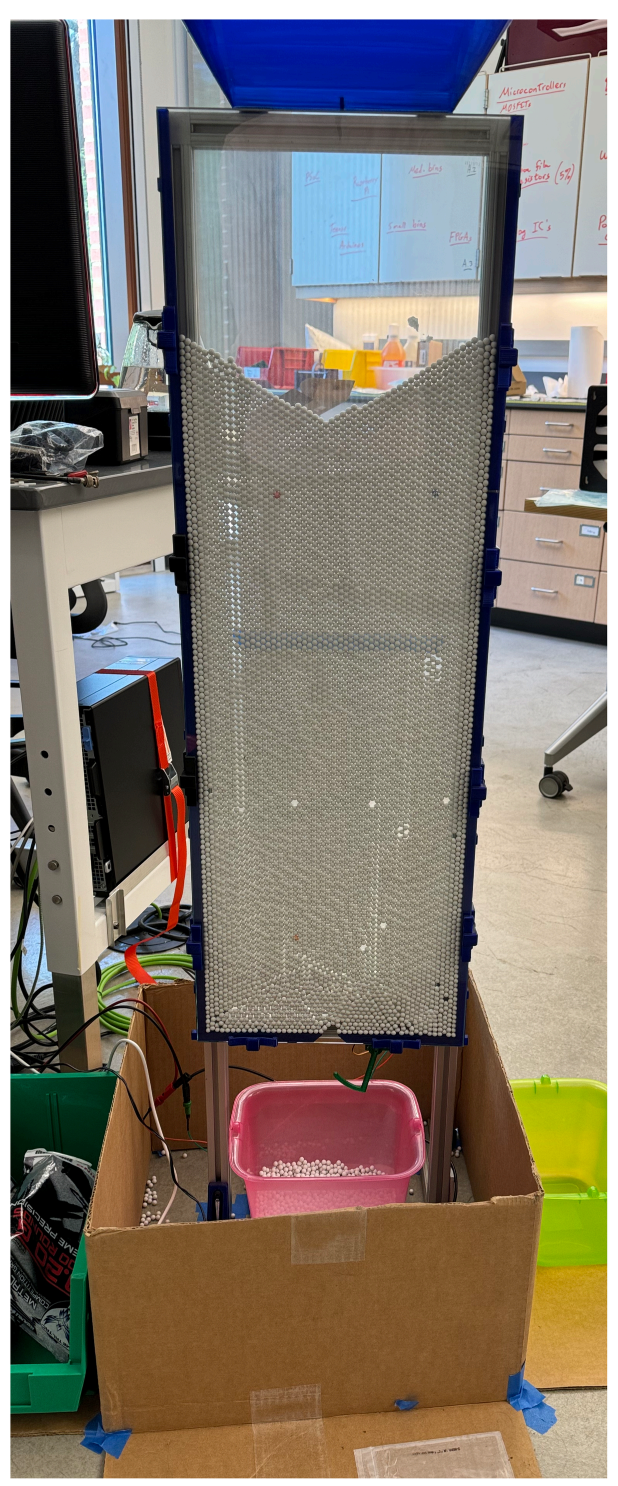
Stochastic Jamming when Particles Flow through Small Openings

Silvia Herzenach and Eric Ayars, Department of Physics, California State University Chico

The dynamics of particle flow through small apertures is poorly understood. When particles flow through openings, even openings larger than the particle size by orders of magnitude, jams occur.

Our investigation addressed jam frequency and flow volume between jams, in hopes of gaining a better understanding of what, if anything, leads to jam occurrences and how one might predict and/or prevent jams from occurring.

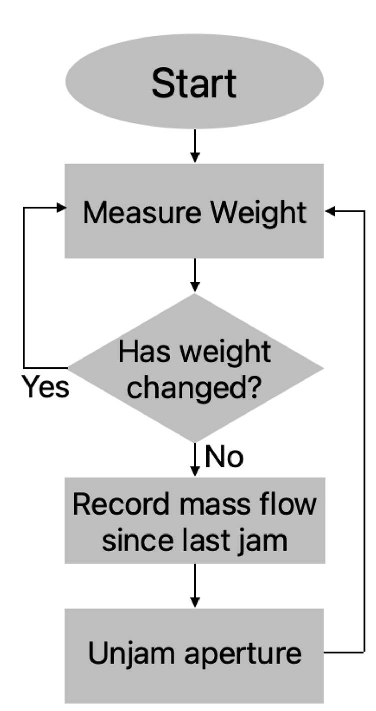
We found that the distribution of flow volumes between individual jamming events followed an exponential distribution. This distribution indicates that there is no 'history' factor in the jamming behavior: the probability of a jam occurring in any time interval is independent of the amount of flow since the last jam.



We built an apparatus that allows easy investigation of two-dimensional particle flow. We used Airsoft pellets for our particles, since they are very uniform in mass and size and are available in bulk for minimal cost. 3D printed spacers and clips hold two tempered-glass panels in place with room for free flow of a single layer of Airsoft pellets between them. We also 3D printed an adjustable aperture at the bottom and a loading bin at the top.

Pellets flowing through the aperture were collected in a hopper on top of a digital mass balance which was interfaced to a computer. The computer could also control a servomotor that operated an 'unjammer': a 3D printed finger that poked though the aperture to restart the flow of pellets after a jam event.

The experiment was controlled by a simple Python program that recorded the mass of pellets that flowed between individual jams. If the program saw no mass change for two iterations, it would consider the aperture jammed. It would record the size of the flow and then unjam the aperture to continue. We would occasionally pause the program to empty the lower hopper into the upper hopper, but other than that the data-collection process was a good time to work on homework! After recording the masses of approximately 8,000 flows, we created histograms of flow size to see what we could learn about the statistics of jamming.



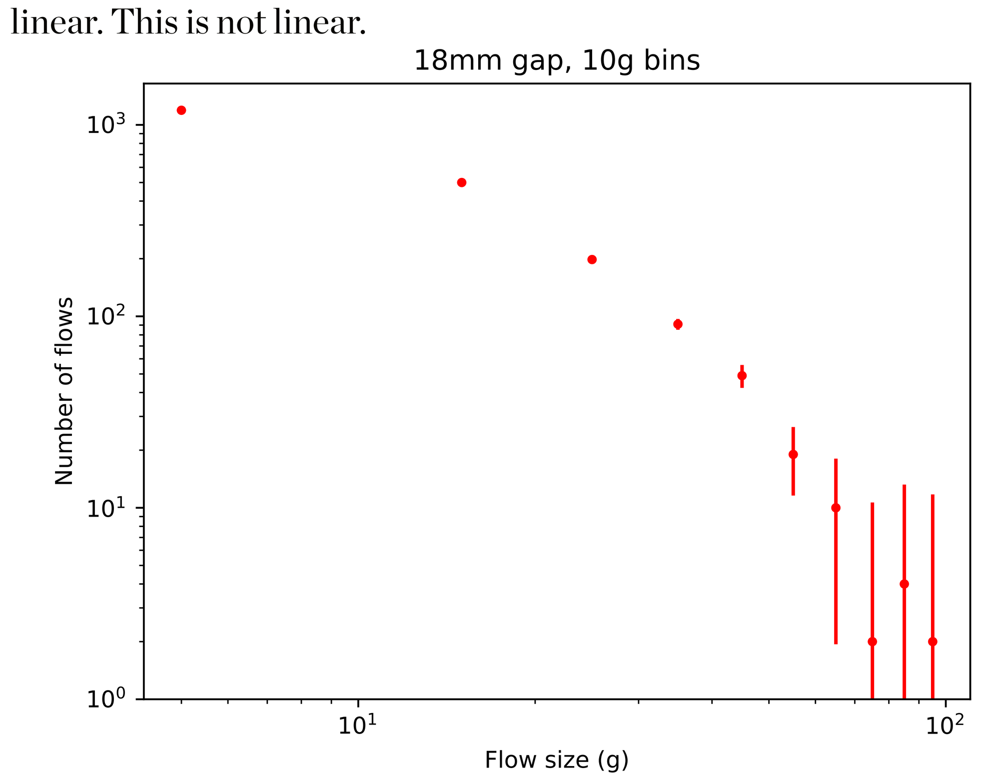
This research was sponsored by an experiment development grant from the Jonathan Reichert Foundation

Our initial hypothesis was that the size of flows between jams would follow a power law: the number of flows in a given size range would be some negative power of the size range.

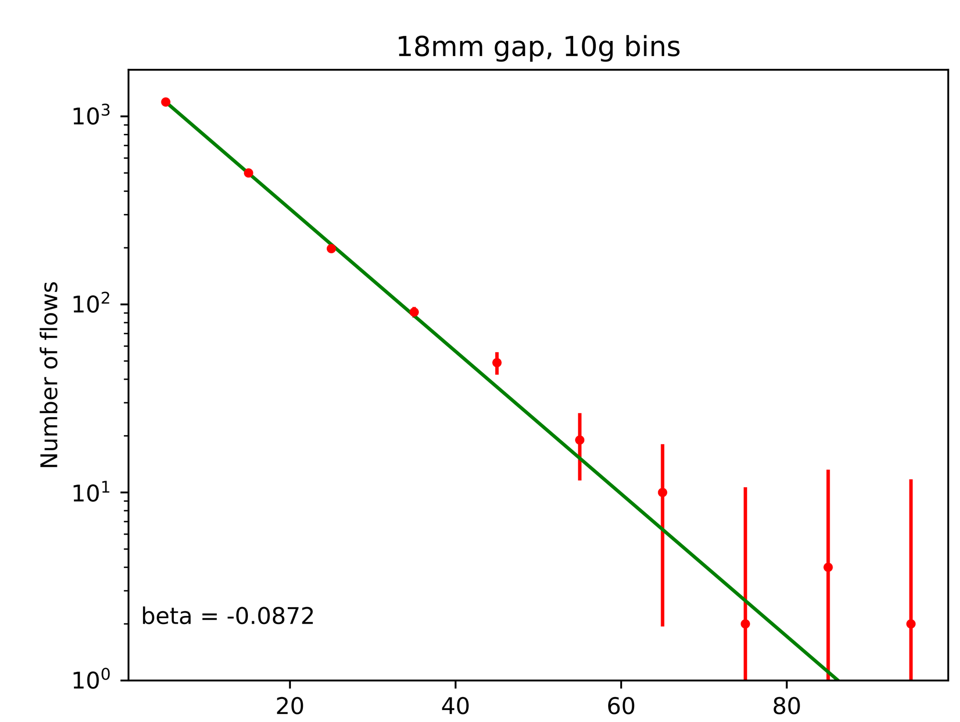
$$\eta(x) = Ax^{-\alpha}$$

This was a reasonable hypothesis: power-law behavior is common in a broad range of natural phenomena such as earthquake size, river lengths, frequency distribution in naturally-occurring noise sources, and so many more. As with many reasonable hypotheses, it was also *wrong*.

Since few if any of the recorded flow masses were identical, we analyzed the data by binning it into ranges, then counting the number of flows in each bin range. The graph below shows a log-log plot of this binned data for an 18mm aperture. A log-log graph of power-curve data should be linear. This is not linear.



If we plot the data on a semi-log plot, as shown below, the graph becomes linear.



This linearity indicates that the actual equation for flow size distribution is exponential:

$$\eta(x) = Ae^{-\beta x}$$

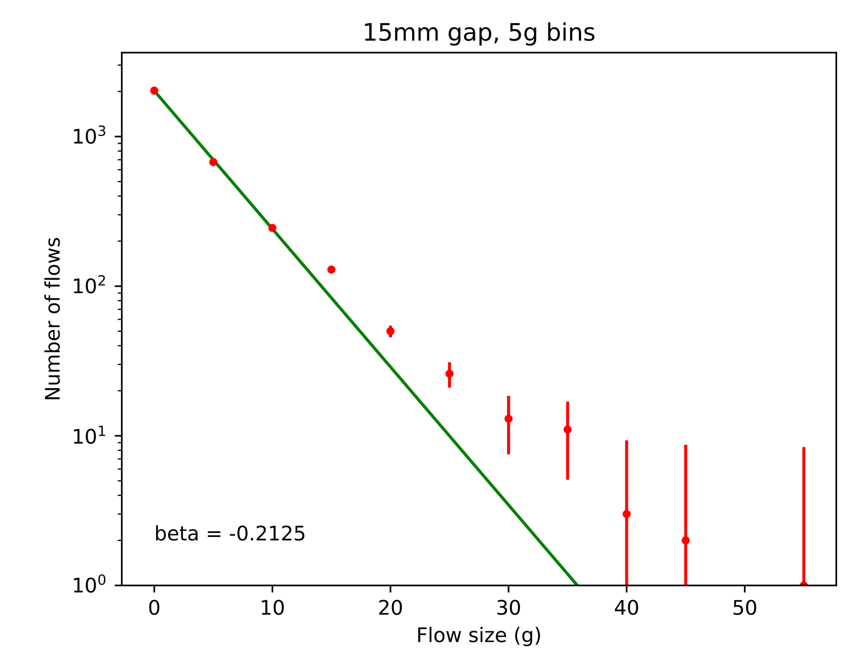
What does it mean for the between-jam particle-flow volume distribution to be exponential? It means that the probability of a jam occurring is independent of the flow history. In other words, for any flow interval dV, the probability of a jam occurring during that flow interval is constant *regardless of how much flow has occurred since the last jam.*

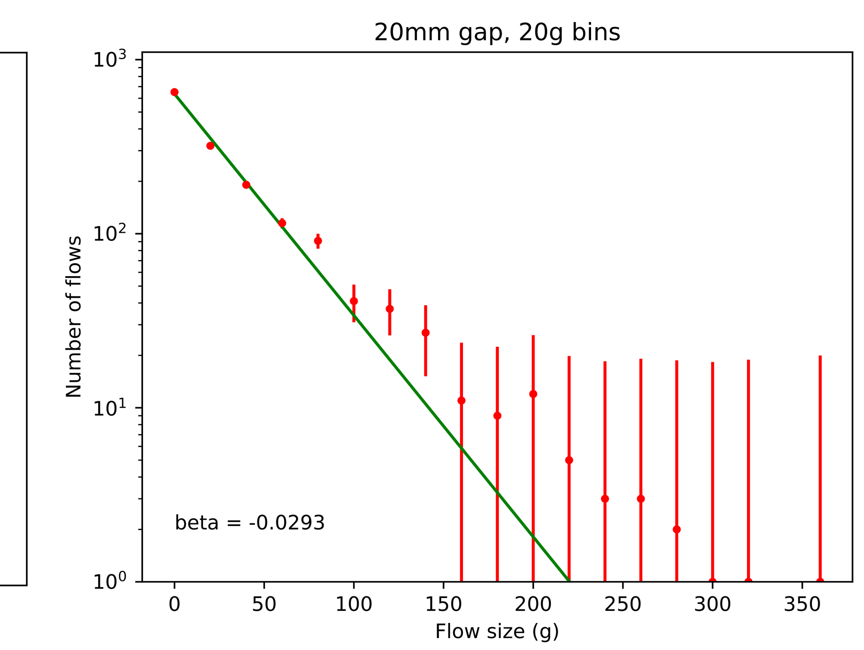
$$\frac{d}{dV}\mathcal{P}(V) = 0$$

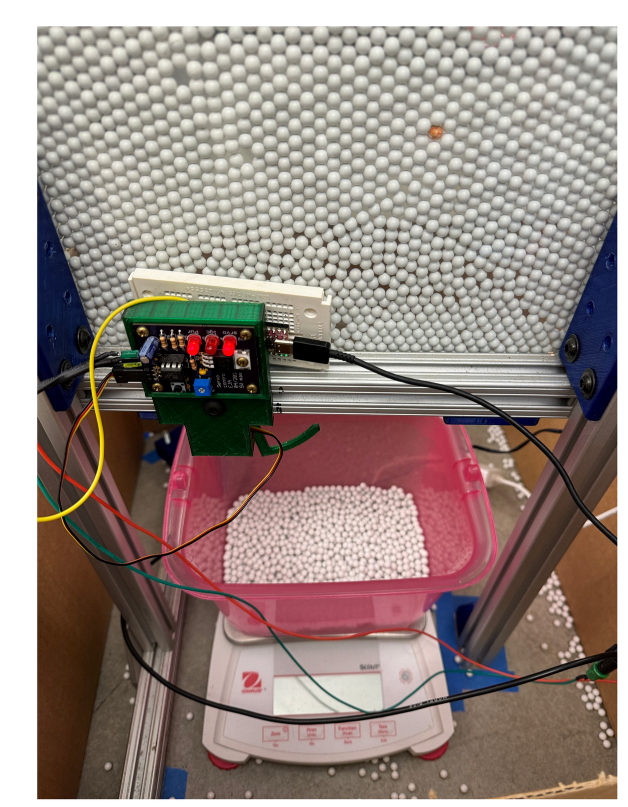
The 'decay constant' β in the equation

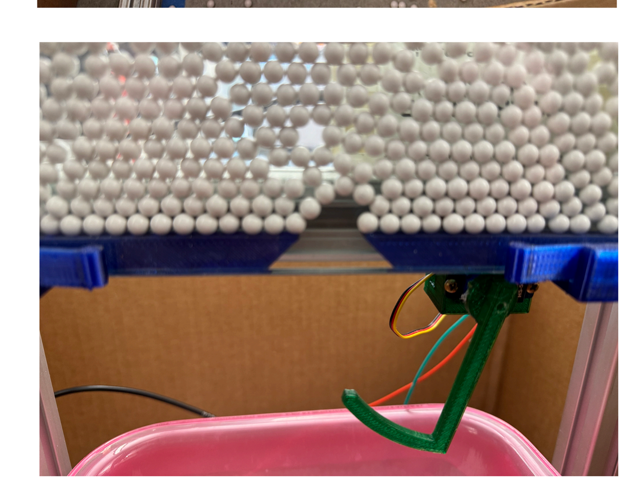
$$\eta(x) = Ae^{-\beta x}$$

depends on the size of the aperture. Larger (smaller) apertures result in smaller (larger) values of β, meaning jams occur more frequently with smaller apertures as expected.









Why is this research important?

1) Many industrial and agricultural processes involve flow of particles through small apertures. Rice into silos, almonds into roasters, polyester beads into injection molding equipment... it all involves the flow of similarly-sized particles through an opening that is much larger than the particle size.

2) Jams happen. These jams can cause processing delays and safety hazards. It would be ideal to have a better understanding of how and why the jams occur, to better prevent them.

3) The constant jam probability means that prediction of jam occurrences is not going to work.