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ON THE ARTISTIC USE OF FLUID FLOW PATTERNS MADE VISIBLE

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Abstract—*The authors present methods of making visible flow patterns in fluid flows that are used in research at the Illinois Institute of Technology and the application of photographs of them for artistic purposes. The flow patterns are made visible by releasing streams of electrolytically generated bubbles in water flows and of filaments of smoke in air flows. Simplified versions of the techniques for use by artists are briefly described. They hope their article will stimulate more artists to consider patterns in fluid flows as sources for the content of their works.*

I. INTRODUCTION

The pursuits of artists and of basic and applied scientists appear to have little, if anything, in common. However, an observant person cannot help noticing the important role played by imagination or, as it is popular to say, creativity, in these endeavours and the admiration some of them have for each other's achievements. Recently attempts have been made to stimulate wider collaboration between artists and scientists and engineers. The tools and results of scientific research are being used more and more by artists in advanced technology countries [1, 2]. The topic of this article is one such instance. Many other examples can be found in past issues of *Leonardo*.

We have also made an artistic application of visual methods of studying stress patterns [3] as have, for example, J. A. Burns and J. K. Burns [4]. One may also mention in this context 'marbling', an art that apparently originated in the 16th century in England and has since been used widely by bookbinders to decorate the edges and covers of books. It is not generally known but worth noting that 'marbling' makes use of rather sophisticated flow phenomena in viscous fluids.

II. ON MAKING FLUID FLOW VISIBLE

Flow of liquids and gases along surfaces, around objects and through enclosed spaces are of much interest and importance to physicists and to various kinds of engineers. Some of the features of these flows aid in the understanding of fundamental aspects of meteorology and oceanography and in the design of aircraft, fluid handling machinery and industrial processes.

Most examples of fluids in motion are highly complicated, since they involve unsteady nonuniform phenomena such as turbulence and waves that, as a rule, defy rigorous mathematical analysis. Often the only road to an adequate understanding of even the simplest of flows is very carefully controlled experiments and empirical analyses. Actually, recorded observations of flow patterns were made by early natural philosophers. Some of the most interesting are the drawings of Leonardo da Vinci in 1507–9 of a stream of water discharging from a pipe into air and then flowing into a quiescent reservoir of water [5] and of patterns of vortices formed behind a walking stick partially immersed in a shallow stream [6]. These drawings reflect his fascination with vortices, waves and other complex flow phenomena.

While some patterns of vortices in flowing water can be seen with the unaided eye, the most effective means of viewing them involves the use of tracer materials suspended in the fluid. In our work we use a relatively new technique for studying water flow that makes use of tiny hydrogen bubbles as tracers. The bubbles are generated electrolytically along a very thin platinum wire (0·04 mm dia.) in the water. When the wire is supplied continuously with electric current, a sheet of bubbles is shed from the wire into the water and, under proper illumination, the path lines of the individual bubbles become clearly visible, being revealed as white streaks in photographs. When the electric current is pulsed,

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the production of bubbles is momentarily interrupted. An interruption in the sheet of bubbles appears as a break in a band of white streaks. Since these breaks appear at known intervals, they are called 'time lines'. The patterns formed by the path lines and time lines reveal details of the motion of the fluid flow. Electrolysis is induced by a potential of several hundred volts between the platinum wire serving as one electrode (negative) at a location upstream of the zone of observation and a second electrode (positive) immersed in the water at a downstream location. The principal electrical components are a DC power supply, a pulse generator and an amplifier. The pulse generator and amplifier, acting as an electronic switch, are capable of producing pulses of current of 0·20–30 sec in duration and of repetition rates ranging from 0·075 to 200 cycles/sec.

The size of the bubbles is controlled by adjusting the voltage across the electrodes. A close control of bubble size is important, because, if they are too small, the amount of light they reflect will be insufficient for making white streaks on photographic film and if they are too large, they will not follow the flow with sufficient accuracy. Thus, for velocities below 10 cm/sec in water, satisfactory results can be obtained only if the diameter of the bubbles range between 10/1000 and 25/1000 mm.

Water flows are often studied in an open channel of rectangular cross section having transparent side walls. The best photographs are made when the bottom of the channel is black and illumination is provided by two or more flood lights shining obliquely through the side walls of the channel from the sides. Additional details of this technique and further examples of intricate flow patterns are given in References 7 and 8 respectively.

A typical photograph of flow patterns made visible by entrained hydrogen bubbles is given in Fig. 1. These alternating vortices are called *Kármán vortex street* in recognition of his successful analysis of the phenomenon with the aid of mathematics. The figure shows eight bands of bubbles produced by eight electrical pulses each of about 0·04 sec duration. The photograph was made looking down upon an open channel formed by two flat Plexiglas side walls and a matte black painted bottom, with water flowing from right to left. The two bands of bubbles at the right have not arrived at the obstruction, a vertical rod. The third band from the right can be seen bending around the rod. The remaining bands are downstream of the rod, showing the vortices formed in the wake of the rod.

A very common technique for delineating flow patterns in air involves the use of smoke filaments. Smoke filaments are often produced by introducing one of the following substances into an airstream

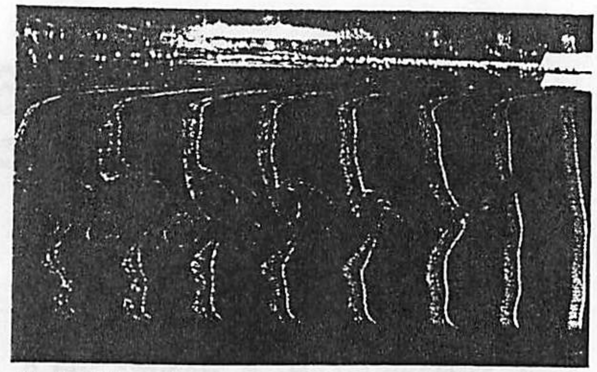

Fig. 1. View of vortices in a water stream in the wake of a rod of circular cross section placed perpendicular to the stream.

Fig. 2. A. Douthat, artistic photograph based on the pattern of vortices shown in Fig. 1.

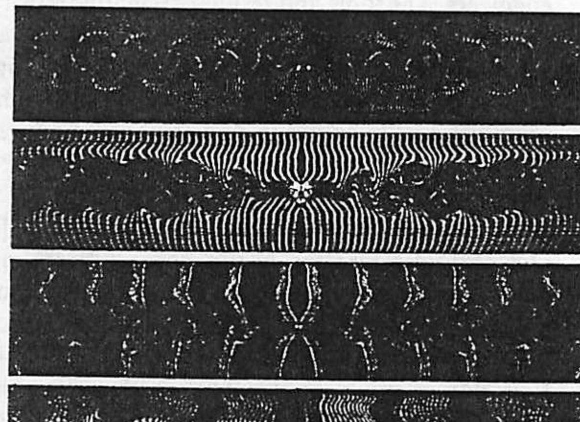

Fig. 3. A. Douthat, four photo-montages of vortices in a water stream in the wake of a rod of circular cross section placed perpendicular to the stream for different pulse rates and durations used to generate hydrogen bubbles.

through small tubes: (1) a solution (e.g. titanium tetrachloride) that reacts with moisture in air to form white particles (smoke); (2) products of incomplete combustion of organic matter (e.g., cigar smoke or smoke from burning straw) or (3) a mist produced by mixing hot oil vapor (e.g., kerosene or paraffin) with air at room temperature. In our

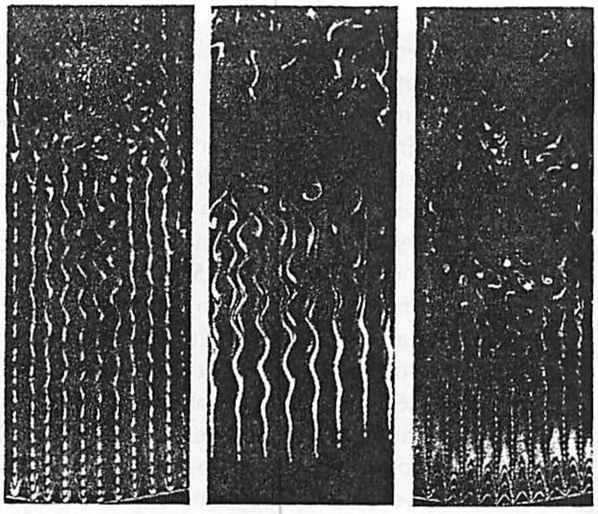

Fig. 4. A. Douthat, three photo-montages of vortices in a water stream in the wake of a row or rake of rods of rectangular cross section.

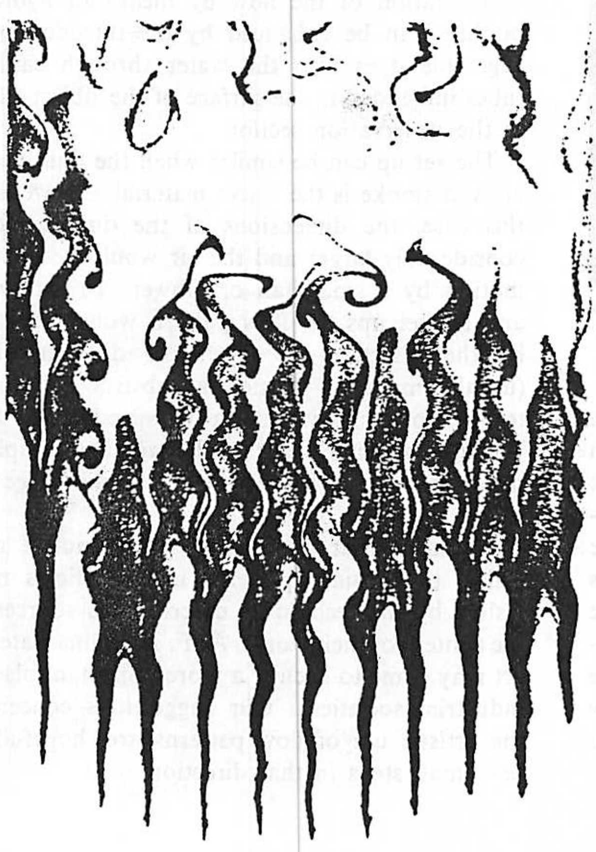

Fig. 5. A. Douthat, artistic photograph based on the vortices in the wake of a row or rake of rods of rectangular cross section shown at the center of Fig. 4.

work with air flows we have used cigar smoke and kerosene vapor.

The quality of photographs of smoke patterns in an air stream depends critically on the illumination. For best results, both the object (rods, models of airplane wings, etc.) and the surrounding walls should be painted matte black so that the smoke will appear in the strongest contrast. The clarity of the smoke patterns is often greatly enhanced when the flow is illuminated only by narrow sheets of light parallel to the field of view. This is accomplished by masking the observation window so that light enters the air duct only through a narrow slit. Various views of the air flow are revealed by the employment of slits at different locations of the window or with different orientations.

We have used two cameras to photograph the flow of water and of air: (1) a Nikon-F, 35 mm SLR camera with bellows attachment and 105 mm, f-4 lens or (2) a Graphic View 4 × 5 camera with a Rapax-Wollensak 135 mm, f-4·7 lens. Either Kodak TRI-X film pushed to ASA 1200 by developing it in Acufine made by Acufine, Inc., Chicago, Ill., U.S.A. or Kodak Royal-Pan film rated at ASA 1250 and overdeveloped in Kodak DK-50 were used to record the images. The overexposure of film and prints and the use of high-contrast film, paper and chemicals are recommended.

III. ARTISTIC APPLICATIONS OF FLOW PATTERNS

The flow pattern of Fig. 1, which shows vortices in a water stream in the wake of a rod of circular cross section, is the basis of artistic compositions made by one of us (A.S D.) (Figs. 2 and 3). In Fig. 3 are montages of photographs made with the same water-rod system but at different pulse rates and durations of generated bubbles, having bands of different widths, spacings and intensities. The artistic photograph in Fig. 2 was taken from a part of the photograph in Fig. 1 and was made by the photographic process of Kodalith separation that utilizes a graphic arts orthotype film made by Kodak, which registers only black and white. Exposing one Kodalith negative from the original negative by using an enlarger and reversing the Kodalith negative onto another one by exposing them in contact, yielded the final negative used for the print. Each of the four pictures in Fig. 3 consists of a pair of photographic prints, one of which is printed using the negative upside down (i.e. reversed). For each pair, the prints were joined along a vertical line through the center of the rod and thus a symmetrical pattern was obtained.

In Fig. 4 are shown the vortices in the wake of a row or rake of rods of rectangular cross section. In Fig. 5 is an artistic photograph based on the middle picture in Fig. 4. It was made by the process of Kodalith separation outlined above.

Photographs of flow patterns in air with kerosene and cigar smoke as tracing material are shown in Figs. 6 and 7 respectively. Two different pairs of photographs and reversed versions of them were combined to form the montage in Fig. 6. The vortices were formed when a stream of air

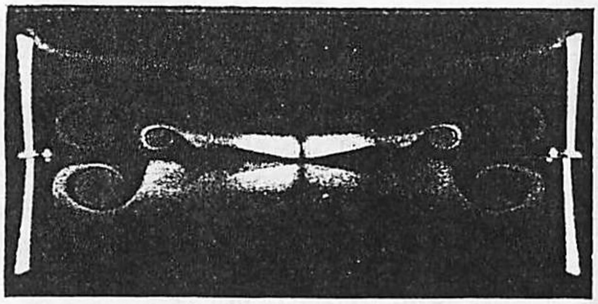

Fig. 6. A. Douthat, a photo-montage of vortices formed when a stream of air impinged on a cube.

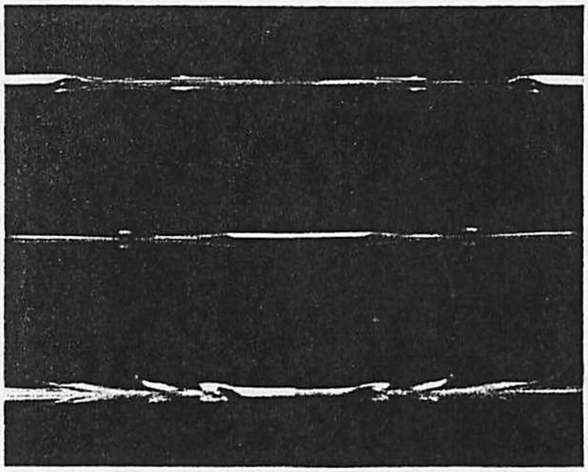

Fig. 7. A. Douthat. a photo-montage of three flow patterns formed downstream of an object mounted on a thin flat plate placed parallel to a pulsating air stream.

impinged on a blunt object, such as a cube. The cube does not appear in Fig. 6 but the reflection from one of its sides can be seen as the white bands at the edges of the photographs. Three photographs and a reversed version of each of them are shown in the montage in Fig. 7. The flow patterns were formed near the surface of a thin flat plate placed parallel to a pulsating air stream downstream of an obtsacle, such as a rod placed on the plate perpendicular to the flow direction. The flow pattern and its reflection in the shiny plate are evident in each photograph.

IV. SIMPLIFIED TECHNIQUES FOR ARTISTIC APPLICATIONS

In the preceding sections we have shown photographs of flow patterns obtained in fluid dynamics research that we find aesthetically pleasing and discussed their possible use for artistic purposes. It is self-evident that the artistic possibilities will be enlarged if an artist can use the apparatus described to produce flow patterns that are not necessarily of scientific interest. Occasionally artists can collaborate with researchers to make use of their experimental equipment for artistic purposes. However, it seems much more exciting and rewarding if an artist designs and constructs his own experimental equipment and learns to produce varied patterns of interest.

Experimental apparatus of the types described can be simplified so that it would not be difficult for an artist to construct it. If water is the fluid to be used, the apparatus could consist of two containers, a feed tank and a receptor tank, each having a capacity of 4 or 5 gal (15 or 20 l.), connected one to the other by a channel having a rectangular cross section with Plexiglas sides. The water would be recycled between the receptor tank to the feed tank by a small pump driven by an electric motor. For best results, it is desirable to keep smooth the inlet flow to the observation section, i.e. to suppress turbulent motion. To this end, one or more fine mesh screens are placed in the flow before it reaches the observation section. Visualization of the flow by means of hydrogen bubbles can be enhanced by the introduction of vegetable dyes into the water through capillary tubes imbedded in the surface of the object placed in the observation section.

The set up can be similar when the fluid used is air and smoke is the tracer material. However, in this case, the dimensions of the duct could be considerably larger and the air would be put into motion by a small fan or blower. In both water and air set ups the flow pattern would be varied by the insertion of objects of different shape (usually made of plastics) as obstructions in the test section and by varying the speed of the flow. The flow of water or air can be regulated simply by means of a throttling valve on the discharge side of the pump or blower.

We hope that our article will stimulate more artists to consider patterns in fluid flows made visible by the techniques described as sources for the content of their works. As F. J. Malina states [9], art may come to occupy a more important place in industrial societies. Our suggestions concerning the artistic use of flow patterns are, hopefully, a few small steps in that direction.

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