Historical Development of Fluid Dynamics

Dr. R.S. Pundhir

J. S. University, shikohabad

Abstract

In this paper we discuss about the history and development of fluid dynamics. Fluid dynamics is the subfield of fluid mechanics. Fluid mechanics is the combination of hydraulics and hydrodynamics. Hydraulics developed as an empirical science beginning from the pre-historical times. The advent of hydrodynamics, which tackles fluid movement theoretically, was in eighteenth century by various scientists. Complete theoretical equations for the flow of non-viscous fluid were derived by Euler and other scientists. In the nineteenth century, hydrodynamics advanced sufficiently to derivate the equation for the motion of a viscous fluid by Navier and Stokes: only laminar flow between parallel plates was solved. In the present age, with the progress in computers and numerical techniques in hydrodynamics, it is now possible to obtain numerical solutions of Navier-Stokes equation.

Keywords: Pascal's law, hydrostatics, hydrodynamics, Hagen- Poiseuille equation, Vortex Dynamics.

1. Introduction

The history of fluid mechanics, the study of how fluids move and the forces on them, dates back to the ancient Greeks. A pragmatic, if not scientific, knowledge of fluid flow was exhibited by ancient civilizations, such as in the design of arrows, spears, boats and particularly hydraulic engineering projects for flood protection, irrigation, drainage and water supply (Garbrecht 1987). The earliest human civilizations began near the shores of rivers, and consequently, coincided with the dawn of hydrology, hydraulics and hydraulic engineering.

Archimedes

The fundamental principles of hydrostatics and dynamics were given by Archimedes in his work on floating bodies (ancient Greek), around 250 BCE. In it, Archimedes develops the laws of buoyancy, also known as Archimedes' Principle. This principle states that a body immersed in a fluid experiences a buoyant force equal to the weight of the fluid it displaces (Caroll 2007). Archimedes mentioned that each particle of a fluid mass, when in equilibrium, is equally pressed in every direction; and he inquired into the conditions according to which a solid body floating in a fluid should assume and preserve a position of equilibrium (Greenhill 1912).

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The Alexandrian

In the Greek school at Alexandria, which flourished under the auspices of the Ptolemies, attempts were made at the construction of hydraulic machinery, and in about 120 BCE the fountain of compression, the siphon and the forcing-pump were invented by Ctesibius and Hero. The siphon is a simple instrument; but the forcing-pump is a complicated invention, which could scarcely have been expected in the infancy of hydraulics. It was probably suggested to Ctesibius by the Egyptian wheel or Noria, which was common at that time, and which was a kind of chain pump, consisting of a number of earthen pots carried round by a wheel. In some of these machines the pots have a value in the bottom which enables them to descend without much resistance, and diminishes greatly the load upon the wheel; and, if we suppose that this value was introduced so early as the time of Ctesibius, it is not difficult to perceive how such a machine might have led to the invention of the forcing-pump (Greenhill 1911).

Sextus Julius Frontinus

Notwithstanding these inventions of the Alexandrian school, its attention does not seem to have been directed to the motion of fluids; and the first attempt to investigate this subject was made by Sextus Julius Frontinus, inspector of the public fountains at Rome in the reigns of Nerva and Trajan. In his work De aquaeductibus urbis Romae commentaries, he considers the methods which were at that time employed for ascertaining the quantity of water discharged from tubes and the mode of distributing the waters of a water supply or a fountain. He remarked that flow of water from an orifice depends not only on the magnitude of the orifice itself, but also on the height of the water in the reservoir; and that a pipe employed to carry off a portion of water from an aqueduct should, as circumstances required, have a position more or less inclined to the original direction of the current. But as he was continued with the law of the velocities of running water as depending upon the depth of the orifice, the want of precision which appears in his results is not surprising (Greenhill 1912).

Seventeenth and Eighteenth Centuries

CASTELLI AND TORRICELLI

Benedetto Castelli and Evangelista Torricelli, two of the disciples of Galileo, applied the discoveries of their master to the science of hydrodynamics. In 1628 Castelli published a small work, Della misura dell' acque correnti, in which he suitably explained several phenomena in the motion of fluids in rivers and canals; but he committed a great paralogism in supposing the velocity of the water proportional to the depth of the orifice below the

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surface of the vessel. Torricelli, observing that in a jet where the water rushed through a small nozzle it rose to nearly the same height with the reservoir from which it was supplied, imagined that it ought to move with the same velocity as if it had fallen through that height by the force of gravity and, hence, he deduced the proposition that the velocities of liquids are as the square root of the head, apart from the resistance of the air and the friction of the orifice. This theorem was published in 1643, at the end of his treatise De motu gravium projectorum and it was confirmed by the experiments of Raffaello Magiotti on the quantities of water discharged from different ajutages under different pressures (Greenhill 1912).

BLAISE PASCAL

In the hands of Blaise Pascal hydrostatics assumed the dignity of a science and in a treatise on the equilibrium of liquids, found among his manuscripts after his death and published in 1663, the laws of the equilibrium of liquids were demonstrated in the most simple manner, and amply confirmed by experiments (Greenhill 1912).

STUDIES BY ISAAC NEWTON

Friction and Viscosity

The effects of friction and viscosity in diminishing the velocity of running water were noticed in the Principia of Isaac Newton, who threw much light upon several branches of hydromechanics. At a time when the Cartesian system of vortices universally prevailed, he found it necessary to investigate that hypothesis and in the course of his investigations he showed that the velocity of any stratum of the vortex is an arithmetical mean between the velocities of the strata which enclose it; and from this evidently follows that the velocity of a filament of water moving in a pipe is an arithmetical mean between the velocities of the filaments which surround it. Taking advantage of these results, Italian-born French engineer Henri Pitot afterwards showed that the retardations arising from friction are inversely as the diameters of the pipes in which the fluid moves (Greenhill 1912).

Orifices

The attention of Newton was also directed to the discharge of water from orifices in the bottom of vessels.

Waves

Newton was also the first to investigate the difficult subject of the motion of waves.

DANIEL BERNOULLI

Daniel Bernoulli's work on hydrodynamics demonstrated that the pressure in a fluid decreases as the velocity of fluid flow increases. He also formulated Bernoulli's law and

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made the first statement of the kinetic theory of gases. In fluid dynamics, Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The principle is named after Daniel Bernoulli who published it in his book Hydrodynamica in 1738 (Greenhill 1912).

JEAN LE ROND D'ALEMBERT

In fluid dynamics, d'Alembert's paradox (or the hydrodynamic paradox) is a contradiction reached in 1752 by French mathematician Jean le Rond d'Alembert. He proved that for incompressible and inviscid potential flow-the drug force is zero on a body moving with constant velocity relative to the fluid.

LEONHARD EULER

The resolution of the questions concerning the motion of fluids was effected by means of Leonhard Euler's partial differential coefficients. This calculus was first applied to the motion of water by d'Alembert and enabled both him and Euler to represent the theory of fluids in formulae restricted by no particular hypothesis (Greenhill 1912).

GOTTHILF HAGEN

Hagen-Poiseuille equation: In 1839, Hagen undertook careful experiment in brass tubes that enabled him to discover the relationship between the pressure drop and the tube diameter under conditions of laminar flow of homogeneous viscous liquids.

Nineteenth Century

HERMANN VON HELMHOLTZ

In 1858, Hermann Von Helmholtz published his seminal paper "Uber Integrale der Hydrodynamischen Gleichungen, Welche den Wirbelbewegungen entsprechen", in Journal fur die reine und angewandte mathematk. So important was the paper that a few years later P.G. Tait published an English translation, "On Integrals of the Hydrodynamical Equations which Express Vortex Motion", in Philosophical Magazine (1867). In his paper Helmholtz established his three "laws of vortex motion" in much the same way one finds them in any advanced textbook of fluid mechanics today. This work established the significance of vorticity to fluid mechanics and science in general. For the next century or so, vortex dynamics matured as a subfield of fluid mechanics, always commanding at least a major chapter in treatises on the subject. Thus, H. Lamb's well-known Hydrodynamics (1932) devotes full chapter to vorticity and vortex dynamics as does G.K. Batchelor's An Introduction to Fluid Dynamics (1967). In due course entire treatises were developed to vortex motion. H. Poincare's Theorie des Tourbillons (1893), H. Villat't's Lecons sur la

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Theorie des Tourbillons (1930), C. Truesdeil's The Kinematics of Vorticity (1954), and P.G. Staffman's Vortex Dynamics (1992) may be mentioned. Earlier individual sessions at scientific conferences were devoted to vortices, vortex motion, vortex dynamics and vortex flows. Later, entire meetings were devoted to the subject.

The range of applicability of Helmholtz's work grew to encompass atmospheric and oceanographic flows, to all branches of engineering and applied science and, ultimately, to superfluids (today including Bose-Einstein condensates). In modern fluid mechanics, the role of vortex dynamics in explaining flow phenomena is firmly established. Well-known vortices have acquired names and are regularly depicted in the popular media: hurricanes, tornadoes, waterspouts, aircraft trailing vortices (e.g Wingtip vortices), drainhole vortices (including the bathtub vortex), smoke rings, underwater bubble air rings, cavitation vortices behind ship propellers and so on. In the technical literature, a number of vortices that arise under special conditions also have names: the Karman Vortex Street wake behind a bluff body, Taylor Vortices between rotating cylinders, Gortler Vortices in flow along a curved wall, etc.

JEAN NICOLAS PIERRE HACHETTE

J.N.P. Hachette in 1816-17 published memoirs containing the results of experiments on the spouting of fluids and the discharge of vessels. His object was to measure the contracted part of a fluid vein, to examine the phenomena attendant on additional tubes, and to investigate the form of the fluid vein and the results obtained when different forms of orifices are employed.

Twentieth Century

DEVELOPMENTS IN VORTEX DYNAMICS

Vortex dynamics is a vibrant subfield of fluid dynamics, commanding attention at major scientific conferences and precipitating workshops and symposia that focus fully on the subject.

Vortex atom theory is the new dimension in the history of vortex dynamics, which was done by William Thomson; later it was developed by Lord Kelvin. His basic idea was that atoms were to be represented as vortex motions in the ether. This theory predated the quantum theory by several decades and because of the scientific standing, its originator received considerable attention. Many profound insights into vortex dynamics were generated during the pursuit of this theory. Other interesting corollaries were the first counting of simple knots by P.G. Tait, today considered a pioneering effort in graph theory, topology, and knot theory. Ultimately, Kelvin's vortex atom was seen to be wrong-headed but the many

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results in vortex dynamics that it precipitated have stood the test of time. Kelvin himself originated the notion of circulation and proved that in an inviscid fluid circulation around a material, contour would be conserved. This result singled out by Einstein in "Zum hundertjahrigen Gedenktag von Lord Kelvins Geburt, Naturwissensschaften" (1924) (title translation: "On the 100th Anniversary of Lord Kelvin's Birth"), as one of the most significant results of Kelvin's work provided an early link between fluid dynamics and topology.

The history of vortex dynamics seems particularly rich in discoveries and rediscoveries of important results, because results obtained were entirely forgotten after their discovery and then were rediscovered decades later. Thus, the integrability of the problem of three-point vortices on the plane was solved in the 1877 thesis of a young Swiss applied mathematician named Walter Grobli. In spite of having been written in Gottingen in the general circle of scientists surrounding Helmholtz and Kirchhoff, and in spite of having been mentioned in Kirchhoff's well-known lectures on theoretical physics and in other major texts such as Lamb's Hydrodynamics, this solution was largely forgotten. In an article appeared in the year 1949, it was noted that mathematician J.L. Synge created a brief revival, but Synge's paper was in turn forgotten. A quarter century later a 1975 paper by E.A. Novikov and a 1979 paper by H. Aref on chaotic advection finally brought this important earlier work to light. The subsequent elucidation of chaos in the four-vortex problem, and in the advection of a passive particle by three vortices, made Grobli's work part of "modern science".

Another example of this kind is the so-called "Localized Induction Approximation" (LIA) for three-dimensional vortex filament motion, which gained favour in the mid-1960s through the works of R.J. Arms, Francis R. Hama, Robert Betchov and others, but turns out to date from the early years of the twentieth century in the work of Da Rios, a gifted student of the noted Italian mathematician T. Levi-Civita. Da Rios published his results in several forms but they were never assimilated into the fluid mechanics literature of his time. In 1972 H. Hasimoto used Da Rios" "Intrinsic Equations" (later rediscovered independently by R. Betchov) to show how the motion of a vortex filament under LIA could be related to the non-linear Schrodinger equation. This immediately made the problem part of "modern science" since it was then realized that vortex filaments can support solitary twist waves of large amplitude.

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