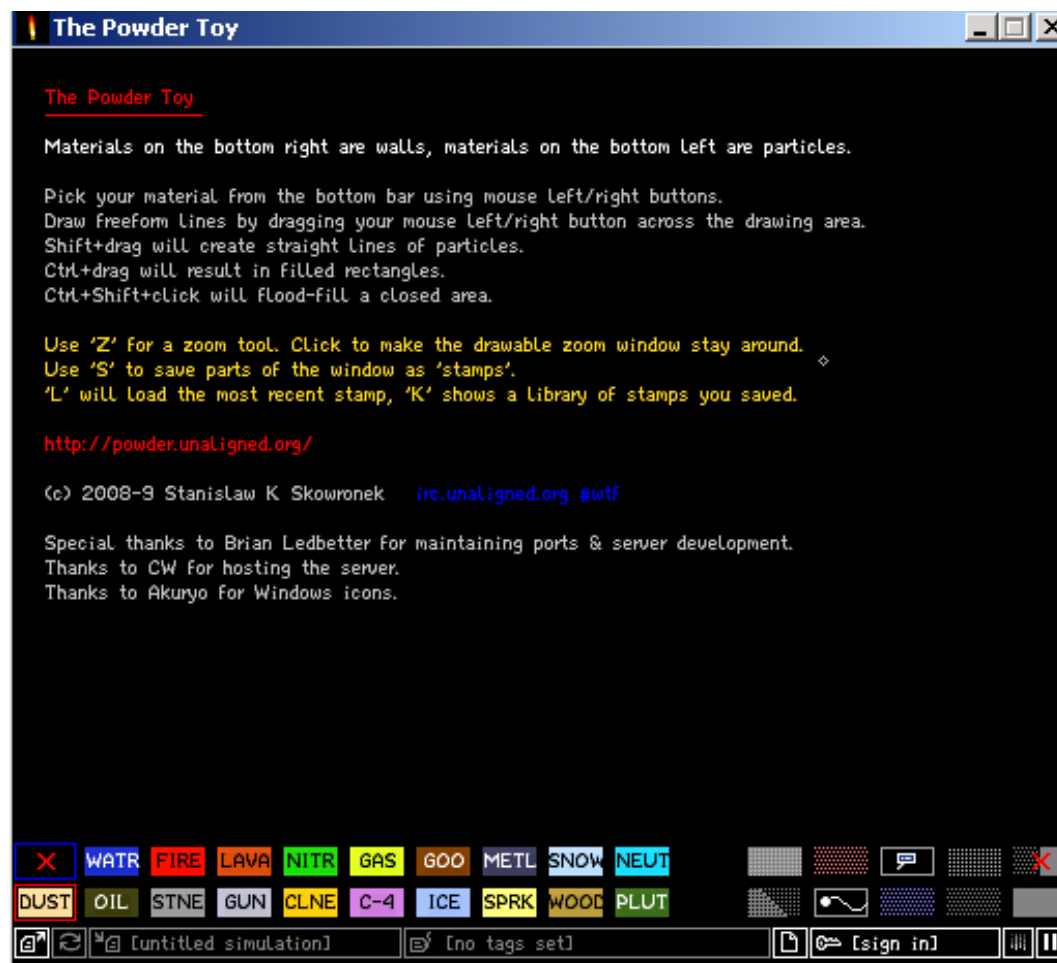


The Powder Toy: 2-Dimensional Gas Dynamics

The Powder Toy is a fascinating mini web application, ostensibly a game but one that provides the most accessible hands-on experience in fluid mechanics of all CFD programs I have reviewed. It has been superseded by a better version which you can find online, but this tutorial relates to the earlier version provided free on this site.

Unzip the program into a folder and run the application, powder.exe.

The controls are simple, the start-up screen tells you most of what you need to know:



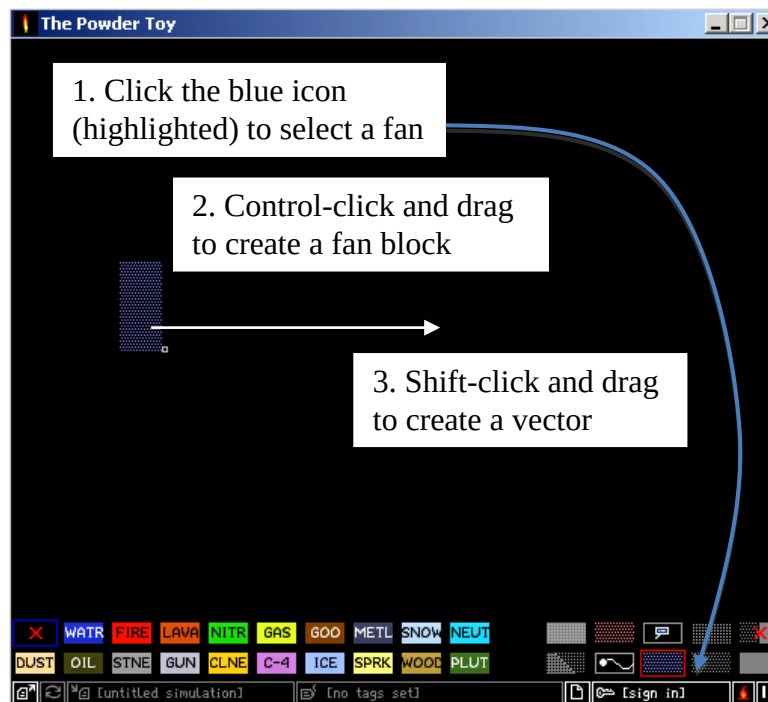
Click anywhere in the screen to clear the help messages and start the simulation.

The Powder Toy is most effective as a non-uniform, unsteady, compressible (gas) simulation. Flow models can be internal or external and with either frictional or frictionless boundaries for modelling of viscous (real) or inviscid (ideal) flows. The effects of heat and shock waves, with a range of combustible and explosive particles, are also accurately modeled.

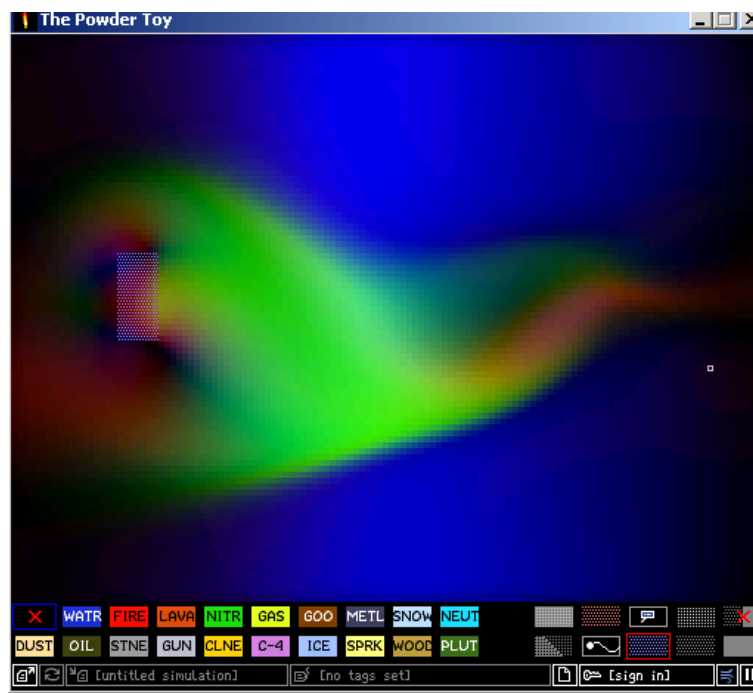
The software can model liquid flows, but the particle model is very simple and is not formally accurate.

Start by placing a fan on the screen. Click the blue block icon, middle bottom of the right hand group of “walls” (boundary conditions). Use the control key and mouse to

drag out a block-shaped fan on screen. Then shift-click the fan and drag a vector indicating the direction and speed of the fan:



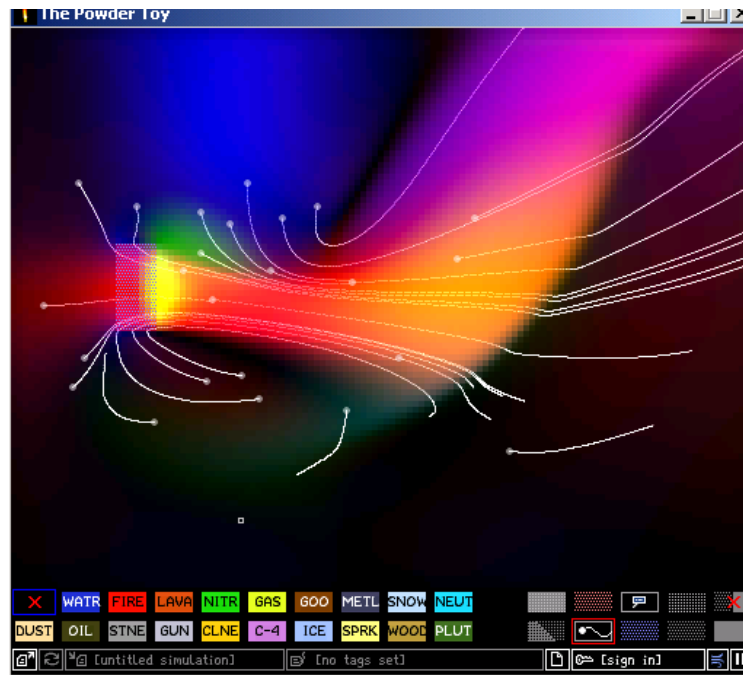
The fan is now running. To see it running, click the “fire” button at the bottom right, next to the pause button. This changes the display to velocity. Warm colours are high velocity, cool colours are low. Watch it, it may do some fairly complex things even now. If it doesn’t seem to be running, shift-click it and drag out a larger vector. The blue fan icon has to be selected to use the fan.



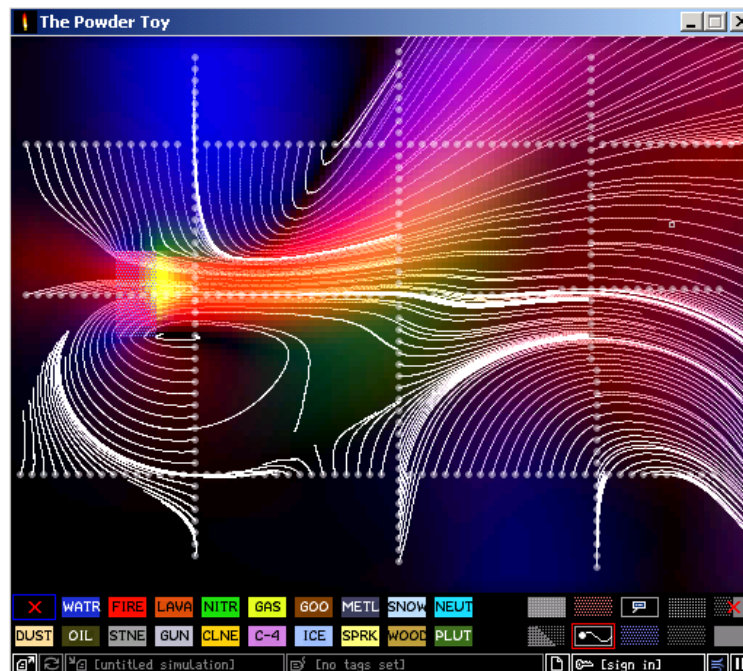
Adjust the fan’s velocity by selecting the blue fan tool and shift-dragging from the fan to create a larger or smaller vector.

Now try adding some streamlines into the picture, to see what’s going on. Click the streamline tool (now highlighted with red border in the right hand group of tools) and

click anywhere on the screen. A streamline appears, indicating lines tangential and proportional to the velocity field:

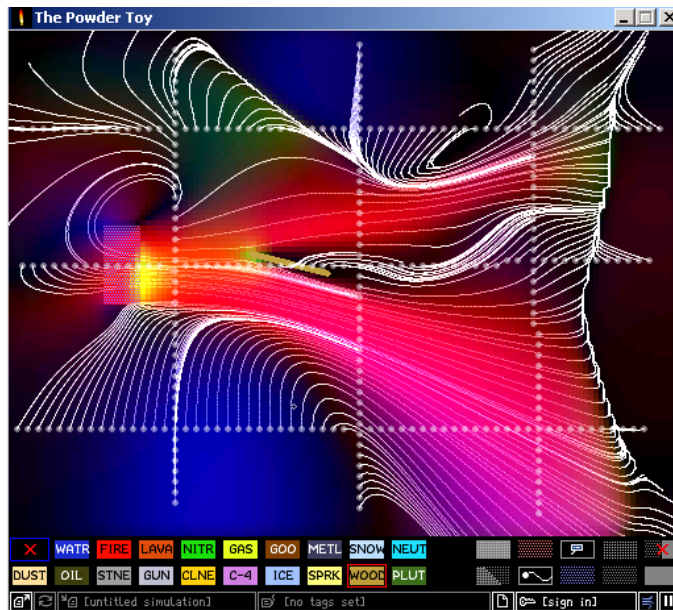


Clear those streamlines by selecting the “delete wall” tool (with red cross on lower right) and then clicking or control-dragging the streamlines (don’t delete the fan!). Place a systematic set of streamlines by shift-dragging lines of streamlines in a grid:



You should begin to see the fan settle into an oscillating state, depending on its size and speed. If it seems to settle into a stable cycle, try changing the speed.

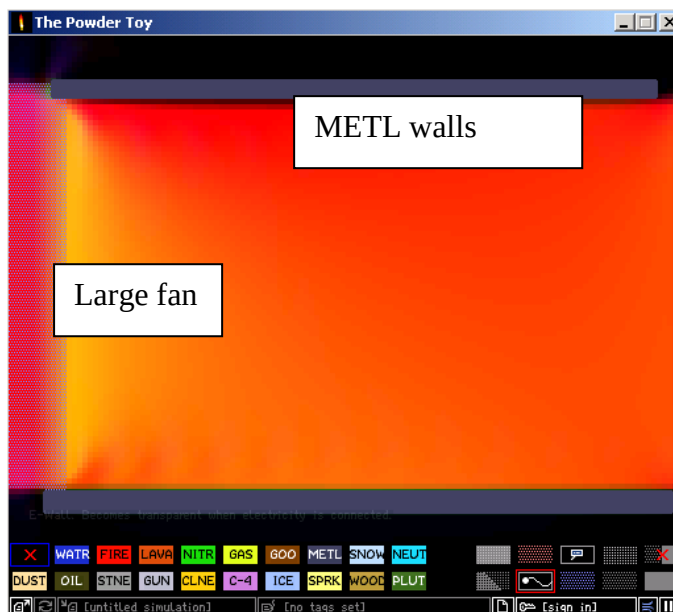
Now try putting a simple aerofoil into the airflow. Click the “wood” tool (second from right on bottom left row of tools) and shift-drag a short line at about 5 degrees to the horizontal in the midst of the main flow:



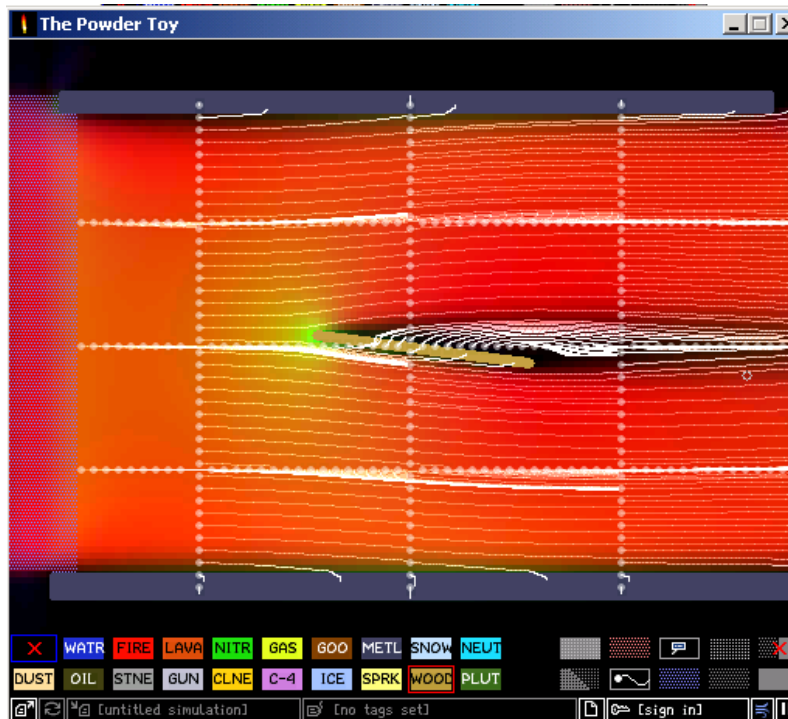
Now it's getting complicated! The simple aerofoil oscillates in various stages of stall, with the occasional burst of lift, much as you would find with a toy plane in a house fan. We need a more controlled environment.

Note also that the streamlines pass through the wood, indicating that it is porous (not unrealistic even for large aircraft). To seal the foil you can construct it of one of the "WALL" materials and then line it in a layer of wood for realist surface friction.

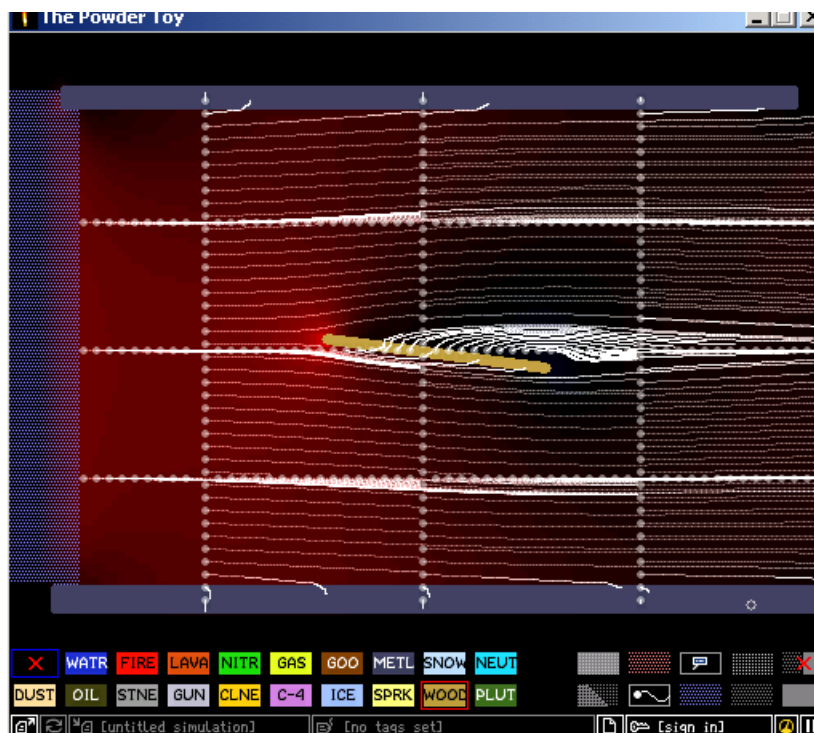
Let's build a model wind tunnel first. Clear the simulation by clicking the "page" button (bottom right, left of the [sign in] field) and draw a larger fan at the left hand edge of the screen. Turn it on as before, then control-drag two long METL (metal) walls to create the tunnel boundaries:



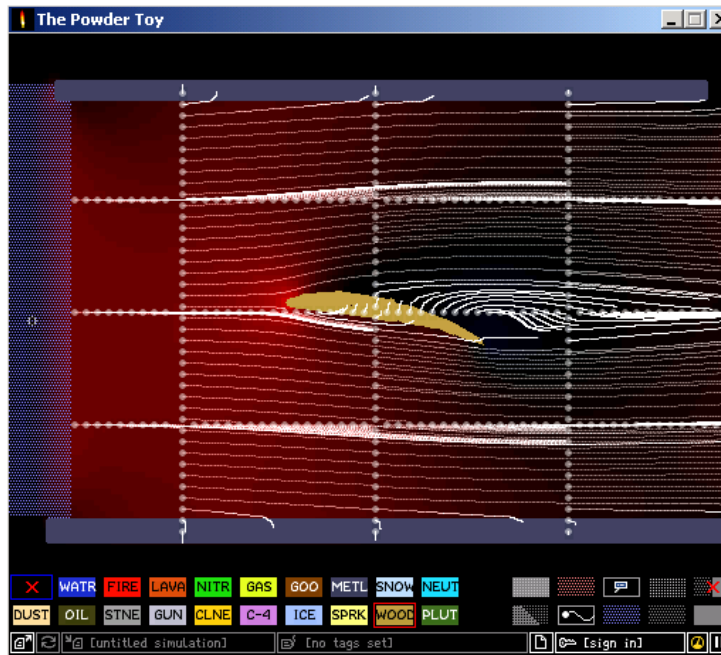
Place a grid of streamlines and a larger aerofoil in the flow:



To make it fly we need to calibrate pressures. Click the “velocity” button again (second from right on bottom, next to the “pause” button.) to switch to pressure view:

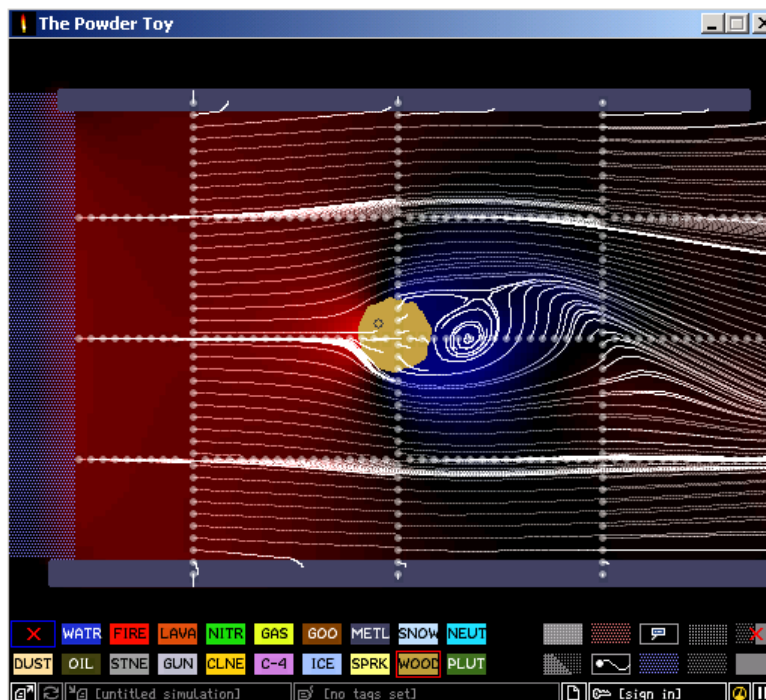


There is a general low-pressure area (dark) behind the aerofoil, indicating drag. We need to modify the aerofoil profile until a distinct low pressure region appears above the aerofoil, indicating lift:



Use the “wood” and erase (red cross, at left) tools to sketch a streamlined aerofoil shape. You should see the reddish high pressure region creep under the wing from in front while the low pressure region spreads over the top of the wing from behind. This indicates a net pressure difference in the vertical direction, creating lift.

Erase the aerofoil when you’re satisfied that it could fly. Now draw a circular cross-section, as though a pipe or cable is in the flow. Start small and watch what it does as you make it larger. Note the high pressure difference that appears, indicating a large drag force. Alternating spiral vortices appear, a phenomenon known as a *von Karman vortex*. The alternating vortices have a characteristic frequency, the “whistling” sound of obstructed wind as given by the Strouhal number (see Section 5).



Boundaries and objects made from the “wood” and “metal” particle tools are porous and frictional. This is a realistic simulation of real aerofoils and internal boundaries such as ducts and architectural walls. To create a frictionless, non-porous boundary, use the “wall” buttons on the right hand side. You can also clad these in wood or metal to create non-porous, frictional boundaries.

The Powder Toy is, as the name implies, a toy, however it is sufficiently accurate to give a realistic sense of the behaviour of fluids in many realistic circumstances. There are no units or scales of measurement, however the visual information is very rich.

Try a few more things before you go on to build your own simulations:

- Sprinkle “snow” or “dust” into the airflow and note how the flow reacts to the additional mass flow.
- Introduce “fire” and notice how the extra thermal energy accelerates the flow (and perhaps burns up your wooden aerofoil)

The other tools are different types of thermal and fluid compounds as particle models, not all of which are realistic. These include water, lava, “NITR” (an explosive liquid), “gas” (also explosive), “goo”, C-4 (high explosive), a “CLNE” tool for cloning or copying any compound it touches, and NEUT+PLUT or plutonium + neutrons for some serious special effects.

The “more pages” button (bottom far left) takes you to some user-developed models, most of which are juvenile but fun. Language warning in places. Please add some good high-end models for these kids to learn from!

Try the following exercises (not assessable but I’d be very interested to see your results):

- Build a wind tunnel with a contraction down to a nozzle. What velocity (colour) can you reach before the outlet chokes?
- Build a model “airzooka” – a sudden pressure difference released inside the barrel of a tube with narrow mouth. Can you make it produce air-rings?
- Establish a strong flow in an open tube, then suddenly close the end. Observe the development of “water-hammer” shock waves. Can you estimate the speed of sound in your fluid?
- Establish slow flow in two parallel pipes, one narrow and one wide diameter. Can you produce laminar and turbulent flow in the two pipes? Look for a parabolic velocity profile in the small pipe, and a more uniform logarithmic or $1/7^{\text{th}}$ profile in the large pipe.
- Lay out a “floor plan” with open and closed windows and a gentle outside airflow. Where are the stagnation zones in your rooms? Can you open or close windows to clear out dust?
- Build a jet engine (use gas thermal particles for fuel + fire or electrical ignition systems) and test its working range.

Save your models with the “s” key.