PIV STUDY OF BEHAVIOR OF INTERACTION OF TWIN FOUNTAINS IN HOMOGENEOUS FLUID

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Summary In this study the behavior of the interaction of twin fountains in a homogeneous fluid is studied experimentally using flow visualization and noninvasive PIV technique over the range of $25 \le \mathrm{Re} \le 400$ and $1 \le Fr \le 5$. The results show that the behavior can be categorized into several regimes: flapping steady; bobbing/flapping/steady; flapping unsteady; bobbing/flapping unsteady; and unsteady circling, which are mapped onto a Re-Fr map.

INTRODUCTION

A fountain is formed when a fluid is injected upward into a less dense fluid, or downward into a denser fluid. The injected fluid exchanges heat and momentum with the surrounding fluid by entrainment. Due to the opposing buoyancy force, it will lose its upward momentum and fall down at a finite height in a circular shaped plume around the upward injected jet and surrounding fluids. The fountain behavior can be fully represented by the Reynolds number and the Froude number defined as $\mathrm{Re} = V_o R_o/\upsilon, \mathrm{Fr} = V_o\big/\sqrt{R_o g(\rho_o - \rho_a)/\rho_a}$, where R_0 is the inlet radius, g is the acceleration due to gravity, ρ_o and ρ_a are the density of inlet jet fluid and ambient fluid at the source and υ is the kinematic viscosity of the inlet jet fluid. Understanding of turbulent fountain behavior has been well established and some understanding of that of weak fountains has also been developed [1-3]. However, only quite recently have the studies on transitional fountains emerged [4, 5].

The interaction of multiple jets/plumes is a very common and important phenomenon in many applications such as displacement ventilation and air-conditioning. But this is an area that the studies are scarce and lacking [6, 7]. In particular, to our best knowledge, no study has been found to investigate the interaction among multiple fountains, which is the motivation of this study.

EXPERIMENTAL SETUP

Experiments have been conducted by injecting saline water vertically upwards into a $1m \times 1m \times 0.6m$ perspex-sided fresh water tank as shown in figure 1 over the range of $25 \le \mathrm{Re} \le 400$ and $1 \le Fr \le 5$, which is achieved by adjusting salinity of fountain fluid and inlet flow rate with a constant inlet size. The volumetric flow rate is measured with an Aalborg high precision needle valve and flow meter. A High-Framing-Rate PIV system, from Dantec Dynamics, is used to perform the PIV experiments. One Redlake HG-100K camera with a maximum resolution of 1504×1128 pixels and at a framing rate of 30 frame per second is used in this system, which is connected to the Redlake Hub Sync Unit. A Lee Laser LDP-100MQG Nd: YAG laser emitting 0.532 μm radiations is utilized to produce the laser. In order to get high quality PIV images, the almost neutrally buoyant polymer spheres (Nylon 12 Polyamide with density 1030 kg/m^3 and mean diameter 50 μm) is added in the fluid as tracer particles. Flow visualization is achieved by using a food dye.

EXPERIMENTAL RESULTS

A snapshot of a typical PIV image is shown in figure 2 for the twin fountains at Re=300 and Fr=2, where the interaction of the twin fountains demonstrates the unsteady flapping behavior. In such a case, when the interaction is at full development the whole interaction region sways horizontally around the middle plane of the twin fountain sources with little changes of the maximum interaction height. This unsteady flapping interaction behavior on the observed plane passed through the twin fountains is two dimensional.

The observed behavior of the interaction of twin fountains is summarized on a Fr-Re regime map as shown in figure 3. It can be categorized as either steady or unsteady. A demarcation curve can be found to distinguish the steady and the unsteady behaviors of interaction, although in this current study the exact location of such curve cannot be determined due to insufficient data obtained from the experiments. However, based on the current experimental results, it is found that the regimes of $\mathrm{Re} \le 100$ with all Fr values considered and $Fr \le 1$ with all Re values considered but Re=400 are in the steady category.

The steady category can be further divided into two sub-regimes: 2D-flapping and 3D-bobbing/flapping. The 2D-flapping behavior is observed for $0 \le \mathrm{Re} < 100$ and $0 \le Fr \le 2$ among all cases considered here. In this regime, the initial flow in the interaction region sways horizontally around the middle plane of the twin fountain sources with gradually increased maximum interaction height for a very short period of time and then becoming stable with no fluctuation in the interaction height and negligible horizontal sway when the interaction attains full development. The steady 3D-bobbing/flapping

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regime is observed for Re=100 with $2 \le Fr \le 5$ and $200 \le \mathrm{Re} \le 300$ with Fr=1. In this sub-regime, the peak of the interaction region initially moves upwards, comes to rest at a finite height and then collapses around the rising peaks. This phenomenon repeats for a short period of time, demonstrating a bobbing behavior. At the same time, the interaction region sways horizontally, not limited on the plane passing through the source centers of the twin fountains, showing a 3D feature. After this, the interaction eventually becomes steady with no change in the maximum interaction height and again no horizontal sway. The maximum interaction height is located on the middle plane of the twin fountain sources. The unsteady interaction can be divided into three sub-regimes: 2D-flapping, 3D-bobbing/flapping and circling. For both 2D-flapping and 3D-bobbing /flapping, the behaviors of unsteady and steady interaction are quite similar with the exception that, in the unsteady regimes, the interaction remains unsteady even at full development, with fluctuating maximum interaction height and continual sway. In the cases of unsteady circling interactions, flapping behavior is observed at the initial stage of interaction, followed by a horizontal rotation of the whole interaction region, even when the interaction attains full development.

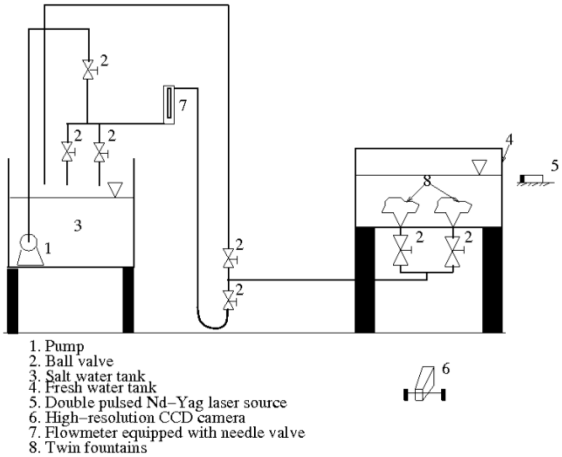

Figure 1: Schematic of the experiment setup

Figure 2: A snapshot of typical PIV images of flapping unsteady interaction of twin fountains at Re=300 and Fr=2

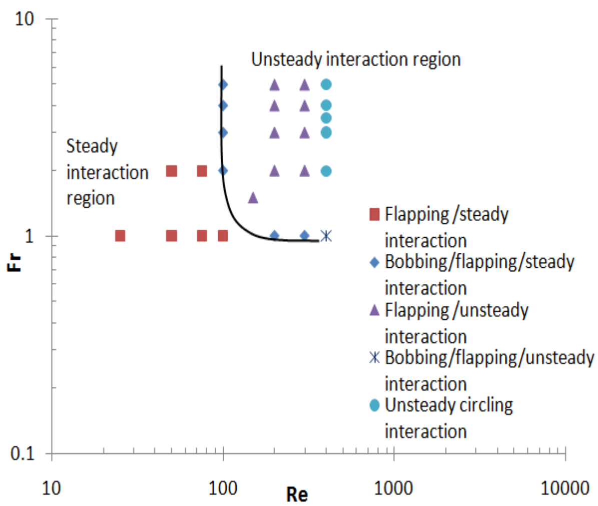

Figure 3: Regime map of twin fountains interaction behavior

CONCLUSIONS

The behavior of interactions of twin fountain has been investigated experimentally using PIV and flow visualization technique. The experimental results show that the interaction behavior can be categorized as either steady or unsteady, depending on the values of Re and Fr. For each category, several sub-regimes can be identified, which are summarized on the Re-Fr map.

ACKNOWLEDGEMENT

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