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A century of fluid mechanics: 1870–1970 / Un siècle de mécanique des fluides : 1870–1970

The use of images in fluid mechanics

L'utilisation des images en mécanique des fluides

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ABSTRACT

Still images, photographs and drawings, as well as movies are widely used in fluid mechanics and this has been true since the very early developments of this discipline. The intrinsic geometrical complexity of fluid flows, in particular when they are turbulent, explains this necessity of using visual representations to gain a physical understanding of the phenomena involved. The aesthetic appeal of images in fluid mechanics research is another reason why their use is more prevalent than in other fields of the physical sciences.

RÉSUMÉ

Les images fixes, photographies et dessins, aussi bien que les films et vidéos sont très largement utilisées en mécanique des fluides, et ce depuis les tous premiers développements de cette discipline. La complexité géométrique intrinsèque des écoulements, et tout particulièrement des écoulements turbulents, explique cette nécessité du recours à une représentation visuelle pour faire émerger une compréhension physique des phénomènes mis en jeu. Le caractère esthétique des images produites en recherche en mécanique des fluides est une autre raison pour laquelle leur utilisation est beaucoup plus importante que dans d'autres champs des sciences physiques.

1. Introduction

Fluid flows are complex objects evolving in a three-dimensional space and in time. Physicists and applied mathematicians manipulate the velocity, vorticity, and pressure fields as mathematical entities, but a complete understanding of the phenomena requires almost always the visualization of the flow through photographs, movies or drawings.

In addition to this necessary visual representation, there is an undeniable esthetic appeal in flow images. Unstable and turbulent flows have this remarkable capacity to generate spontaneously ordered but fluctuating structures that fascinate both laymen and specialists.

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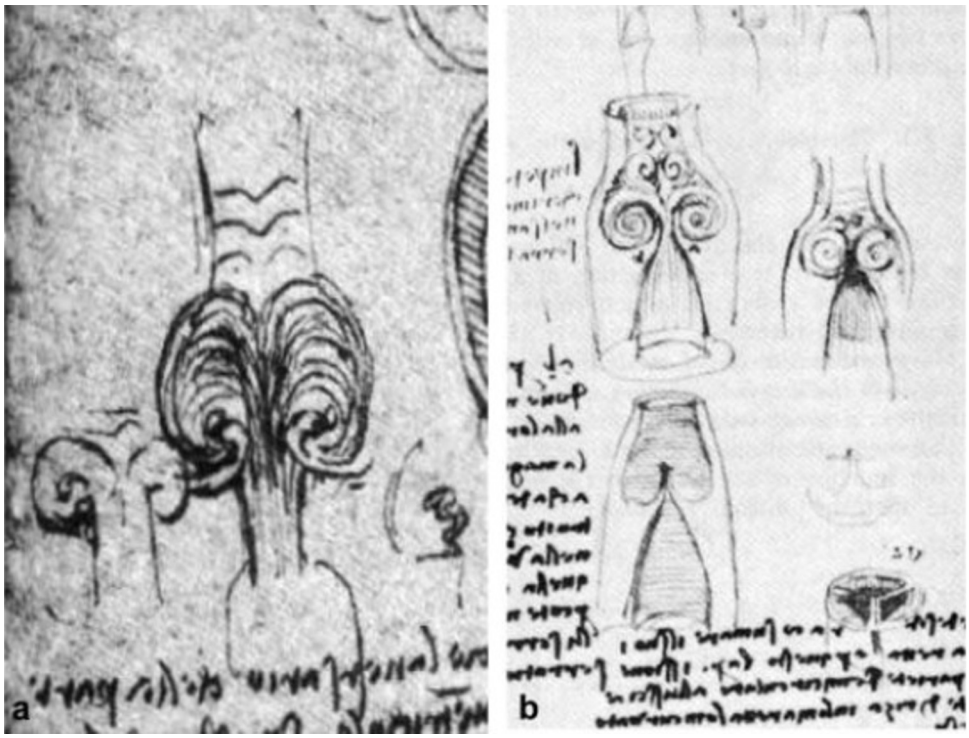

Fig. 1. Drawings by Leonardo da Vinci on the flow in a model of cardiac circulation. Images taken from [1].

Images have thus acquired a preeminent status in the work of fluid dynamicists, firstly for their own reflection and then to communicate with colleagues, students, and the general public. We describe here the multiple facets of these uses, beginning with a short summary of the developments of the techniques used to produce images. We then describe in more detail the role played by images in two major conceptual breakthroughs, namely, at the turn of the twentieth century, the separation of flows into a boundary layer and an outer flow and the discovery of permanent structures in turbulent boundary layers and shear flows in the 1960s and 1970s. Finally, we discuss the current status of images which definitely go beyond the support of a qualitative description of the flow structure.

2. From eye and pencil to ultrafast digital cameras and dpiv, the development of techniques

The need for a graphical representation of flows appears immediately when we try to analyze them. Through history, the depiction of fluid flows has gone from a simple visual observation, recorded on paper thanks to the memory and to the interpretation of the observer, to a very sophisticated quantitative analysis highly resolved in time.

The notebooks of Leonardo da Vinci give many examples of direct visual representations. For all the free surface flows that represent the major part of the drawings, Leonardo uses the deformations of the free surface and the entrainment of bubbles within the liquid to build his graphical analysis of flows. But, for “internal flows”, Leonardo develops a strategy which is still in use today: he seeds the fluid, otherwise transparent, with small particles, plant seeds, sawdust…, to reveal its motion and transcribe it to paper. Doing so, he is initiating a truly scientific analysis of flow fields. A very striking example is his study of the cardiac flow (Fig. 1). Following his anatomical observations, he designs a model of the left heart made out of glass and reveals the recirculation vortices initiated by the sudden enlargement of the aortic duct [1]. The original observations of Leonardo on this subject are very similar to modern visualizations obtained with much more sophisticated techniques. But if we consider his drawings of turbulent eddies created by jets of water falling into basins and pools, it is more difficult to separate a scientific analysis from an idealized artistic rendering.

Four centuries after Leonardo’s birth, eye and pencil are still the only means of recording the motion of fluids. A remarkable study of this kind is done by Felix Savart on liquid sheets resulting from the impact of water jets [2–4] and published in the *Annales de chimie et de physique* in 1833. Savart controls precisely the velocity of the jets and their impact parameters and a clever stroboscopic device enables him to draw very precisely the shapes of the water/air interfaces (Fig. 2).

The discovery of photography in the middle of the nineteenth century is a true revolution because it is now possible to record faithfully the motion of fluids. Photographic films on rolls of celluloid are available as soon as 1885; they are slow compared to modern ones by typically an order of magnitude, but thanks to electricity, high-speed photography became quickly a reality. A good example is given by Worthington in 1897 with a synchronizing system (Fig. 3) which is the key to record the impact of a solid sphere in a liquid and the subsequent interface deformation and generation of droplets [5].