# LIFETIME OF TURBULENT PATCH IN TAYLOR COUETTE SETUP

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*Abstract* In linearly stable shear flows like pipe and plane Couette flows, the transition from the laminar to the turbulent regime occurs abruptly. To better understand this transition, the time evolution of turbulent patches, created by controlled finite amplitude perturbations, have been studied in the literature. These studies mostly focused on pipe flows for which a finite lifetime of the patch was proven. The same conclusion was drawn in the only available study performed in a **T**aylor **C**ouette setup. Here, we measured the lifetime in a different size TC setup. We show that the lifetime is indeed finite and also very sensitive to the boundary condition, but not much to the perturbation mechanism. We suggest that in addition to the Reynolds number, the lifetime depends on the aspect ratio to the radius ratio of the setup.

## INTRODUCTION

Linearly stable shear flows such as pipe and plane Couette flows show an abrupt transition from the laminar to the turbulent regime. The time evolution of a turbulent patch, created by sufficiently large finite amplitude perturbations, have been investigated to better understand this transition [7, 6, 8, 3, 2]. All these studies have agreed on the exponential probability distribution of the lifetime and the increase of the mean lifetime with Reynolds number. However, there was a dispute over the divergence of the mean lifetime at a critical Reynolds number. This dispute was finally settled by Avila *et al.* [2] which proved a super-exponential scaling of the mean lifetimes in pipe flows that indicates that no threshold of lifetime divergence exists. Consistent with the obtained results in pipe flows, a finite lifetime was reported in the only available study performed in a **T**aylor **C**ouette setup [5]. But there, the influence of geometrical properties, boundary condition and perturbation type (global or local) were not examined. In the current work, we aim to examine the effect of these parameters on the patch lifetime in a TC setup.

## EXPERIMENTAL MEASUREMENT SETUP

The setup consisted of two concentric cylinders with the geometrical properties listed in Table 1. The end plates were attached to the outer cylinder with a gap of 1.5 mm between the end surfaces of the inner cylinder and the plates. Two geometrical non-dimensional numbers, the aspect ratio $\Gamma = L/d$ and the radius ratio $\eta = r_i/r_o$, are defined. The Reynolds number is described as $Re = \frac{r_o \Omega_o d}{\nu}$ where $\Omega_o$ and $\nu$ are the angular velocity of the outer cylinder and the kinematic viscosity of fluid.
Two mechanisms were deployed to create the patch: first, **G**lobal **P**erturbation (GP hereafter) by counter-rotating of the inner cylinder (at a frequency of 0.65 Hz) for 3 sec, and second, **L**ocal **P**erturbation (LP hereafter) by simultaneous injection and suction of water from two holes in the middle of the inner cylinder. It has to be noted that except during the global perturbation, the inner cylinder was always stationary.
For flow visualisation, Iriodin pigments (Iriodin 121) were added to water. The particles were illuminated by exposing the cylinders to white (halogen) light from a projector. To capture the flow a CCD camera with a frequency of 10 Hz and resolution of 500 × 2800 pixels (corresponding to 37.5 mm width × 200 mm height in physical space) was used. For determining the lifetime, each image matrix was subtracted and normalized by the average of 100 images taken from the laminar flow. Standard deviation of the normalized image displayed a clear distinction between the images with and without the patch.

| Parameter | $r_i(mm)$ | $r_o(mm)$ | $d(mm)$ | $\eta$ | $\Gamma$ | $Re_{cr}$ |
|---|---|---|---|---|---|---|
| Current study | 110 | 120 | 10.0 | 0.917 | 22 | ≈6000 |
| Borrero-Echeverry *et al.*[6] | 66.38 | 76.20 | 9.82 | 0.871 | 36 | ≈16000 |

**Table 1.** Geometrical properties of setup. $r_i$ and $r_o$ are the inner and outer cylinder radius and $d = r_o - r_i$ is the gap size. $Re_{cr}$ is the Reynolds number where sudden transition from laminar to turbulent flow takes place.

## RESULTS

A common feature was observed at all Reynolds number (Figure 1); the distribution had an exponentially decaying tail after an initial patch formation time. The probability of survival was described as an exponential function of the time and Reynolds number, $P(t, Re) \sim exp(-(t)/\tau(Re))$, where $\tau$ is the mean characteristic lifetime determined by fitting a line to the tail of each distribution. The mean characteristic lifetime grew by increasing the Reynolds number, with the super-exponential function suggested by Hof *et al.* [7, 6], $\tau(Re)^{-1} = exp(-exp(aRe+b))$, as the best fit for this growth. This indicates the boundedness of the lifetime in TC setup.

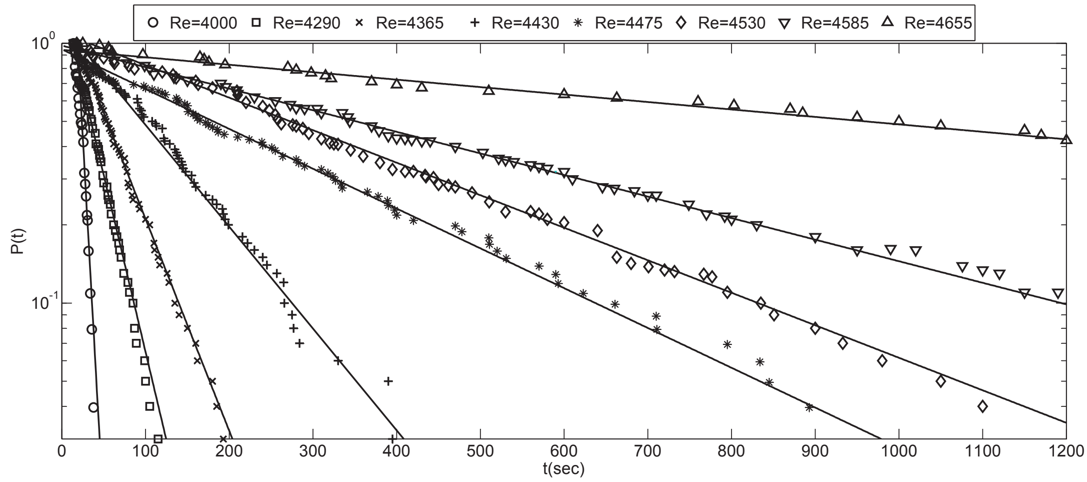
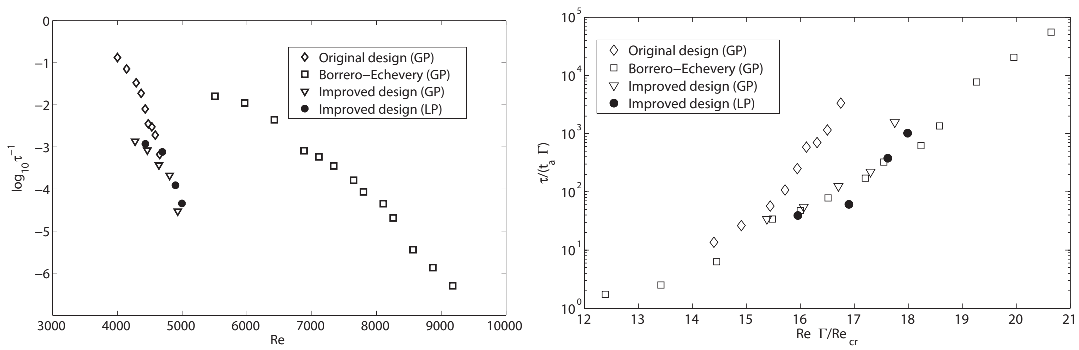



**Figure 1.** Probability of observation of the patch with time. Lines are exponential fits through the data points which have lifetimes higher than 18 sec.




(a) (b)

**Figure 2.** (a) the characteristic lifetimes of the patch in original and improved design generated with **G**lobal **P**erturbation and **L**ocal **P**erturbation and in the previous study with GP [3]. (b) Normalized characteristic lifetimes.

Experiments with GP and LP in the improved design[1] showed that the type of perturbation does not affect the lifetime as long as it creates the patch. The considerable difference in the lifetime between the current and previous study (as demonstrated in Figure 2.a) drew our attention to the possible role of geometry. The characteristic lifetime was scaled based on the geometrical properties ($\Gamma$ and $\eta$) and the critical Reynolds number ($Re_{cr}$). Advection time unit, $t_a = d/r_o\Omega_o$, was identified as another relevant scaling parameter since it translates the total lifetime period to the total number of rotations. By choosing $\Gamma$, $Re_{cr}$, and $t_a$ as scaling parameters, the results coincided (Figure 2.b). It is noteworthy that the critical Reynolds number itself is a function of $\eta$ (Dubrulle *et al.* [4]). To confirm our proposition with respect to the role of geometry, it is suggested to repeat the lifetime measurement in a flexible setup such as the one designed by Avila & Hof [1], which provides the possibility of different geometrical configurations and stationary end plates.

## References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[1] In the original TC-setup design, the turbulent patch was mostly attached to the top plate during its lifetime. This might be due to disturbances caused by air bubbles being stuck in the top gap during the filling of the setup, or due to secondary flows causing the patch to drift upwards. The geometry was modified to better release bubbles and reduce secondary flows with an extra ring, and this is called the "improved design".