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History of fluid mechanics

1.1 Fluid mechanics in everyday life

There is air around us, and there are rivers and seas near us. 'The flow of a river never ceases to go past, nevertheless it is not the same water as before. Bubbles floating along on the stagnant water now vanish and then develop but have never remained.' So stated Chohmei Kamo, the famous thirteenth-century essayist of Japan, in the prologue of *Hohjohki*, his collection of essays. In this way, the air and the water of rivers and seas are always moving. Such a movement of gas or liquid (collectively called 'fluid') is called the 'flow', and the study of this is 'fluid mechanics'.

While the flow of the air and the water of rivers and seas are flows of our concern, so also are the flows of water, sewage and gas in pipes, in irrigation canals, and around rockets, aircraft, express trains, automobiles and boats. And so too is the resistance which acts on such flows.

Throwing baseballs and hitting golf balls are all acts of flow. Furthermore, the movement of people on the platform of a railway station or at the intersection of streets can be regarded as forms of flow. In a wider sense, the movement of social phenomena, information or history could be regarded as a flow, too. In this way, we are in so close a relationship to flow that the 'fluid mechanics' which studies flow is really a very familiar thing to us.

1.2. The beginning of fluid mechanics

The science of flow has been classified into hydraulics, which developed from experimental studies, and hydrodynamics, which developed through theoretical studies. In recent years, however, both have merged into the single discipline called fluid mechanics.

Hydraulics developed as a purely empirical science with practical techniques beginning in prehistoric times. As our ancestors settled to engage in farming and their hamlets developed into villages, the continuous supply of a proper quantity of water and the transport of essential food and

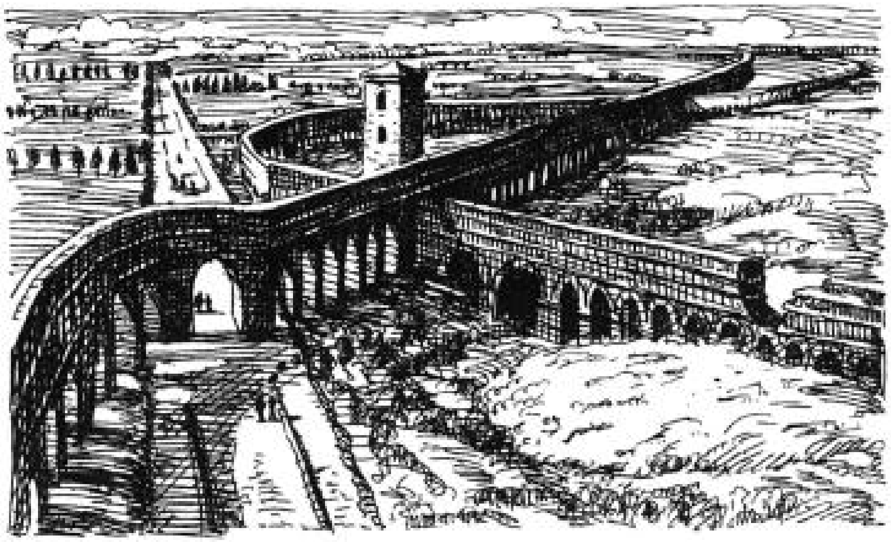

Fig. 1.1 Restored arch of Roman aqueduct in Compania Plain, Italy

materials posed the most important problems. In this sense, it is believed that hydraulics was born in the utilisation of water channels and ships.

Prehistoric relics of irrigation canals were discovered in Egypt and Mesopotamia, and it has been confirmed that canals had been constructed more than 4000 years BC.

Water in cities is said to have began in Jerusalem, where a reservoir to store water and a masonry channel to guide the water were constructed. Water canals were also constructed in Greece and other places. Above all, however, it was the Romans who constructed channels throughout the Roman Empire. Even today their remains are still visible in many places in Europe (Fig. 1.1).

The city water system in those days guided relatively clear water from far away to fountains, baths and public buildings. Citizens then fetched the water from water supply stations at high street corners etc. The quantity of water a day used by a citizen in those days is said to be approximately 180 litres. Today, the amount of water used per capita per day in an average household is said to be approximately 240 litres. Therefore, even about 2000 years ago, a considerably high level of cultural life occurred.

As stated above, the history of the city water system is very old. But in the development process of city water systems, in order to transport water effectively, the shape and size of the water conduit had to be designed and its

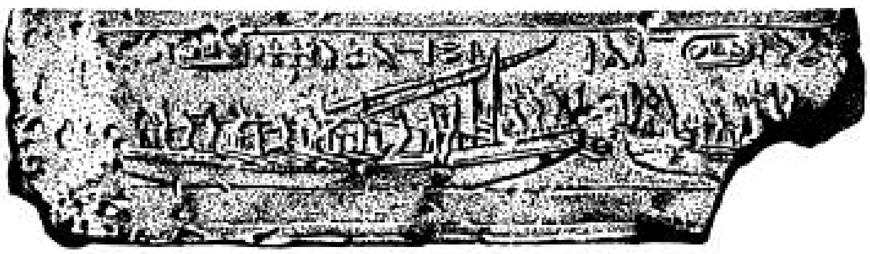

Fig. 1.2 Relief of ancient Egyptian ship

Fig. 1.3 Ancient Greek ship depicted on old vase

inclination or supply pressure had to be adjusted to overcome friction with the wall of the conduit. This gave rise to much invention and progress in overcoming hydraulic problems.

On the other hand, the origin of the ship is not clear, but it is easy to imagine the course of progress from log to raft, from manual propulsion to sails, and from river to ocean navigation. The Phoenicians and Egyptians built huge, excellent ships. The relief work shown in Fig. 1.2, which was made about 2700BC, clearly depicts a ship which existed at that time. The Greeks also left various records of ships. One of them is a beautiful picture of a ship depicted on an old Grecian vase, as shown in Fig. 1.3. As these objects indicate, it was by progress in shipbuilding and also navigation techniques that allowed much fundamental hydraulic knowledge to be accumulated.

Before proceeding to describe the development of hydraulics, the Renaissance period of Leonardo da Vinci in particular should be recalled. Popularly he is well known as a splendid artist, but he was an excellent scientist, too. He was so well versed in the laws of natural science that he stated that 'a body tries to drop down onto the earth through the shortest path', and also that 'a body gives air the same force as the resistance which air gives the body'. These statements preceded Newton's law of gravity and motion (law of action and reaction).

Particularly interesting in the history of hydraulics is Leonardo's note where a vast description is made of the movement of water, eddies, water waves, falling water, the destructive force of water, floating bodies, efflux and the flow in a tube/conduit to hydraulic machinery. As examples, Fig. 1.4 is a sketch of the flow around an obstacle, and Fig. 1.5 shows the development of vortices in the separation region. Leonardo was the first to find the least resistive 'streamline' shape.

Leonardo da Vinci (1452–1519)
An all-round genius born in Italy. His unceasing zeal for the truth and incomparable power of imagination are apparent in numerous sketches and astonishing design charts of implements, precise human anatomical charts and flow charts of fluids. He drew streamlines and vortices on these flow charts, which almost satisfy our present needs. It can therefore be said that he ingeniously suggested modern flow visualisation.

In addition, he made many discoveries and observations in the field of hydraulics. He forecast laws such as the drag and movement of a jet or falling water which only later scholars were to discover. Furthermore he advocated the observation of internal flow by floating particles in water, i.e. ‘visualisation of the flow’. Indeed, Leonardo was a great pioneer who opened up the field of hydraulics. Excellent researchers followed in his footsteps, and hydraulics progressed greatly from the seventeenth to the twentieth century.

Fig. 1.4 Sketches from Leonardo da Vinci's notes (No. 1)

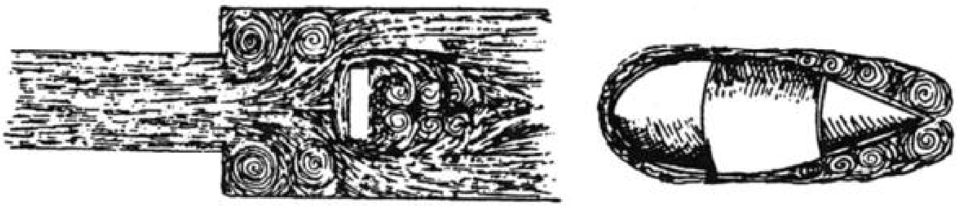

Fig. 1.5 Sketches from Leonardo da Vinci's notes (No. 2)

On the other hand, the advent of hydrodynamics, which tackles fluid movement both mathematically and theoretically, was considerably later than that of hydraulics. Its foundations were laid in the eighteenth century. Complete theoretical equations for the flow of non-viscous (non-frictional) fluid were derived by Euler (see page 59) and other researchers. Thereby, various flows were mathematically describable. Nevertheless, the computation according to these theories of the force acting on a body or the state of flow resulted in a very different outcome from the experimentally observed result.

In this way, hydrodynamics was thought to be without practical use. In the nineteenth century, however, it made such progress as to compete fully with hydraulics. One example of such progress was the derivation of the equation for the movement of a viscous fluid by Navier and Stokes. Unfortunately, since this equation has convection terms among the terms expressing the inertia (the terms expressing the force which varies from place to place), which renders the equation nonlinear, it was not an easy thing to obtain the analytical solution for general flows – only such special flows as laminar flow between parallel plates and in a round tube were solved.

Meanwhile, however, in 1869 an important paper was published which connected hydraulics and hydrodynamics. This was the report in which Kirchhoff, a German physicist (1824–87), computed the coefficient of contraction for the jet from a two-dimensional orifice as 0.611. This value coincided very closely with the experimental value for the case of an actual orifice – approximately 0.60.

As it was then possible to compute a value near the actual value, hydrodynamics was re-evaluated by hydraulics scholars. Furthermore, in the present age, with the progress in electronic computers and the development of various numerical techniques in hydrodynamics, it is now possible to obtain numerical solutions of the Navier–Stokes equation. Thus the barrier between hydraulics and hydrodynamics has now been completely removed, and the field is probably on the eve of a big leap into a new age.