Chaotic Behavior in Non-Laminar Water Flow

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By varying the flow rate of water flow, period bifurcation can be seen in time intervals between successive drops. Chaotic behavior can be observed when the flow rate is close to the flow rate of laminar flow.

I. INTRODUCTION

Chaos theory and nonlinear systems have long captivated researchers due to its extensive applications in weather predictions, information theory, and medicine. A small change in initial conditions can lead to drastic changes in the entire system. The chaotic behavior of a leaky faucet is first researched by Martien et al.[2] in 1984. By varying the flow rate of water, the temporal evolution of droplet release reveals the phenomenon of period bifurcation in chaos theory. We explored period bifurcation in the time intervals between successive droplets, unveiling the transition from regular patterns to chaotic dynamics. Specifically, our focus lies on the critical region where the chaotic behavior begins to occur. In this regime, periods of droplets become unpredictable. Through systematic investigation and analysis, we aim to gain a broader understanding of chaotic systems and fluid dynamics.

II. THEORY

At lower flow rates relative to laminar flow, successive water droplets are released at a constant time interval. As the flow rate approaches laminar flow, water droplets are clumped up together at the nozzle to produce unpredictable releases of water. The period of successive droplet releases can be precisely measured and analyzed to determine when the system approaches chaotic behavior.

III. EXPERIMENT SETUP

Our experimental setup can be summarized in Figure 1. Water droplets are initially released through a 1mm nozzle pipette to a beaker. Using a scale and LoggerPro program, a flow rate can be calculated from the slope of grams of water over time. To ensure accurate detection of water droplets, two photodiode sensors were placed to detect water droplets at similar spots. By overlaying the signals from the sensors on an oscilloscope, we can find the optimal positions of the sensors. As water droplets are detected, a signal is sent to the corresponding sensor. An overlay of signals on an oscilloscope can be seen in Figure 2. Data was collected at 10000 Hertz for a total of 1.2 million data points using LABVIEW. Data was then further analyzed using Python.

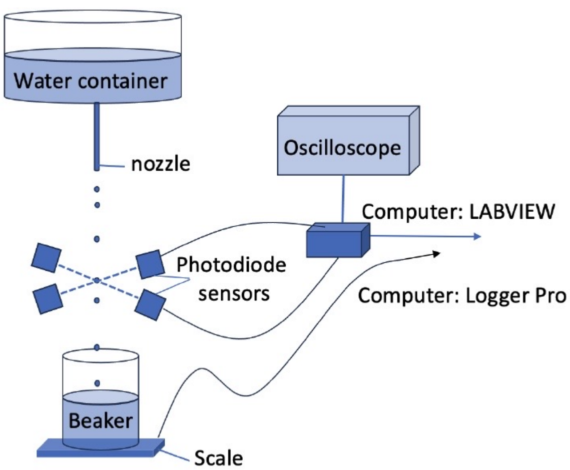

FIG. 1. Experiment Setup[1]

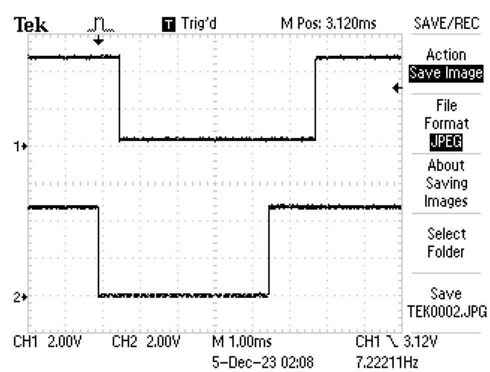

FIG. 2. Setup seen from Oscilloscope

IV. RESULTS AND DISCUSSION

Our experimental results are presented as Poincare Sections Plots in Figure 3 and as histogram of periods in Figure 4. Qualitatively, chaotic and random behavior appear gradually as the flow rate is increased.

The Poincare section plots reveal period doubling behavior before entering the chaotic regime at a flow rate

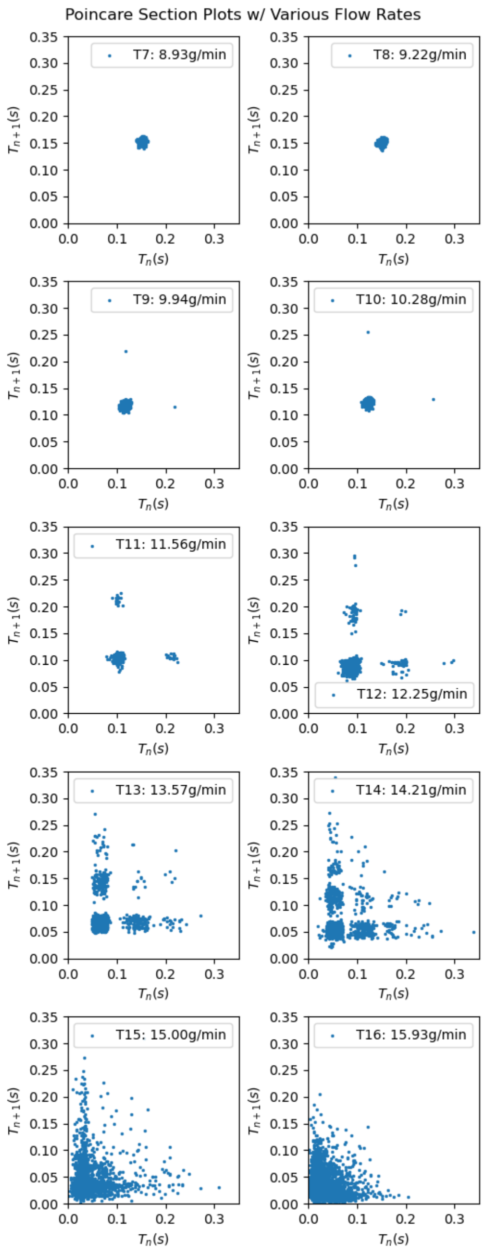

FIG. 3. Poincare Section Plots

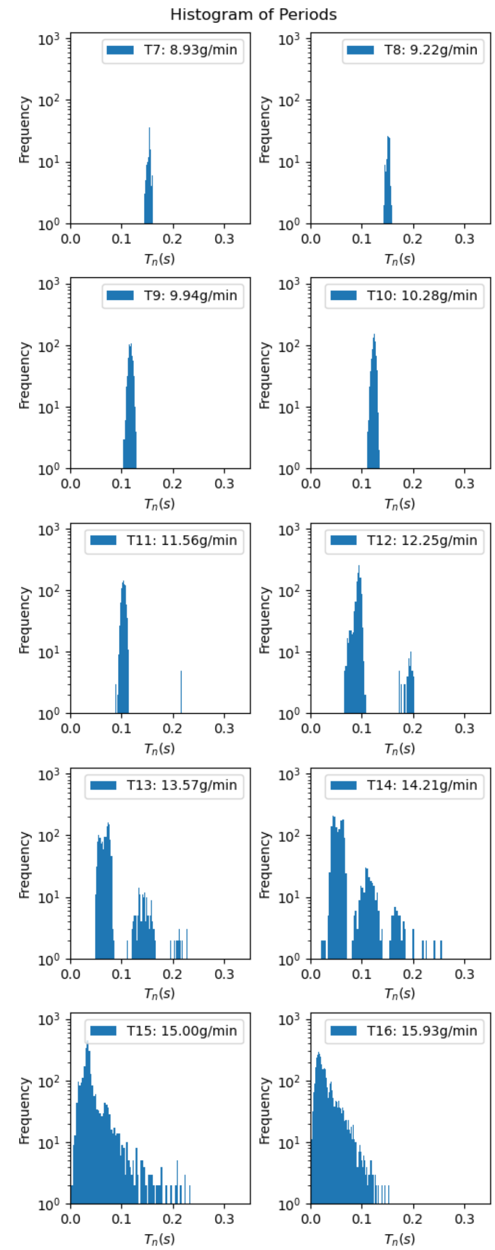

FIG. 4. Histogram of Periods

of around 15.00g/min. Period doubling is even more evident in the histograms of periods.

Some potential errors include humidity and wind in the lab, which can affect droplets from being detected. This is mitigated by covering the apparatus with a black cloth during data collection. Data was also collected in a single day to ensure conditions are mostly constant. We also observed that the flow rate of laminar flow can vary from trial to trial, thus the exact flow rate at which chaotic behavior occurs can vary as well.

Another error in the experiment is the alignment of sensors as seen in Figure 2. Due to the unique positioning of each sensors, it is difficult to fully align the signals on the oscilloscope. An OR gate is applied to the data to ensure water droplets are detected accurately.

V. CONCLUSION

A qualitative assessment of period doubling shows that it continued to increase with the flow rate until the flow rate approaches close to laminar flow. In the chaotic regime, periods between successive droplet releases appear to be random and unpredictable.

ACKNOWLEDGMENTS

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[1] Liu, G., and Klappenbach, Z. Measuring the chaos of water droplets using photo-diode sensors.

[2] Martien, P., Pope, S., Scott, P., and Shaw, R. The chaotic behavior of the leaky faucet. *Physics Letters A 110*, 7 (1985), 399–404.