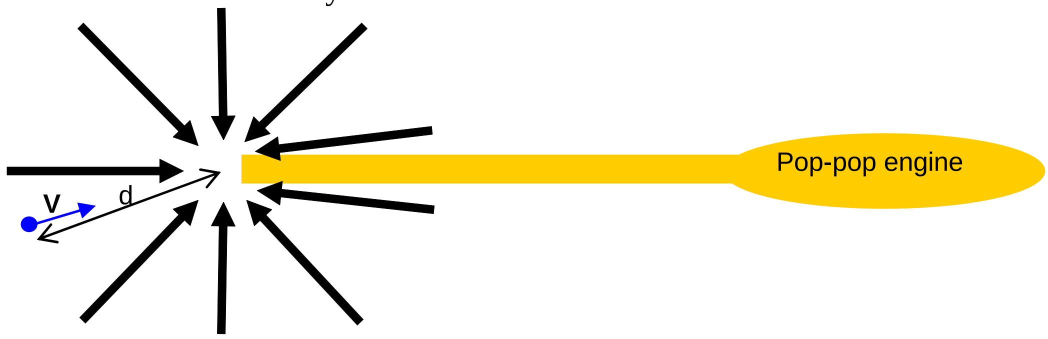
Working principle of a pulsed waterjet

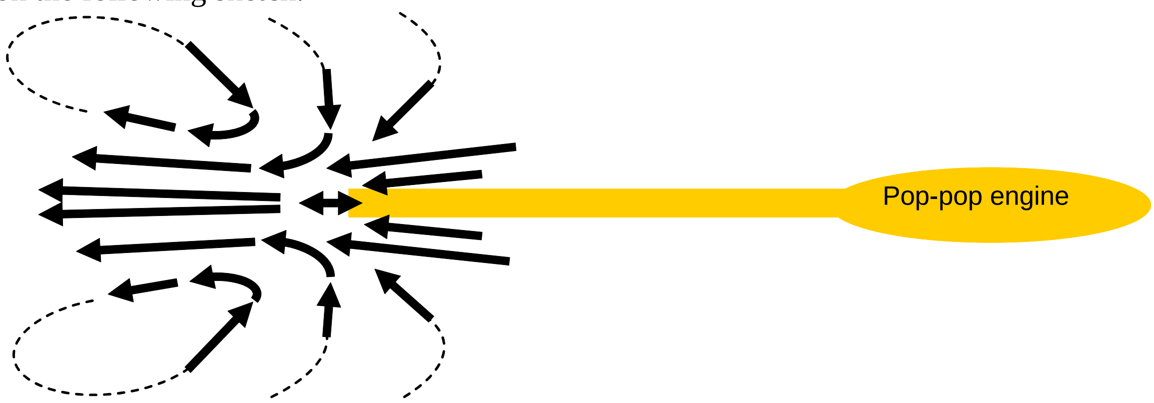
By Jean-Yves

During the propulsive phase outgoing water drives surrounding water in the same direction and it presses on the water located in front of the jet (Bernoulli and Venturi responsibility !).

During the relaxation phase a low pressure is created at the nozzle end. To fill this “black hole” water comes from any direction.



Globally (by applying the superimposing principle) the water streams move as shown on the following sketch.



We had the opportunity to check this, on one hand by looking at small particles (coal dust) sprinkled in the test tank, and on the other hand by means of the micro mooring buoy pictured hereunder.

This mooring buoy consists in a weight (2g) laid on the tank bottom and a small polyurethane foam float held at an adjustable distance from the bottom thanks to a sewing thread and a little pin.

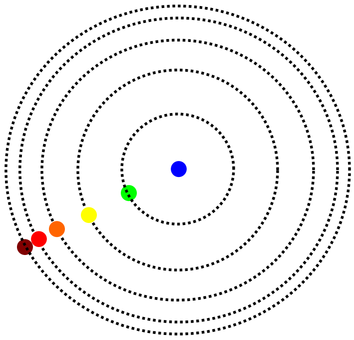
When the float is located in a stream (for instance in the nozzle axis) the thread takes an inclination which depends on the stream velocity and direction.

When the float is in a vortex it describes a more or less elliptic movement which confirms the above sketch.

Note: What was just described and what will follow concern a nozzle which is deep enough into the water and away from the hull stern. Should it not be the case, the result could be different; especially during the relaxation phase. Indeed, during this phase the nozzle will create a low level just above its end and could suck air.

The working principle of the propulsion phase is intuitive. Everybody knows that when he holds a watering hose or a shower-head he must exert a stress to resist the one of the waterjet. But, the fact that no stress is felt in the relaxation phase could require an explanation.

Let's consider concentric spheres around the nozzle end.



The volume of the smallest one is A, the volumeof the next one is 2A, the third one is 3A…

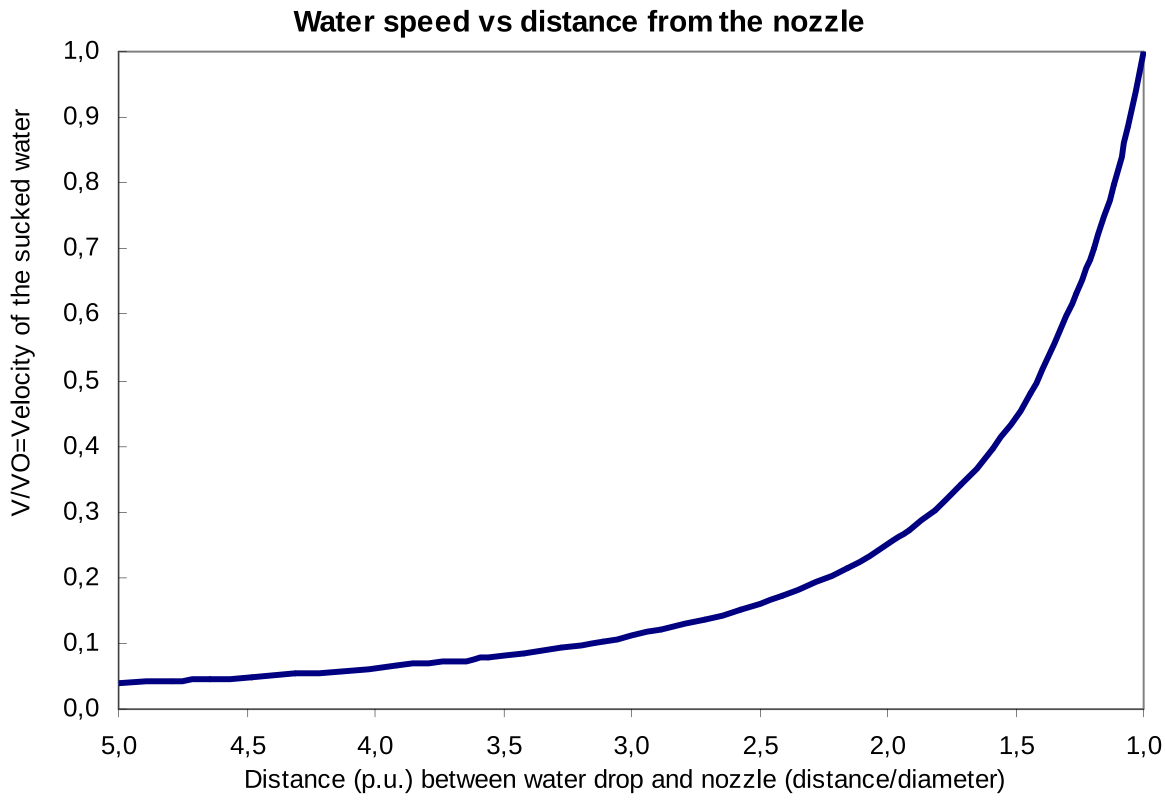
Water being sucked at the centre, one drop occupies successively (at regular time intervals) the positions represented in brown, red, orange, yellow, green, blue.

The distance run by this water drop between two successive identical durations increases, hence its velocity increases.

Knowing the relation between the volume of a sphere and its radius we can calculate at any time the position of the water drop an dits velocity (neglecting the pipe volume).

t	R=kt^(1/3)	R'=Kt^(-2/3)		(suite)	
1	1,0	1,000	20	2,7	0,136
1,2	1,1	0,886	24	2,9	0,120
1,4	1,1	0,799	30	3,1	0,104
1,7	1,2	0,702	35	3,3	0,093
2	1,3	0,630	40	3,4	0,085
3	1,4	0,481	45	3,6	0,079
4	1,6	0,397	50	3,7	0,074
5	1,7	0,342	60	3,9	0,065
6	1,8	0,303	70	4,1	0,059
7	1,9	0,273	80	4,3	0,054
8	2,0	0,250	90	4,5	0,050
10	2,2	0,215	100	4,6	0,046
14	2,4	0,172	110	4,8	0,044
17	2,6	0,151	125	5,0	0,040

By picking in this table the second and third columns (and 5th and 6th) we can draw velocity versus distance. And for a better understanding we will represent the displacement from the left to the right to set as evident the fact the water accelerates when going towards the nozzle.



Looking at this graph allows to seeing that the velocity increases rapidly when the water drop approaches the nozzle. It also shows that for instance at a distance of only three times the nozzle diameter the velocity is approximately ten times less than the one at the nozzle end.

The thrust (negative in this case) of a water stream being proportional to the square of its velocity, as soon as we measure it away from the nozzle the value is minute. We could check that experimentally by doing on one hand some flow measurements at the nozzle axis at a distance of several times its diameter, and on the other hand by doing thrust measurements.

Up to a permanent sucking flow of 42ml/s in a nozzle of diameter 6mm we couldn't measure something. 42ml/s was the limit of the test bench. This value is significant because it is more than all the values generated by our pop-pop engines tested up to now.

With the same flow, during the measurement of sucking stresses (negative thrust), when the target was very close to the nozzle (2 to 3mm distance) it used to stick to it. When in addition the target was perpendicular to the nozzle it clogged it and the test was interrupted. Above a few millimetres nothing was recorded because of a very minute stress.

In addition, to any direction corresponds two opposite ways (except the pipe, but when going away the pipe cross section area becomes negligible compared to the sphere surface). The velocities being minute and being opposed two by two, the global resulting thrust is quasi nil.