The charmed string: self-supporting loops through air drag

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Summary

The string shooter experiment uses counter-rotating pulleys to propel a closed string forward. Its steady state exhibits a transition from a gravity-dominated regime at low velocity towards a high-velocity regime where the string takes the form of a self-supporting loop. Here we show that this loop of light string is not suspended in the air due to inertia, but through the hydrodynamic drag exerted by the surrounding fluid, namely air. We investigate this drag experimentally and theoretically for a smooth long cylinder moving along its axis. We then derive the equations describing the shape of the string loop in the limit of vanishing string radius. The solutions present a critical point, analogous to a hydraulic jump, separating a supercritical zone where the wave velocity is smaller than the rope velocity, from a subcritical zone where waves propagate faster than the rope velocity. This property could be leveraged to create a white hole analogue similar to what has been demonstrated using surface waves on a flowing fluid. Loop solutions that are regular at the critical point are derived, discussed and compared to the experiment. In the general case, however, the critical point turns out to be the locus of a sharp turn of the string, which is modelled theoretically as a discontinuity. The hydrodynamic regularisation of this geometrical singularity, which involves non-local and added mass effects, is discussed on the basis of dimensional analysis.