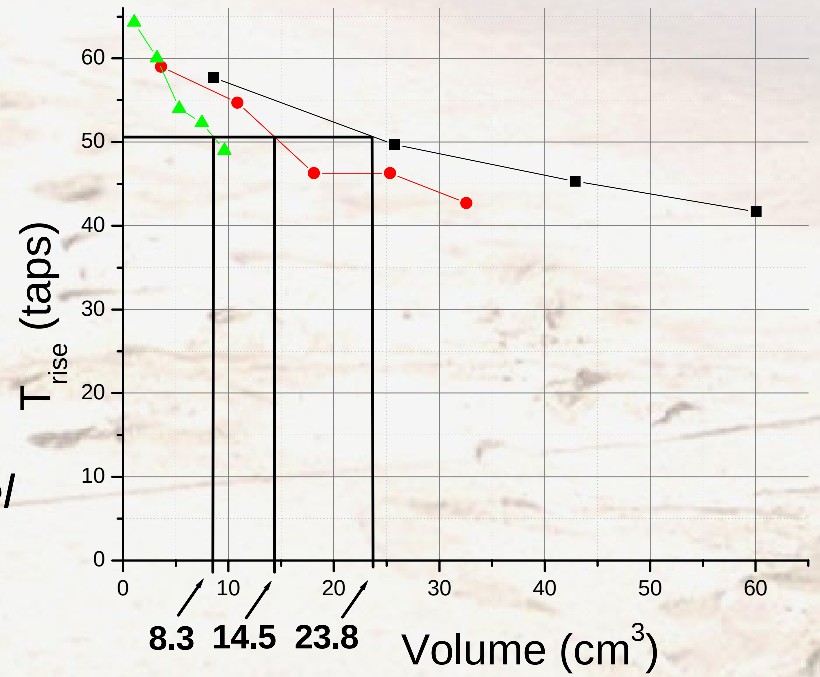




- In 1mm glass beads the ¾” and ½” steel intruders are rising faster for increasing #intruders (1” intruders constant)
- For all sizes of steel intruders used in 0.5mm glass beads, T_{rise} is decreasing for larger sizes of the compound

Results – Size (multi, d=0.5mm)

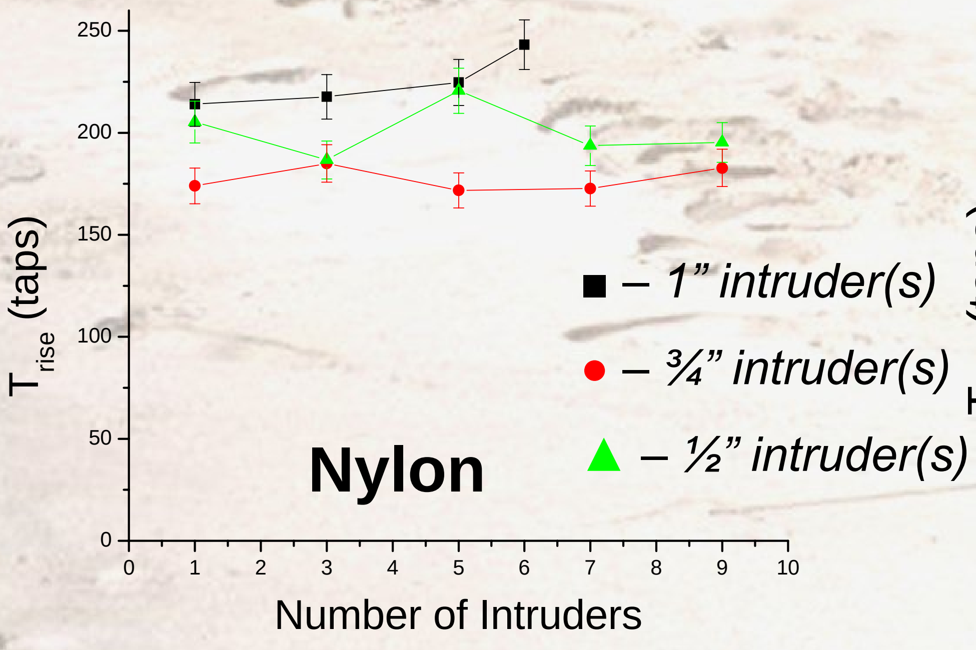


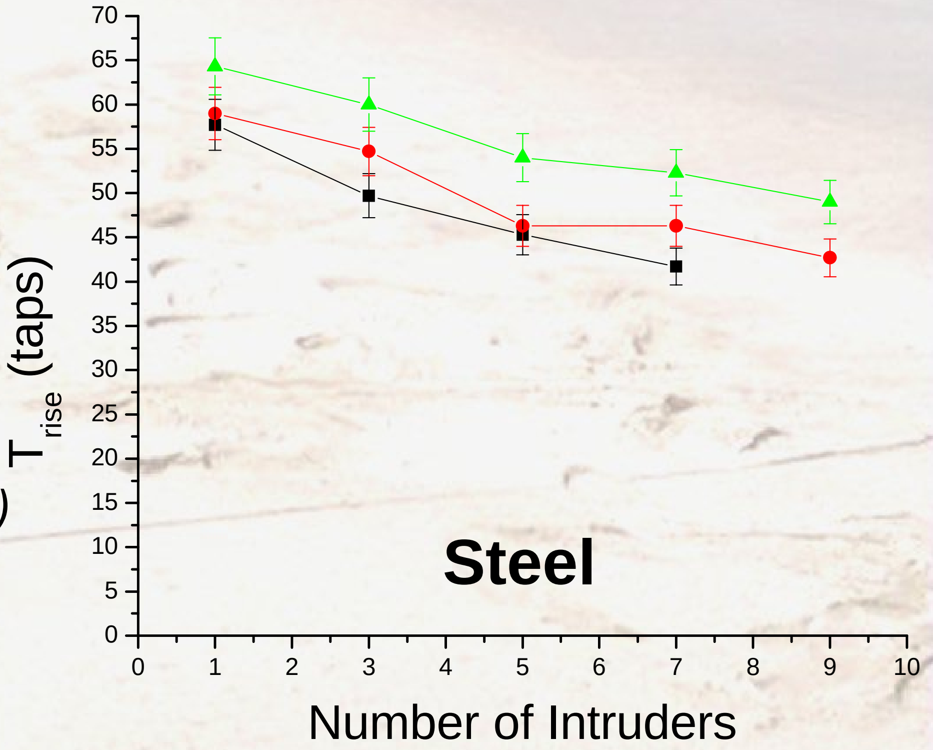


Effective diameter: To obtain same T_{rise} (rule of thumb):

1 1" intruder ~ 1.5 ¾" intruders ~ 3.1 ½" intruders

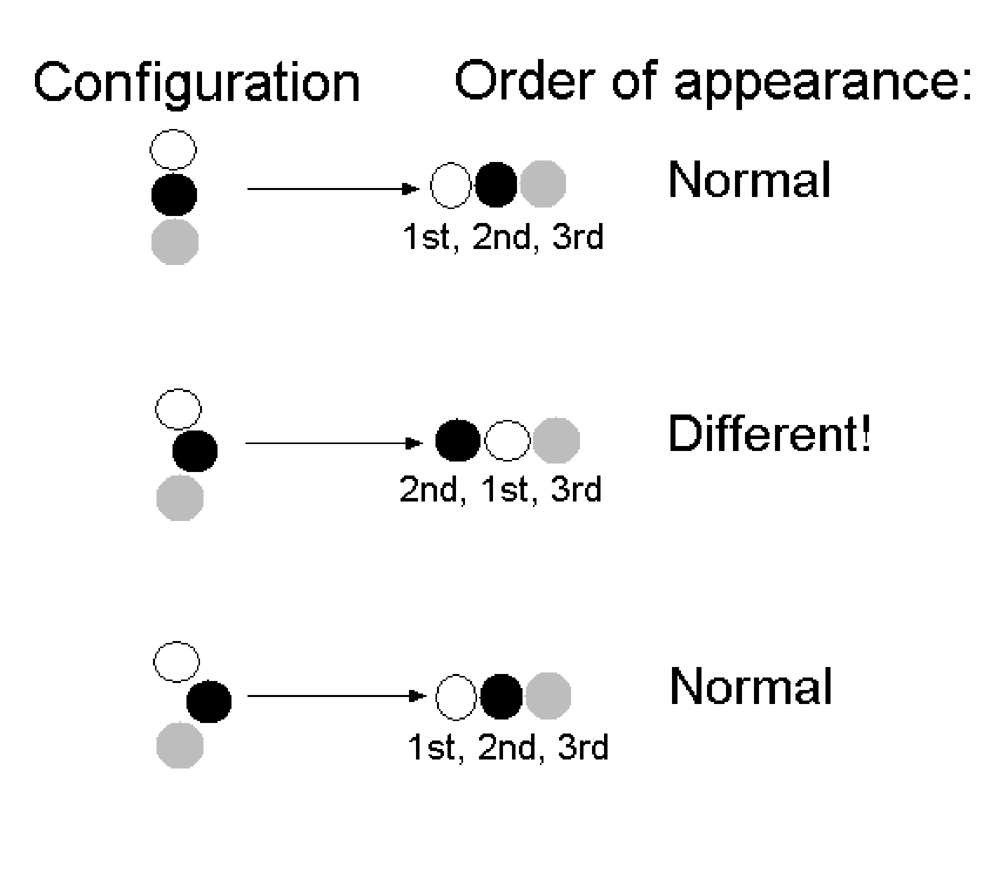
Results – Size (multi, d=0.5mm)





- Nylon configurations over 5 intruders can not be considered as a ‘compound’ anymore; some intruders stay behind
- T_{rise} approximately constant for nylon just as in single size dependence graph and for 1mm glass beads

Results - Miscellaneous



Placing three ¾” steel intruders vertical something interesting occurred: the 2nd intruder caught up with the 1st intruder! (1mm glass)

This phenomenon is very sensitive to the initial offset of the 2nd intruder: its center has to be ≈½radius from the axis of the cylinder

Conclusions & Discussion (1)

- Density dependence (ρ/ρ_m):
  - d=0.5mm glass: T_{rise} peak around $\rho/\rho_m \approx 0.5$ a factor 3 higher than $T_{asymptote}$
  - d=1mm glass: T_{rise} shows barely a peak around $\rho/\rho_m \approx 0.5$, just unstable. T_{rise} is considered to be slightly increasing

- Size dependence (D/d):
  - The single as well as multi intruder experiments (both glass bead sizes) show for intruders far from the density peak: a larger single intruder or a larger 'compound' configuration rises faster
  - Intruders (single & multi) near this peak rise at a constant speed if 1mm glass beads are used.

    In 0.5mm the single intruder rises slower if the diameter is increased, but the multi nylon experiment is highly unstable
  - Effective diameter: 'rule of thumb' relating 3 different sizes of steel intruders: 1 1" intruder ~ 1.5 ¾" intruders ~ 3.1 ½" intruders

Conclusions & Discussion (2)

- Miscellaneous:
  - Depth dependence: considered to be linear slowing down a bit in the upper layer
  - A different filling height does not seem to affect the result, but more data is required to check this more profoundly
  - Using different configurations for 3 intruders did not affect T_{rise} significantly in our experiment. This experiment needs to be performed with more than 3 intruders to be sure for all intruders
  - Three intruders vertical: 2nd intruder can catch up with 1st one if offset is ≈½radius. This result has to be treated with great cautiousness, because of the sensitivity of the system: various other experiments are needed to investigate it thoroughly

Recommendations

- 3D-Flow visualization using MRI; try to reveal the interactions happening inside the 3D-cylinder
- To improve the ‘rule of thumb’ considering the effective diameter more experiments have to be performed
- In general more data is needed to get more significant results regarding all granular material experiments

Acknowledgements

I wish to thank Heinrich, Sid and Matthias for supervising my project and Detlef for informing me about the internship available at the University of Chicago.

Furthermore I’d like to thank the rest of the Jaeger/Nagel-group for the helpful reflections during the weekly group meetings and for helping me out on other moments.

I want to address a special “thank you” to Brenda for conquering all my problems regarding my Social Security Number, flight tickets, payroll and many more…

Questions?