

Peanut Butter vs. Nut Effect

Smooth vs. Crunchy

Independent satirical technical note / Revised 9 October 2026 / Four-page main text

Abstract

We investigate mixing kinetics of bidisperse chocolate-coated ellipsoids in a rotating cubic vessel. A population of 300 larger prolate bodies and 600 smaller oblate bodies is modeled with the Jolt rigid-body engine in Godot. Axis, angular speed, nominal bulk fill, equivalent-volume size ratio, and rotation count are controlled. Height-stratified composition and a finite-population Lacey-style index provide complementary measures of coarse mixing. A 30,000-case design comprises 1,000 trajectories sampled at 30 rotation counts; checkpoints within a trajectory are correlated. The completed subset reported here is separated from the planned sweep. The model is described as plausibly granular, because its contact mechanics have not been calibrated to candy. Ten gentle flips remain a culinary heuristic rather than an established minimum.

1. Introduction

Larger, oblong peanut M&Ms; are placed beneath smaller, disc-like peanut butter candies. Similar assumed material densities (1.2-1.3 g/cm³) do not imply equal mass or transport. Granular matter supports distinct static and flowing regimes [1,2]; mixing competes with segregation [3,4]. Ellipsoid packing experiments even used proportions close to M&Ms; [5]. Shape-sensitive drum simulations and three-dimensional imaging of real nuts make orientation a credible concern [6,7]. None of these studies establishes a minimum flip count for this container.

The practical question is not merely whether motion occurs, but the first rotation count at which a specified observation scale is adequately mixed. We therefore define an operational endpoint before examining outcomes. Applications include equitable solitary Mars rations, Antarctic game-night logistics, and imagined rocket snack-balance certification. These motivating applications are satirical; no aerospace qualification is asserted.

2. Physical and numerical scope

The cube is a modeling choice for the specified square container. Full rotations are 360 degrees; an end-over-end flip is 180 degrees. The simulation uses continuous rotation in terrestrial gravity, not hand shaking, microgravity, or Mars gravity. Variable-gravity tumbler experiments caution against direct transfer to Mars [8]. Peanut and peanut-butter labels denote synthetic shape populations, not measured commercial specimens. The subjects are not affiliated with, endorsed by, or commissioned by the confectionery manufacturer.

3. Methods

Both species have material density 1,250 kg/m³. The oblate semiaxes are (0.030, 0.0135, 0.030) m. The prolate axes are proportional to (1.45, 0.90, 0.7662835), rescaled to the selected equivalent-volume radius ratio. These intentionally enlarged surrogate candies are not dimensional replicas. Mass is density times analytic ellipsoid volume; 42-vertex convex hulls approximate contact surfaces, so collision volume and analytic mass volume differ slightly.

The planned design contains 1,000 seeded trajectories, balanced approximately across three axes and five speeds (0.25, 0.5, 1.0, 1.5, 2.0 rev/s). Nominal bulk fill is sampled uniformly from 0.35 to 0.65; size ratio is sampled uniformly from 1.4 to 1.8. Every trajectory contributes checkpoints $N = 1, \dots, 30$, plus a baseline. Fill is converted to cube size using an assumed packing fraction of 0.55. Thus it is a control parameter, not a measurement of settled bed height or exact headspace.

World-space axes through the cube center are face (1,0,0), edge (1,0,1)/sqrt(2), and body diagonal (1,1,1)/sqrt(3). Gravity acts along negative y. The diagonal axis therefore also differs in inclination; this experiment does not isolate corner geometry from axis inclination. Bodies begin on non-overlapping, slightly jittered species-separated lattices, larger below smaller, and settle for two seconds. The baseline is recorded after settling, which can already partially mix the layers. The upper species does not occupy exactly one geometric third at every size ratio.

Godot/Jolt [9,10] runs at 240 physics steps/s, with friction 0.45, restitution 0.08, linear damping 0.02, angular damping 0.04, and continuous collision detection. Six thick moving box colliders seal the cube. Center overshoot beyond the nominal inner wall is logged; qualification requires overshoot no greater than 5% of the cube edge and no center outside the outer wall. This tolerance is a numerical limitation, not physical wall compliance. Checkpoints are taken one step after each completed turn, without pausing to settle.

4. Sampling and endpoint

Sort all 900 centers by world-space height and divide them into three equal-count samples of 300. Count the peanut fraction p_j in each. These are height-ranked thirds of the population, not fixed geometric thirds of the cube; they avoid empty headspace samples but can miss lateral segregation. The population fraction is $p = 1/3$. Let $S_2 = \text{mean}[(p_j - p)^2]$, $S_0 = p(1-p)$, and $S_r = p(1-p)(900-300)/(300(900-1))$. The reported Lacey-style index is $M = (S_0 - S_2)/(S_0 - S_r)$ [11]. Values just above one are retained, not clipped.

A checkpoint passes when $M \geq 0.95$ and every $|p_j - p| \leq 0.05$, subject to containment. N^* is the first of three consecutive passing checkpoints. An unobserved endpoint is right-censored at the 30-turn horizon. This practical equivalence tolerance is not a hypothesis-test declaration that the full three-dimensional distribution is statistically uniform.

5. Results: completed numerical subset

15 containment-valid completed trajectories provided 450 post-baseline rotation checkpoints. 4 trajectories met the three-checkpoint criterion. The earliest qualifying run was diagonal at 2 rev/s ($N^* = 5$); its nominal fill was 0.50 and size ratio 1.60. The slowest/least-mixed selected run was face at 1 rev/s ($N^* = >30$). These are descriptive rankings, not universal optima. The earliest passer later reached $M = 0.892$ at $N = 30$; early qualification did not guarantee permanent mixing.

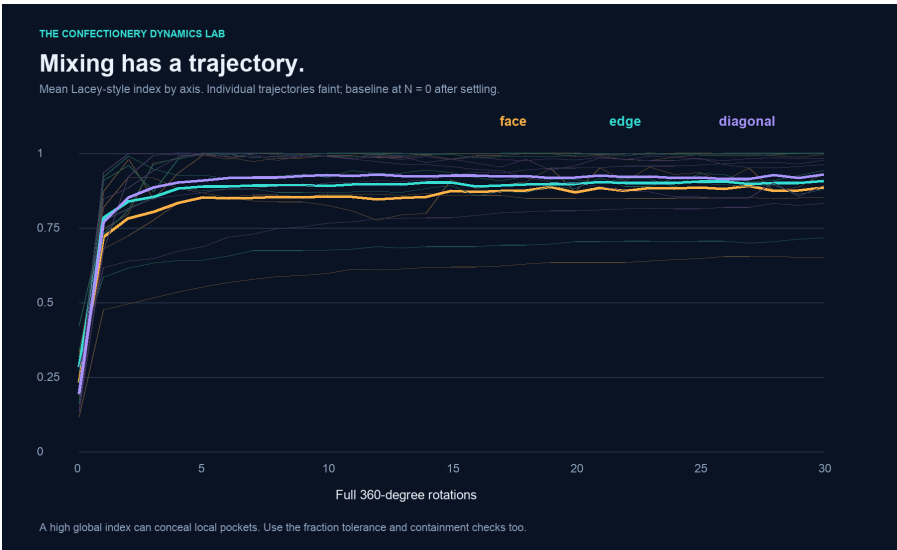


Figure 1. Measured Lacey-style index versus completed rotations. Faint lines show individual trajectories; brighter lines are axis means. Correlated checkpoints are not independent replicates. Baseline mixing reflects the two-second preparation stage.

The curve should be read as a competition between rearrangement and segregation, not as a mandatory exponential rise. Early improvement can be followed by small gains, reversals, or a persistent plateau. A plateau near random-mixing variance expresses diminishing returns at this sampling scale; it does not establish microscopic homogeneity. We do not fit a rate constant or force monotonicity merely to make the snack appear cooperative.



Figure 2. Axis/speed heatmap of first qualifying rotation count. Cells retain censored outcomes when computing the median; counts show qualifying/completed trajectories. The pilot fixes fill = 0.50 and size ratio = 1.60; the full sweep varies both. Blank cells are not imputed.

6. Discussion and limitations

Granular rearrangement can mix and segregate simultaneously [3,4]. Shaking studies identify size sorting, convection and sensitivity to air pressure [12,13,14]; reverse segregation also occurs under some conditions [15,16]. Our rotational protocol neither reproduces those experiments nor identifies a unique Brazil nut mechanism. The numerical winner reaching its endpoint at five turns and later losing uniformity is an observation about this pilot, not proof that vigorous hand shaking always un-mixes candy.

Noncircular tumblers and long-duration experiments show geometry-dependent segregation and evolving patterns [17,18]. Available headspace can alter free-surface rearrangement. However, nominal fill also changes vessel size here, and therefore changes the ratio of centrifugal to gravitational acceleration at fixed speed. Comparisons cannot cleanly isolate headspace from that dynamical change. A follow-up should hold cube size fixed, vary particle count, record actual settled bed height, and compare dimensionless speed ω^2 times characteristic radius divided by g [19].

A minimum for actual M&Ms; requires independent physical repetitions, measured size distributions and friction, multiple spatial sampling grids, uncertainty intervals, and convergence checks for timestep and collision shape. Modern reviews outline the additional constitutive and shape physics needed for predictive models [20,21]. The current three-band statistic cannot detect all lateral clusters or radial cores. Deterministic seeds improve traceability but do not guarantee bit-identical multithreaded physics across machines or engine versions. The enlarged candy scale prevents direct transfer of absolute rotation speeds to a kitchen jar.

The completed subset does not establish fill-level or size-ratio effects if those controls are fixed in the pilot. The 30,000-case manifest defines further work; generated configurations are not measured results. No missing run is replaced with an analytic mixing curve. Principal experimental limitation: subjects were eaten. More precisely, the physical tasting committee reports attrition; the simulated subjects remain available for replication.

7. Conclusion

No universal minimum rotation count is established. The reproducible outcome is a conditional first-passage count for a specified model, seed, and coarse sampling criterion. Ten gentle flips, equivalent to five complete rotations, are a deliberately memorable rule of thumb pending validation. An Ig Nobel nomination may proceed before launch-vehicle certification.

Declarations

Funding: Self-funded, snacks. **Competing interests:** The investigators prefer a fair handful. **Data and code:** Included Godot project, seeded manifest, JSONL/CSV outputs, analysis scripts, and recorded-motion film. **Status:** Unreviewed satirical technical note; numerical observations are labeled as such.

Supporting Methods S1-S6 give the mechanism map, sampling derivation, and validation plan. The bibliography cites 37 journal articles, one preprint, and two software sources; citations establish context, not institutional endorsement.

Supporting methods and research context

S1. What a tumbler changes

The most direct geometric precedent is Jain, Ottino and Lueptow's study of combined size and density segregation in noncircular tumblers [17]. It supports treating vessel geometry as an experimental control, but its material contrasts and quasi-two-dimensional geometry differ from our equal-density, three-dimensional cube. Experiments in spherical tumblers likewise make fill and composition relevant controls [22]. Wall roughness can change the segregation pattern [23]; the current sweep holds its nominal friction setting fixed and does not resolve candy-shell texture.

Tilted-cylinder experiments document changing band behavior along a vessel, including slurry conditions [24]. That is a reason to report inclination, not a direct dry-cube prediction. Our face and edge axes are horizontal, while the body diagonal is inclined. Their comparison combines geometry and orientation relative to gravity. Surface-velocity measurements across three-dimensional tumblers provide additional support for reporting vessel dimensions, flowing-layer geometry and dimensionless speed together [19].

Recent work proposes an interface-mixing-driven instability for axial band formation in long tumblers [25,26]. Locally mixed material can pack more densely than separated regions even when the grains have equal material density. This distinction between material density and bulk packing density is central to the snack question. We have not measured the required density fields or identified such an instability in our cube; invoking the mechanism here is a hypothesis for follow-up, not a diagnosis.

S2. Mixing and segregation can coexist

Savage and Lun formulate size-selective void filling and squeeze expulsion in inclined chute flow [27]. Gray and Chugunov explicitly include competing segregation and diffusive remixing [28]. Extensions address size plus density contrast and distributions of grain sizes [29,30]. These models justify asking which transport processes balance; they are not equations implemented by this rigid-body simulation.

Shear-induced segregation exhibits changes of behavior with flow conditions [31]. Confined-flow simulations show that increasing overburden pressure can weaken segregation relative to collisional diffusion [32]. A recent closure predicts segregation velocity across several flow geometries [33]. These are relevant comparisons for future quantitative modeling. Their calibrated regimes cannot be assumed to include our oblate/prolate, rapidly rotating cube.

Overview treatments distinguish granular flow regimes and emphasize constitutive limitations [34,35]. Consequently, a single exponential mixing curve is not imposed on the pilot. Apparent diminishing returns, persistent cores, or reversals must remain visible. A concentration statistic alone cannot distinguish shear diffusion, convection, kinetic sieving and geometric trapping.

S3. Shape, contact and numerical validation

Ellipsoid packing and observed nut reorientation motivate shape-resolved colliders [5,7]. Particle-scale anisotropy also connects with bulk stress and friction in sheared grains [36]; this is broader evidence for contact structure, not evidence that peanut butter candies obey that experiment. Photoelastic methods can quantify contact forces in suitable transparent surrogate grains [37]. Ordinary candy shells are not assumed photoelastic.

The discrete element tradition follows individual contacts and particle motion [38]; its experimental validation is not inherited merely by using a game engine. Godot/Jolt provide the implemented rigid-body solver and collision machinery [9,10]. Work on velocity-Verlet contact integration illustrates that numerical choices can affect granular predictions [39]. We do not claim Jolt uses that integrator or that this paper validates Jolt for granular research.

Before physical interpretation, rerun matched seeds at finer timesteps, increase hull resolution, vary friction and restitution, tighten the containment tolerance, and compare repose angles and single-candy impact tests with measurements. Record engine build and settings. These are proposed validation studies; the completed pilot supplies no convergence result. Use trajectory-level repetitions for uncertainty, since the thirty observations from each trajectory share one evolving state.

S4. Sampling derivation and limitations

Lacey's normalization compares observed concentration variance with segregated and random limits [11]; alternative segregation indices highlight the dependence on how mixture quality is defined [40]. Our count-based adaptation weights all candies equally despite unequal volume. For a random assignment of $K = 300$ peanut labels among $T = 900$ fixed positions, the peanut count X in a band of $n = 300$ positions is hypergeometric. Thus $\text{Var}(X/n) = p(1-p)(T-n)/(n(T-1))$, with $p = K/T$. This gives S_r ; linearity of expectation gives $E[S_2] = S_r$ even though the three band fractions are dependent. This derivation is our finite-population adaptation, not an equation attributed verbatim to Lacey.

$S_o = p(1-p)$ is attained when these three equal-count bands consist of one all-peanut band and two all-peanut-butter bands. Therefore $M = 1$ represents the random-label expected variance, not a ceiling. The tolerance test measures only coarse vertical composition. Later analysis should add fixed-volume three-dimensional bins and nearest-neighbor species statistics. The observed checkpoint sequence alone cannot establish statistical uniformity at every spatial scale.

S5. Endpoint and reporting plan

N^* is the first start of three passing observations, so its latest confirmable value is 28 in a 30-turn record. The displayed label >30 means no confirmed endpoint within the observation window, not proof that a candidate at 29 or 30 fails. Exclude an entire trajectory from aggregate curves if any checkpoint has severe containment failure. Report excluded counts, passing fractions and censored outcomes. The full 1,000-trajectory manifest is a planned experiment; this document reports only the completed pilot.

S6. Scope of the bibliography

References were selected for a specific mechanism, method, measurement or software dependency. Publisher-deposited metadata and primary source pages were checked on 9 October 2026. Journal articles, the Piacenza preprint and software documentation are labeled separately. No cited institution or researcher reviewed, sponsored or endorsed this note. Researcher links and citation-to-claim notes are provided in reference-guide.html.

References

- [1] Heinrich M. Jaeger, Sidney R. Nagel, Robert P. Behringer. Granular solids, liquids, and gases. *Reviews of Modern Physics* 68 1259-1273 (1996). [10.1103/revmodphys.68.1259](#)
- [2] P. G. de Gennes. Granular matter: a tentative view. *Reviews of Modern Physics* 71 S374-S382 (1999). [10.1103/revmodphys.71.s374](#)
- [3] J. M. Ottino, D. V. Khakhar. Mixing and Segregation of Granular Materials. *Annual Review of Fluid Mechanics* 32 55-91 (2000). [10.1146/annurev.fluid.32.1.55](#)
- [4] John Mark Nicholas Timm Gray. Particle Segregation in Dense Granular Flows. *Annual Review of Fluid Mechanics* 50 407-433 (2018). [10.1146/annurev-fluid-122316-045201](#)
- [5] Aleksandar Donev, Ibrahim Cisse, David Sachs, Evan A. Variano, Frank H. Stillinger, Robert Connelly, Salvatore Torquato, P. M. Chaikin. Improving the Density of Jammed Disordered Packings Using Ellipsoids. *Science* 303 990-993 (2004). [10.1126/science.1093010](#)
- [6] Claudia Piacenza, Marco Marconati, Colin Hare, Andrea C. Santomaso, Marco Ramaioli. Mixing Grains with Different Elongation in a Rotating Drums. *arXiv preprint 1809.00153* (2018). <https://arxiv.org/abs/1809.00153>
- [7] Parmesh Gajjar, Chris G. Johnson, James Carr, Kevin Chrispeels, J. M. N. T. Gray, Philip J. Withers. Size segregation of irregular granular materials captured by time-resolved 3D imaging. *Scientific Reports* 11 8352 (2021). [10.1038/s41598-021-87280-1](#)
- [8] Antje Brucks, Tim Arndt, Julio M. Ottino, Richard M. Lueptow. Behavior of flowing granular materials under variable g. *Physical Review E* 75 032301 (2007). [10.1103/physreve.75.032301](#)
- [9] Godot Engine contributors. Using Jolt Physics. Godot Engine 4.7 documentation (2026). https://docs.godotengine.org/en/4.7/tutorials/physics/using_jolt_physics.html
- [10] Jorrit Rouwe and contributors. Jolt Physics. Software source repository (2026). <https://github.com/jrouwe/JoltPhysics>
- [11] P. M. C. Lacey. Developments in the theory of particle mixing. *Journal of Applied Chemistry* 4 257-268 (1954). [10.1002/jctb.5010040504](#)
- [12] Anthony Rosato, Katherine J. Strandburg, Friedrich Prinz, Robert H. Swendsen. Why the Brazil nuts are on top: Size segregation of particulate matter by shaking. *Physical Review Letters* 58 1038-1040 (1987). [10.1103/physrevlett.58.1038](#)
- [13] James B. Knight, H. M. Jaeger, Sidney R. Nagel. Vibration-induced size separation in granular media: The convection connection. *Physical Review Letters* 70 3728-3731 (1993). [10.1103/physrevlett.70.3728](#)
- [14] Matthias E. Möbius, Benjamin E. Lauderdale, Sidney R. Nagel, Heinrich M. Jaeger. Size separation of granular particles. *Nature* 414 270-270 (2001). [10.1038/35104697](#)

References / continued

- [15] Daniel C. Hong, Paul V. Quinn, Stefan Luding. Reverse Brazil Nut Problem: Competition between Percolation and Condensation. *Physical Review Letters* 86 3423-3426 (2001). [10.1103/physrevlett.86.3423](#)
- [16] Troy Shinbrot, Fernando J. Muzzio. Reverse Buoyancy in Shaken Granular Beds. *Physical Review Letters* 81 4365-4368 (1998). [10.1103/physrevlett.81.4365](#)
- [17] Nitin Jain, Julio M. Ottino, Richard M. Lueptow. Combined size and density segregation and mixing in noncircular tumblers. *Physical Review E* 71 051301 (2005). [10.1103/physreve.71.051301](#)
- [18] Steven W. Meier, Diego A. Melani Barreiro, Julio M. Ottino, Richard M. Lueptow. Coarsening of granular segregation patterns in quasi-two-dimensional tumblers. *Nature Physics* 4 244-248 (2008). [10.1038/nphys881](#)
- [19] NICHOLAS A. POHLMAN, STEVEN W. MEIER, RICHARD M. LUEPTOW, JULIO M. OTTINO. Surface velocity in three-dimensional granular tumblers. *Journal of Fluid Mechanics* 560 355-368 (2006). [10.1017/S0022112006000437](#)
- [20] Ken Kamrin, Kimberly M. Hill, Daniel I. Goldman, Jose E. Andrade. Advances in Modeling Dense Granular Media. *Annual Review of Fluid Mechanics* 56 215-240 (2024). [10.1146/annurev-fluid-121021-022045](#)
- [21] Anthony R. Thornton, Kimberly Hill, Lu Jing, Benjy Marks, Deepak R. Tunuguntla. Modeling Granular Segregation: Insights from Four Decades of Research. *Annual Review of Condensed Matter Physics* 17 369-393 (2026). [10.1146/annurev-conmatphys-031424-125004](#)
- [22] Tilo Finger, Florian von Rüling, Sára Lévy, Bence Szabó, Tamás Börzsönyi, Ralf Stannarius. Segregation of granular mixtures in a spherical tumbler. *Physical Review E* 93 032903 (2016). [10.1103/physreve.93.032903](#)
- [23] Umberto D'Ortona, Nathalie Thomas, Richard M. Lueptow. Influence of rough and smooth walls on macroscale granular segregation patterns. *Physical Review E* 93 022906 (2016). [10.1103/physreve.93.022906](#)
- [24] Tim Arndt, Tanja Siegmann-Hegerfeld, Stanley J. Fiedor, Julio M. Ottino, Richard M. Lueptow. Dynamics of granular band formation: Long-term behavior in slurries, parameter space, and tilted cylinders. *Physical Review E* 71 011306 (2005). [10.1103/physreve.71.011306](#)
- [25] Umberto D'Ortona, Richard M. Lueptow, Nathalie Thomas. Origin of granular axial segregation bands in a rotating tumbler: An interface-mixing driven Rayleigh-Taylor instability. *Physical Review Research* 6 L032038 (2024). [10.1103/physrevresearch.6.l032038](#)
- [26] Umberto D'Ortona, Richard M. Lueptow, Nathalie Thomas. Mechanisms leading to axial segregation of bidisperse particles in rotating tumblers. *Physical Review E* 114 035402 (2026). [10.1103/d6jy-d5h7](#)
- [27] S. B. Savage, C. K. K. Lun. Particle size segregation in inclined chute flow of dry cohesionless granular solids. *Journal of Fluid Mechanics* 189 311-335 (1988). [10.1017/S002211208800103x](#)
- [28] J. M. N. T. GRAY, V. A. CHUGUNOV. Particle-size segregation and diffusive remixing in shallow granular avalanches. *Journal of Fluid Mechanics* 569 365-398 (2006). [10.1017/S0022112006002977](#)

References / continued

- [29] D. R. Tunuguntla, O. Bokhove, A. R. Thornton. A mixture theory for size and density segregation in shallow granular free-surface flows. *Journal of Fluid Mechanics* 749 99-112 (2014). [10.1017/jfm.2014.223](#)
- [30] Benjy Marks, Pierre Rognon, Itai Einav. Grainsize dynamics of polydisperse granular segregation down inclined planes. *Journal of Fluid Mechanics* 690 499-511 (2012). [10.1017/jfm.2011.454](#)
- [31] Yi Fan, K. M. Hill. Phase Transitions in Shear-Induced Segregation of Granular Materials. *Physical Review Letters* 106 218301 (2011). [10.1103/physrevlett.106.218301](#)
- [32] Alexander M. Fry, Paul B. Umbanhowar, Julio M. Ottino, Richard M. Lueptow. Diffusion, mixing, and segregation in confined granular flows. *AIChE Journal* 65 875-881 (2019). [10.1002/aic.16494](#)
- [33] Yifei Duan, Lu Jing, Paul B. Umbanhowar, Julio M. Ottino, Richard M. Lueptow. Granular segregation across flow geometries: a closure model for the particle segregation velocity. *Journal of Fluid Mechanics* 1016 A2 (2025). [10.1017/jfm.2025.10360](#)
- [34] Charles S. Campbell. Granular material flows - An overview. *Powder Technology* 162 208-229 (2006). [10.1016/j.powtec.2005.12.008](#)
- [35] Yoël Forterre, Olivier Pouliquen. Flows of Dense Granular Media. *Annual Review of Fluid Mechanics* 40 1-24 (2008). [10.1146/annurev.fluid.40.111406.102142](#)
- [36] Carmen L. Lee, Ephraim Bililign, Emilien Azéma, Karen E. Daniels. Particle Scale Anisotropy Controls Bulk Properties in Sheared Granular Materials. *Physical Review Letters* 135 108201 (2025). [10.1103/gp8t-v82n](#)
- [37] Karen E. Daniels, Jonathan E. Kollmer, James G. Puckett. Photoelastic force measurements in granular materials. *Review of Scientific Instruments* 88 051808 (2017). [10.1063/1.4983049](#)
- [38] P. A. Cundall, O. D. L. Strack. A discrete numerical model for granular assemblies. *Géotechnique* 29 47-65 (1979). [10.1680/geot.1979.29.1.47](#)
- [39] Dhairya R. Vyas, Julio M. Ottino, Richard M. Lueptow, Paul B. Umbanhowar. Improved velocity-Verlet algorithm for the discrete element method. *Computer Physics Communications* 310 109524 (2025). [10.1016/j.cpc.2025.109524](#)
- [40] Bei-Bing Dai, Jun Yang, Feng-Tao Liu, Xiao-Qiang Gu, Kai-Rong Lin. A new index to characterize the segregation of binary mixture. *Powder Technology* 363 611-620 (2020). [10.1016/j.powtec.2020.01.005](#)