"Drifting Cups on a Meandering Stream" in China

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"Drifting cups on a meandering stream" is a game originating from the ancient China. It takes advantage of the stopover of the cup at the different positions on a meandering stream to choose a person sitting on the bank to participate the game. In this paper, a model is devised to make the cups move around or stop at some place on the stream as required by the game. A typical flow field is abstracted and studied using the PIV technique and the topological analysis. Some motions of the cup on the stream have been explained in the mechanics theory.

Key Words : Drifting Object, Meandering Stream, Particle Image Velocity, Flow Field Analysis

1. The Story on "Drifting Cups on a Meandering Stream"

On March 3, AD 353, Wang, Xi-Zhi (Fig. 1) who is one of the most famous calligraphers of China invited 41 guests to join him for a special action-composing poems and drinking liquor at Lanting of Saoxing, Zhejiang province, China. The guests were asked to sit on the banks of a small meandering stream and some floating cups filled with liquor were released from upper reaches of the stream (Fig. 2). The rule of the action was that when a cup was driven to the place next to a guest and had a brief stopover, the guest either had to compose an extempore verse, or otherwise had to drink 3 cups of liquor as penalty if he failed to compose a poem. In this party, 11 persons each made two poems, 15 persons each made one poem, 16 persons failed to do so and were punished. Finally 26 persons made thirty-seven poems called Lanting poetry. The renowned preface written by Wang, Xi-Zhi for this poetry was called "the first running hand". Now this action has been handed down in China and spread to Korea and Japan (Nakayama, et al., 1997a ; 1997b), because it is a very interesting and elegant cultural game.

Fig. 1 Portrait of Wang, Xi-Zhi (AD 321-379)

Fig. 2 The lanting poetry party (from an ancient Chinese painting)

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2. The Interest to Study the Phenomenon of "Drifting Cups on a Meandering Stream"

The most interesting phenomenon is that a drifting object can randomly enter some vortex regions from the main flow in the meandering stream. In order to clarify the mechanism of this phenomenon, we should consider a lot of factors, such as the shape of the channel of the water, the flow velocity and turbulence, the mass and shape of the cups, and so on. These problems are worth considering in the fluid mechanics. Actually, meandering is an obvious feature of the natural stream and river. In the meandering streams there are many vortices, reversal flows and dead zones, which directly affects the safety of sail, riverbanks and transfer of the material, such as the pollution (Hunt, 1999; Valentine and Wood, 1997), in the water. Many related phenomena have attracted the attention of scientists.

3. Present Study

3.1 Experimental and computational models of the meandering stream

Figure 3 is a picture of the actual meandering stream at Lanting Park, which is newly-built and is not good for playing the game "drifting cups". As a cooperative research item with Prof. Nakayama's group, we tried to design new channels of meandering stream. Using plasticene and changing the shape of the stream channel ceaselessly, we found some schemes satisfying the features of the meandering stream for the game "drifting cups". Figure 4 shows the experimental setup and one scheme of the new meandering water channels. It can be observed that the shape of the channel has some fundamental characteristics: meandering, contracting and expanding. Figure 5 shows the stream-line image of one of the new meandering stream channels. It can be seen that the flows separate and form big vortices on the side of the main flow in the expansion sections, such as position 1, 2, 3, 4, 5 and 6 and that the flows are accelerated in the contraction sections. These results are consistent with the phenomena observed in the experiment. In order to study the flow field in more detail, a typical section of the meandering stream model is selected for a PIV experiment.

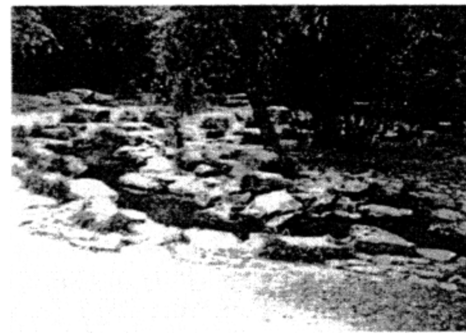

Fig. 3 The meandering stream in Lanting

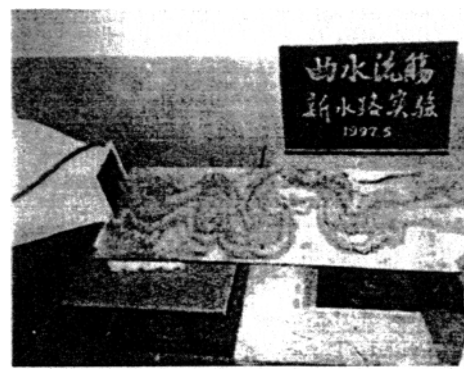

Fig. 4 Experimental model using the plasticene.

Fig. 5 The stream-line image of a meandering stream

3.2 Experimental researches on a new typical section model

3.2.1 Typical section model

For a PIV experiment, we devise a typical section model (Fig. 6) of the meandering stream. It has a contraction and an expansion, and can make a cup's stopover in the water as required by the game. The drifting object is a cylindrical cup

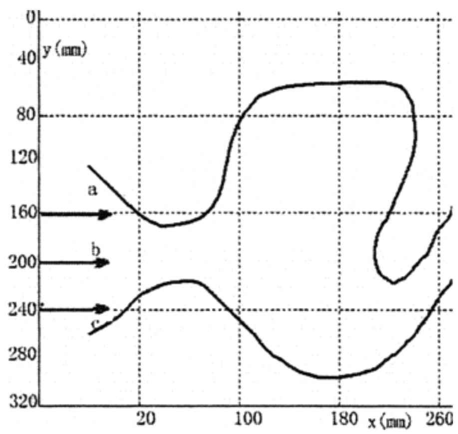

Fig. 6 Top view of the model

with the radius 6.5mm.

3.2.2 Flow field measurement: PIV

The surface flow field of this section model is measured and processed by the PIV technique (Lin and Rockwell, 1999). Using Yag pulse laser as a source of light sheets, a CCD camera records particle images in the water with an appropriate time interval. An instantaneous velocity field can be obtained by processing the images with the PIV system. In this experiment, the whole process of cup-floating on the stream is recorded. The development of unsteady flow field can be analyzed.

3.2.3 Topology of the surface flow field

Figure 7 is a picture of the particle image of the flow field to be used in the PIV. Figure 8 is the velocity vector field processed from Fig. 7 Applying a topological theory (Xia et al., 1991) to the velocity field shown in Fig. 8, a typical flow field chart including the critical points is abstracted (Fig. 9).

N and S denote nodes and saddles; N' and S' denote semi-nodes and semi-saddles, respectively. The semi-nodes and semi-saddles are nodes and saddles located at the boundary, respectively. The total number of saddles and nodes (spirals and noddles) of such a structure has to satisfy a certain rule. Here.

$$\left(\Sigma N+\frac{1}{2}\Sigma N'\right)-\left(\Sigma S+\frac{1}{2}\Sigma S'\right)=0 \quad (1)$$

Fig. 7 Particle image

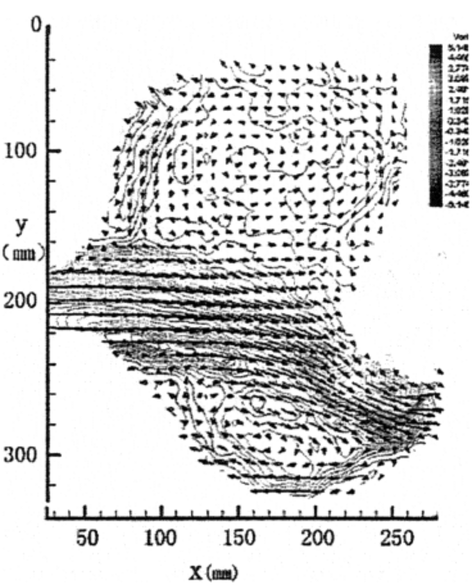

Fig. 8 Velocity vector field of Fig. 2

From Fig. 9, we have

$$\Sigma N=2,\ \Sigma S=2,\ \Sigma N'=2,\ \Sigma S'=2$$

The number of the critical points satisfies the Eq. (1).

From the above topological analysis, we can see that these critical points separate the whole flow field into three parts: main flow region M, vortex regions V1 and V2, and shear flow regions S1 and S2 as shown in Fig. 10. The unsteady property of the flow field makes these regions unstable, especially in the neighbourhood of the critical points.

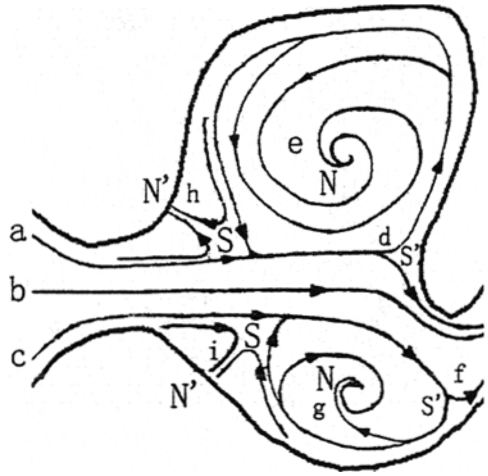

Fig. 9 Topological image of the flow field

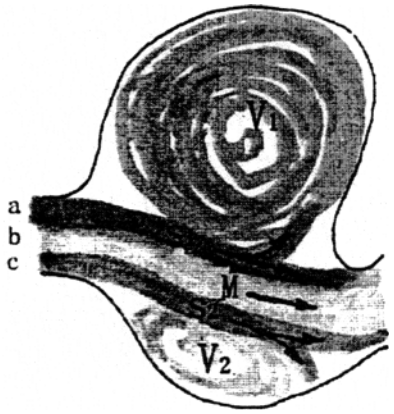

Fig. 10 The sketches of the simplified model

3.2.4 Statistical results of PIV measurement

With the plentiful PIV measurements, we find that the flow in the typical section model makes the drifting cups produce different trajectories shown in Fig. 11. The cups are released at three different positions a, b and c, which are the starting positions of regions S1, M and S2 respectively. The cups starting from b will follow the main flow like trajectory N, while the cups starting from a and c have two kinds of trajectories: following the main flow like L3 and R1 or entering into the vortex regions like L1, L2, R2 and R3.

The experiment data indicate that the cup released at the different positions definitely has a different probability of entering the two big vortex regions and stopping in some places, as shown in Table 2.

Table 2 (refer to Fig. 9 and Fig. 10)

Entering region	Position a	Position b	Position c
V1 vortex region	34% (5% stop at h region)	0	0
V2 vortex region	0	0	23% (7% stop at i region)
Main flow region	66%	100%	77%

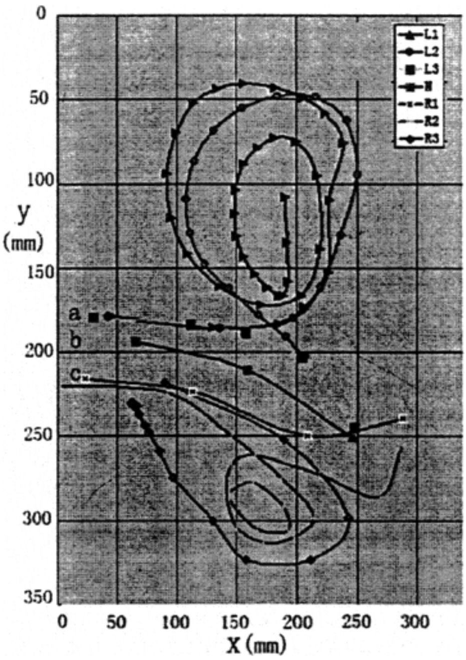

Fig. 11 The trajectories of the cup released at different positions

The meandering stream is often made of several similar sections like Fig. 6. The motion of the cup in the former section will affect the probability of the cup' stopover in the following sections. That is why each poet has different probability to make a poem. In addition, the unsteady property of the flow field is an important factor affecting the motion of the cups.

3.2.5 Unsteady property of the flow field

As observed in the experiment and shown in Fig. 11, the cup can leave main flow and move around in a big vortex region, and the cup moving in the vortex region can also enter the main flow. In addition, the track of the cup is not definite. Obviously, the random characteristics of the cup's motion are caused mainly by the unsteady property of the flow field. Except the factor of turbulence, topological structure of the flow field is also an important reason. As shown in Fig. 9, the semi-saddle is connected to the saddle. This topological structure is not stable. The connection line can break away at any moment and at any place. The unstable coupling of the main flow region and the big vortex region makes the flow field unsteady and complex. So the track of the cup in the flow field is irregular.

4. Discussion and Conclusion

There are not only a lot of the relics of the meandering streams, but also some new ones built in recent years in China. These exhibit people's intense interest in the drifting cups on the meandering stream originating from the game by Wang Xi-Zhi. From the point of view of fluid mechanics, drifting cups on the meandering stream stress the researches on the structure of complex flow and the behaviour of the drifting objects in the meandering channel, especially the researches on the problem: what kind of meandering stream can realize the game which requires that the drifting cups stop randomly on the meandering stream. The most ideal design for a meandering stream is to make the drifting cups achieve the identical probability of entering every vortex region along the stream. In fact it is very difficult.

In our study results, we find that all the meandering streams, which qualify the requirements of the game, share some common features:

- For the channel: contraction sections, expansion sections and a proper curvature. Contraction sections accelerate the flow. Expansion sections make the flow separate and form vortex regions on the side of the main flow. A proper curvature can bend the main flow. Under this condition, the inertia of the drifting object can help it escape from the main flow and enter vortex regions.
- For the flow: high Re number and high turbulence. These features will enhance the possibility of the drifting object's entering vortex region from the main flow and vice versa.

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