Water Spiral
A Study on Circular, Elliptical and Swirling Jet Flows

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Introduction

The present work revolves around circular, elliptical and swirling jet flows (Fig. 1).

Everyone certainly knows that when opening the tap, a circular water jet is released into the sink. When changing the orifice shape from a circle to an ellipse, we observe a jet that exhibits a chain-like shape – the so-called elliptical jet. By further imposing a swirl on the jet, we end up with a spiral – the swirling jet.

The undocumented phenomenon of swirling jets with elliptical cross-sections is investigated both experimentally and theoretically as the main novelty of this work.

Fig. 1: Jets: (a) circular jet, (b) elliptical jet, (c) swirling jet

The main research questions are:

- *Which physical effects cause a jet to twist into a spiral?*
- *How do the jet characteristics behave under parameter variation?*
- *How can the swirling jets be accurately reproduced?*

Conclusion

With the first study on swirling jets with an elliptical orifice, innovation, and novelty have been achieved both on the experimental side with the development of a passive nozzle device as well as on the theoretical front with novel derivations of the theoretical models and the investigation of the wavelengths. The work now raises the question:

Are there industrial applications?

The answer spans across various industrial fields. It is intuitive that a swirling jet could enhance mixing characteristics, which, e.g., could be applicable in polymer mixing. The breakup characteristics of jets under the influence of swirl change as well, which might have further applications.

Methodology

To predict the behavior of the different jets, a complex theoretical framework based on the renowned Navier-Stokes equations:

$$\underbrace{\rho\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\cdot\nabla)\mathbf{v}\right)}_{\text{Mass} \times \text{acceleration}} = \underbrace{\nabla\cdot\boldsymbol{\sigma} + \rho\mathbf{g}}_{\text{Sum of forces}}, \quad \underbrace{\nabla\cdot\mathbf{v} = 0}_{\text{Mass continuity}}$$

was derived – the Cosserat equations [1]. The present derivation directly from the Navier-Stokes equations is another novelty of the research.

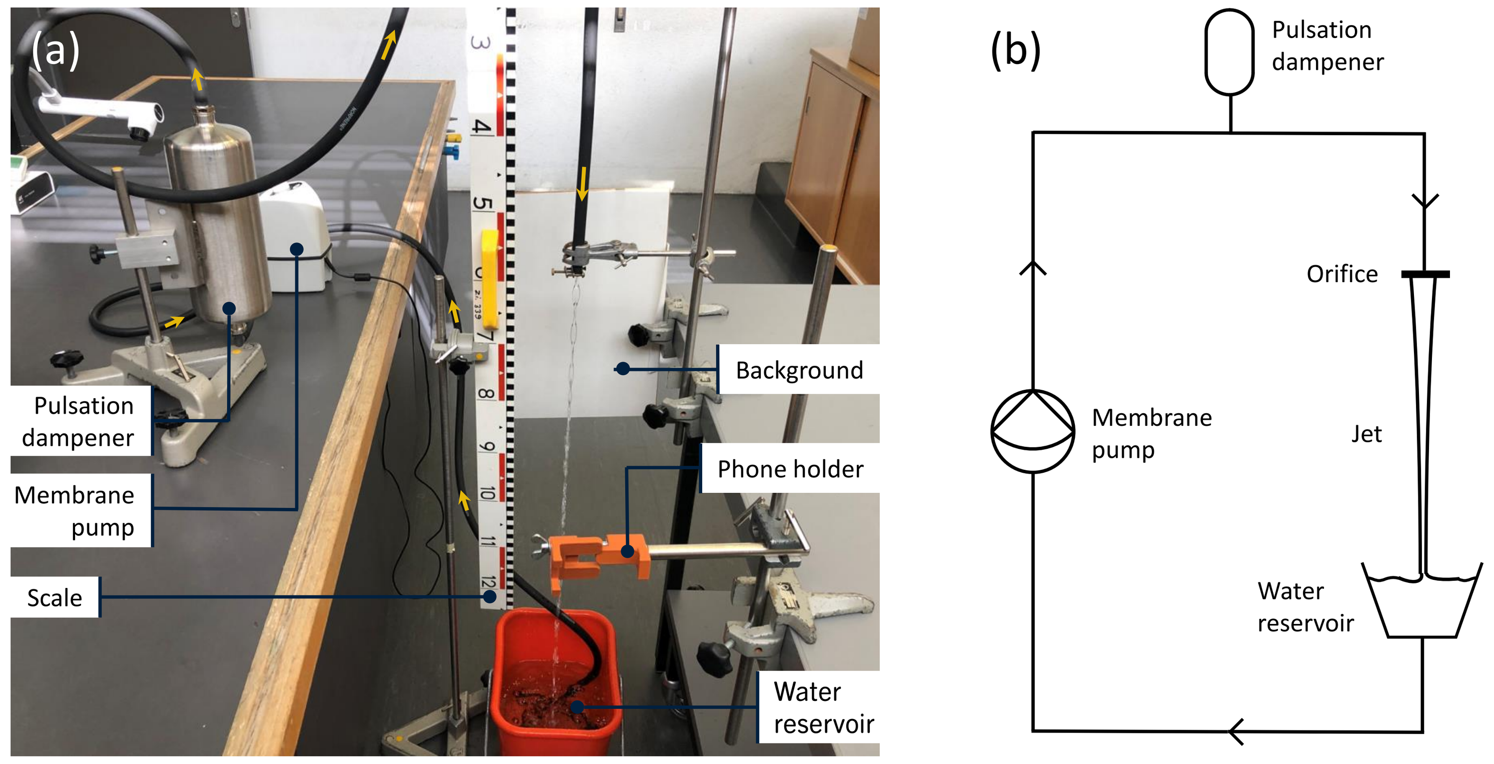

Fig. 2: (a) flow circuit with components, (b) depiction of the flow circuit

On the experimental side, a flow circuit (Fig. 2) with a membrane pump and a pulsation dampener was constructed to achieve continuous flow and a controlled experimental setup.

To reproduce the swirling jets, a 3D-printed nozzle device system was developed which passively imposes a swirl on the base flow of a jet (Fig. 3).

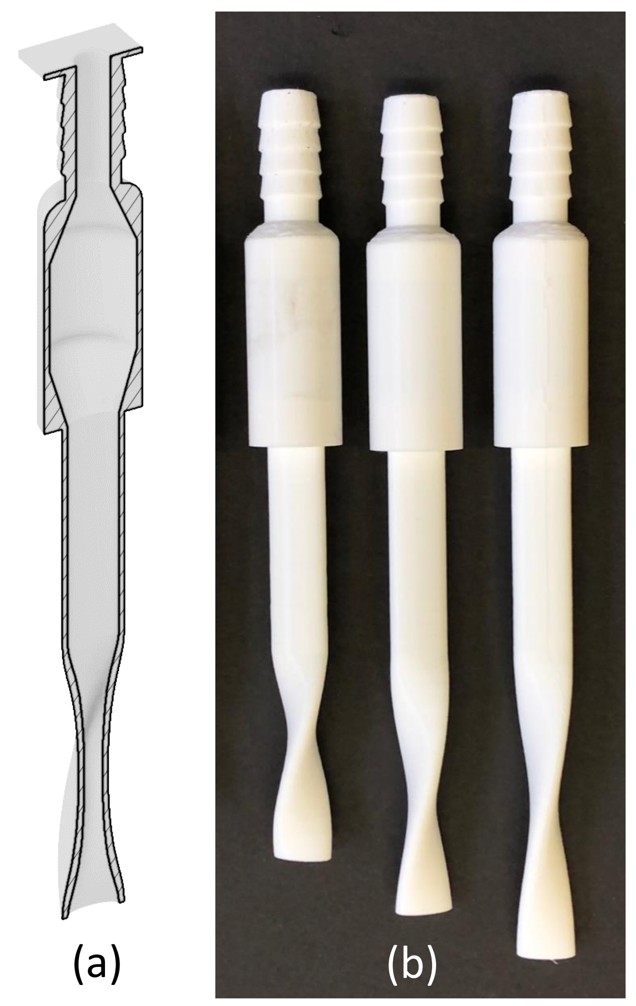

Fig. 3: Nozzles to impose swirl. (a) CAD cross-section of a nozzle, (b) several 3D-printed nozzles with different twists

Summary

The research aims to understand and model the physics of swirling jets and determine the conditions under which a jet will twist into a spiral. The phenomenon of swirling jets with a passive nozzle system is not discussed in literature and is the main novelty of this research.

New derivations for theoretical models are established and compared. Novel findings are obtained for the wavelengths and shapes of the jets and conditions are found for a jet to twist into a spiral.

Results

The wavelengths of the elliptical and swirling jets and the 3D shape of the circular and elliptical are all theoretically modeled and compared with experimental data. Overall, the experimental results show very good agreement with the theory.

The models prove to be accurate and allow us to answer the initial research questions. Theoretically and experimentally, the dependency of the jet on the governing physical effects is validated and critical conditions for the onset of a spiral are found. Based on the initial parameters, it is clear now whether we obtain an elliptical or swirling jet. Furthermore, a novel method is established to distinguish the different jets based on the wavelength characteristics (Fig. 4).

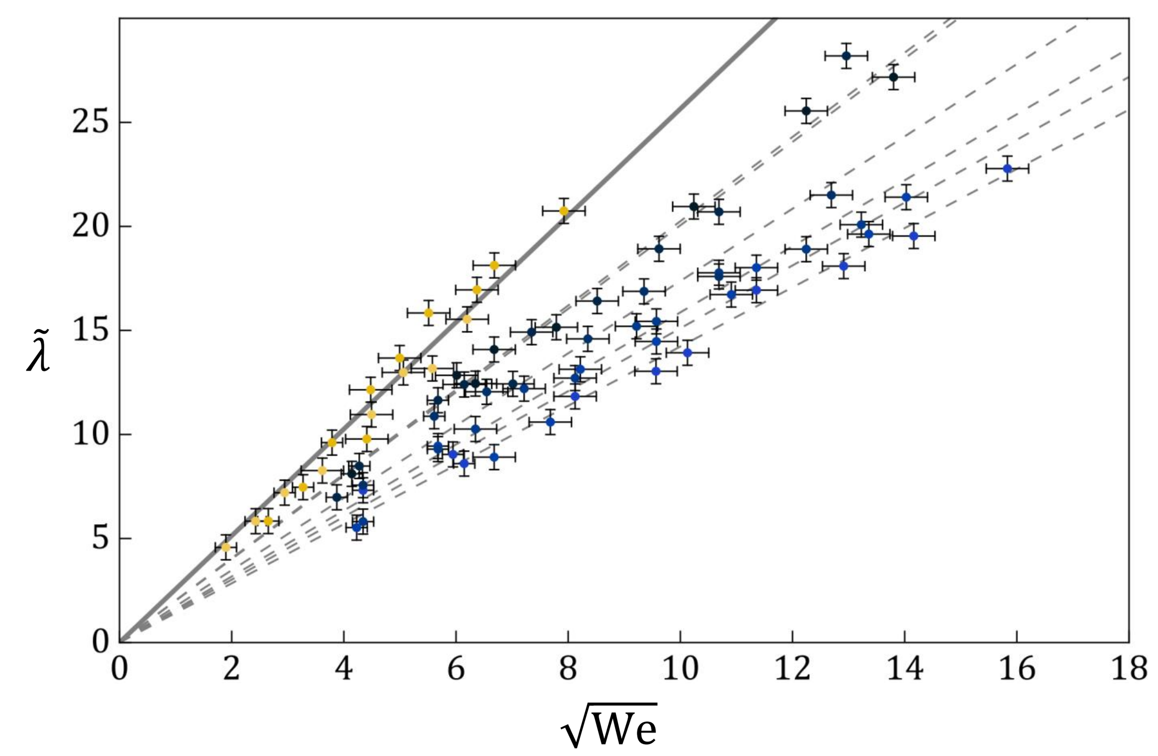

Fig. 4: Wavelength behavior plot. The yellow data points represent two datasets of elliptical jets and the blue data points six datasets of swirling jets with different nozzles and swirls.

References

[1] D. A. Caulk and P. M. Naghdi. On the Onset of Breakup in Inviscid and Viscous Jets. Journal of Applied Mechanics, 46(2):291–297, 06 1979.

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