This page is complementary to: www.sittampalam.net/PrincetonGraduates.pdf.

> Now the question is this: if you had a lake, or a swimming pool – a big supply of water – and you put the sprinkler completely under water, and sucked the water in, instead of squirting it out, which way would it turn? Would it turn the same way as it does when you squirt water out into the air, or would it turn the other way?
> **Richard P. Feynman, *"Surely You're Joking, Mr. Feynman!"* W. W. Norton, New York (1997); p 63**

First, let us consider an analogy here. In the game of baseball, for instance, whether the pitcher catches the ball in or throws it out, he recoils always in the same direction – backward – due to the momentum change he imparts to the ball in his forward direction in both cases (same as being shot by a bullet or shooting one out). In a similar manner, the sprinkler nozzles would back away irrespective of the direction of water flow… we may tend to say. However, we are ignoring a very vital factor here: When the outside medium is air (as in baseball or in normal sprinkler use), certain effects can well be discounted as insignificant – but not when that medium is changed to a fluid very much denser than air. Next, therefore, let us also consider and quantify the effect of this equally important factor now – the water ambient – for the full and final answer.

The centrifugal force of a body of mass taking a curve (or bend) is always outward of the curve – even when the body moves the opposite way. Hence, under the torque that results across the two curves of the S-section, the sprinkler tends to rotate in one and the same sense for both directions of water flow. However, an extra factor – the ambient pressure – comes prominently into play when the sprinkler is completely under water: As in the case of any fluid, the water flowing in or out of the sprinkler causes also the water in the outside region of each nozzle to attain a local velocity (v), much higher than that in the region around the rest of the sprinkler body; as a result, the effective pressure head in the two nozzle regions drops appreciably (as $v^2/2g$, where g is acceleration due to gravity, thanks to the work of Prof. Bernoulli); and the nozzles are pulled *forward*, or sucked away from to the centrifugal effect of the flow inside. Now, which way the sprinkler will turn, in net, under steady state conditions becomes a tug-of-war between essentially these two forces (making it the designer's problem to tinker with the various parameters to demonstrate any desired net effect).

TEST RESULTS

HOUSEHOLD SPRINKLER (6" straight pipe; 4 transverse orifices at each end for spin action; the outward orifices make 90°, 70°, 50°, and 30°, respectively, to pipe axis; energy and hence v and $v^2/2g$ suffer much here)

- Static water head in sprinkler at start of flow: 15ft.
  Nozzle rotation for water *outflow* into air (normal use): 88 rpm; backing away from outflow.
  Nozzle rotation for water *outflow* with sprinkler completely under water: 6 rpm; backing away from outflow.
- Static suction (negative) water head in same sprinkler at start of flow: 15ft and 23ft.
  Nozzle rotation for water *inflow* with sprinkler completely under water: No motion detected *either* way, even under increased (23ft) suction, in this commercial sprinkler (due to energy losses as noted above); see next.

HOMEMADE S-SHAPED SPRINKLER [6" nozzle to nozzle; the smooth S-section (for minimal flow energy losses), with a flexible central tube as pivot and water outlet, was then fabricated (as freshman Feynman did)]

- Static suction water head in unit at start of flow: 23ft (with the pressure-tight unit hung by the central tube). Though not free to turn in full cycles, each nozzle *did distinctly lunge not less than 1/4" forward*; and the persistent forward turning tendency observed was lost with an as visible backward jerk when the suction pressure was turned off. ***It is thus concluded that the general tendency for an underwater S-curve sprinkler drawing in water is to move in <u>reverse</u> to its normal turning when squirting water out into the air.***

The forward motion under suction pressure (as against backward for positive pressure) was even more dramatic with our 1,200W Hoover at home. Its 1" diameter and 2ft long nozzle (an inflexible straight tube without attachment) was freely hung in air, in a horizontal position, with a 2ft cord. (The flexible rubber hose connecting this nozzle to the main machine was mostly vertical.) And switching on the suction saw the nozzle *lunge by 1"* and settle down in that forward direction at 5/16" – a physical delight now even for a nontechnical kid to try out!

Finally, the third factor – viscous drag on test body – which considerably inhibits any body movement in water (compared to air), was of no help in these observations.

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