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TURBULENT HISTORY OF FLUID MECHANICS

Essay summary

In this essay, a timeline of fluid mechanics history is presented. The intention of the timeline is to systematically capture the evolution process from the beginning i.e. liquid statics to fluid kinematics and modern fluid dynamics. The timeline contains list of great minds and important events throughout the history of the fluid mechanics – most notable discoveries and observations that led to many improvements in theory and applications of fluid mechanics.

Key words: fluid mechanics, fluid dynamics, hydrodynamics, history

1. Antiquity

Fluid mechanics has a history of erratically occurring early achievements, then an intermediate era of steady fundamental discoveries in the eighteenth and nineteenth centuries. Ancient civilizations (e.g. the Greeks, Romans and Phoenicians) had enough knowledge to solve certain flow problems. Sailing ships with oars and irrigation systems were both known in prehistoric times.

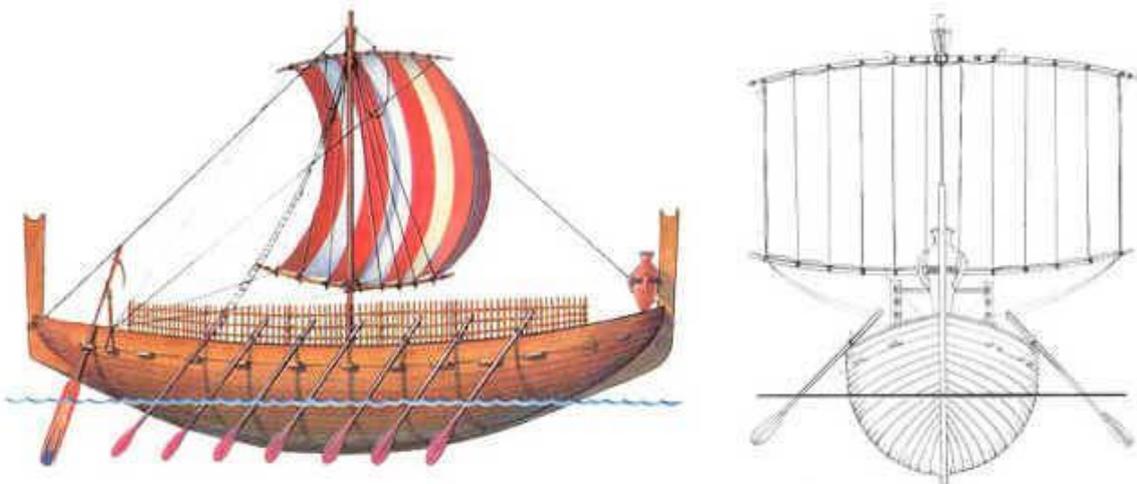


Fig. 1 Phoenician wind and slave-powered trading ship

Over the years, king **Hiero of Syracuse** (308-215 BC) was made aware that his Royal Goldsmith was living a lifestyle that was beyond his means and he suspected that the Goldsmith was using royal gold, intended for the royal crown, to augment his personal

wealth. The goldsmith was rumored to be preparing the crowns with a cheaper alloy than pure gold. No one knew how to prove or disprove the speculation that the Royal Goldsmith was stealing from the crown. The problem of determining the gold content of the royal crown was given to **Archimedes** (285-212 BC), a noted Greek mathematician and natural philosopher. Archimedes knew that silver was less dense than gold, but did not know any way of determining the relative the density of an irregularly shaped crown. While in the public baths, Archimedes observed that the level of water rose in the tub when he entered the bath. He realized this was the solution to his problem and supposedly, in his excitement, he leaped up and ran naked through the streets back to his laboratory screaming “Eureka, Eureka!” (I’ve got it!). Archimedes formulated the laws of buoyancy, also known as Archimedes' Principle, and applied them to floating and submerged bodies, actually deriving a form of the differential calculus as part of the analysis. This principle states that a body immersed in a fluid experiences a buoyant force equal to the weight of the fluid it displaces.

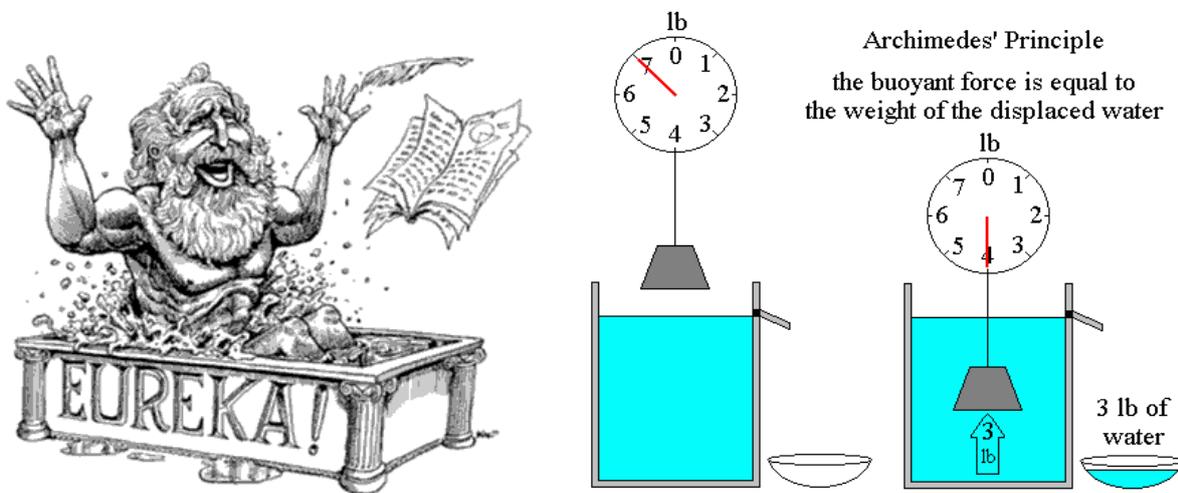


Fig. 2 Schematic drawing of Archimedes and his principle

2. Middle Ages

Up to the Renaissance, there was a steady improvement in the design of such flow systems as ships, canals, and water conduits, but no recorded evidence of fundamental improvements in flow analysis.



Leonardo da Vinci (1452-1519) derived the equation of conservation of mass in one-dimensional steady flow. Leonardo was an excellent experimentalist, and pioneered the flow visualization genre close to 500 years ago. His notes contain accurate descriptions of waves, jets, hydraulic jumps, eddy formation, and both low-drag streamlined and high-drag parachute designs. Da Vinci described turbulence decomposition as: "*Observe the motion of the surface of the water, which resembles that of hair, which has two motions, of which one is caused by the weight of the hair, the other by the direction of the curls; thus the water has eddying motions, one part of which is due to the principal current, the other to the random and reverse motion.*" He also provided the earliest reference to the importance of vortices: "*So moving water strives to maintain the course pursuant to the power which occasions it and, if it finds an obstacle in its path, completes the span of the course it has commenced by a circular and revolving movement.*"



Fig. 3 Da Vinci's sketch of free-surface turbulence behind obstacle

3. Seventeenth and Eighteenth Centuries

A Frenchman, **Edme Mariotte** (1620-1684), built the first wind tunnel and tested models in it. He published a description of a wind tunnel in "*Traite du mouvement des eaux*" in 1686. **Wenham** and **Browning** constructed one in the 1870's, theirs was the first tunnel where accurate sub-scale aerodynamic data was obtained and systematically recorded for later application to the design of the full-scale Flyer. To this day the process is essentially the same - engineers first design according to theory then test their designs sub-scale in the wind tunnel.



Galileo Galilei (1564-1642) and his two disciples **Castelli** and **Torricelli** in 1628 published work in which they explained several phenomena in the motion of fluids in rivers and canals, but they committed a great paralogism in supposing the velocity of the water proportional to the depth of the orifice. Torricelli, observing that in a jet where the water rushed through a small ajutage 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** in 1648 on the quantities of water discharged from different ajutages under different pressures.



Blaise Pascal (1623-1662) wrote about the equilibrium of liquids, which was found among his manuscripts after his death and published in 1663; the laws of the equilibrium of liquids were demonstrated in the simplest manner, and amply confirmed by experiments. The "*Treatise on the Equilibrium of Liquids*" by Pascal is an extension to **Simon Stevin**'s research on the hydrostatic paradox and explains what may be termed as the final law of hydrostatics; the famous Pascal's principle. Stevin's paradox states that the pressure in a liquid is independent of the shape of the vessel and the area of the

base, but depends solely on its height. Pascal is known for his theories of liquids and gases and their interrelation, and also his work regarding the relationship between the dynamics of hydrodynamics and rigid bodies. His inventions include the *hydraulic press* (using hydraulic pressure to multiply force) and the *syringe*.

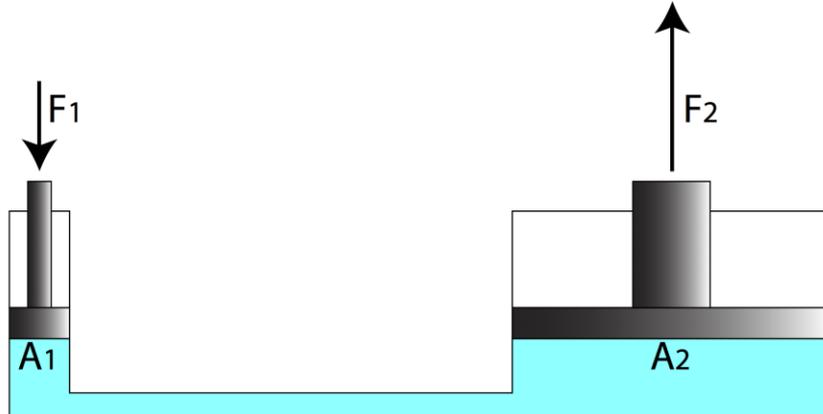
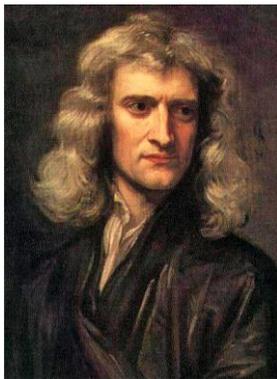


Fig. 4 Schematic drawing of a hydraulic press system



In 1687, **Isaac Newton** (1642-1727) postulated his laws of motion and the law of viscosity of the linear fluids now called *Newtonian*. Newtonian fluid is a fluid in which the viscous stresses arising from its flow, at every point, are linearly proportional to the local strain rate - the rate of change of its deformation over time. While no real fluid fits the definition perfectly, many common liquids and gases, such as water and air, can be assumed to be Newtonian for practical calculations. Newton was also the first to investigate the difficult subject of the motion of waves.

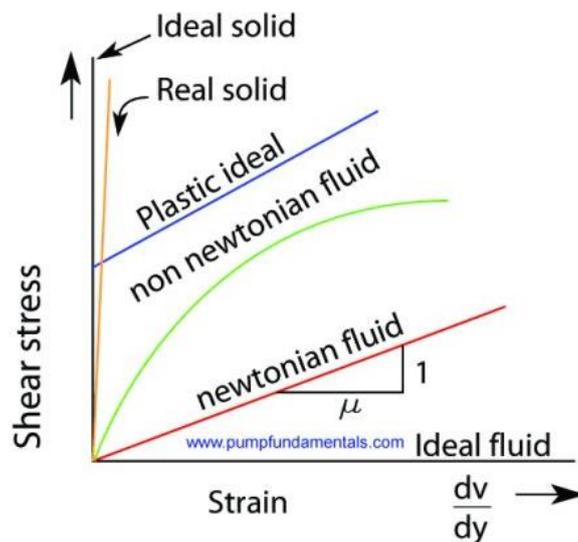


Fig. 5 Correlation of shear stress and strain for fluids and solids



Daniel Bernoulli (1700-1782) published a book *Hydrodynamica* in 1738. The book deals with fluid mechanics and is organized around the idea of conservation of energy. Daniel Bernoulli explained the nature of hydrodynamic pressure and discovered the role of loss of vis viva in fluid flow, which would later be known as the *Bernoulli principle*. It was known that a moving body exchanges its kinetic energy for potential energy when it gains height. Daniel realised that in a similar way, a moving fluid exchanges its kinetic energy for pressure. A consequence of this law is that if the velocity increases then the pressure falls. The book also discusses hydraulic machines and introduces the notion of work and efficiency of a machine.

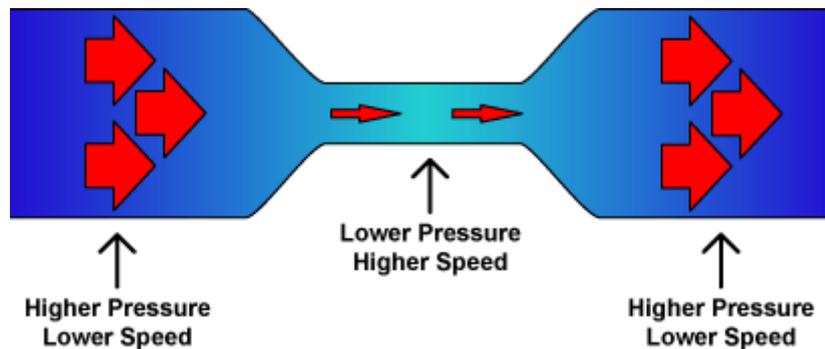


Fig. 6 Schematic drawing of Bernoulli's principle



Jean le Rond d'Alembert (1717-1783), while generalizing the theory of pendulums of **Jacob Bernoulli**, discovered a principle of dynamics so simple and general that it reduced the laws of the motions of bodies to that of their equilibrium. He applied this principle to the motion of fluids, and gave a specimen of its application at the end of his *Dynamics* in 1743 and in his *Traité des fluides* in 1744. He noted that portion of the fluid passing from one place to another preserves the same volume when the fluid is incompressible, or dilates itself according to a given law when the fluid is elastic. His ingenious method, published in 1752, in his *Essai sur la resistance des fluides*, was brought to perfection in his *Opuscles mathematiques*, and was adopted by Leonhard Euler.



Leonhard Euler (1707-1783) developed both the differential equations of motion and their integrated form, now called the *Bernoulli equation*. **D'Alembert** used them to show his famous *paradox*: that a body immersed in a frictionless fluid has zero drag. Theory and experiments had some discrepancy. This fact was acknowledged by D'Alembert who stated that, "*The theory of fluids must necessarily be based upon experiment.*" For example the concept of ideal liquid that leads to motion with no resistance, conflicts with the reality. This discrepancy between theory and practice, *D'Alembert paradox*, serves to demonstrate the limitations of theory alone in solving fluid problems.

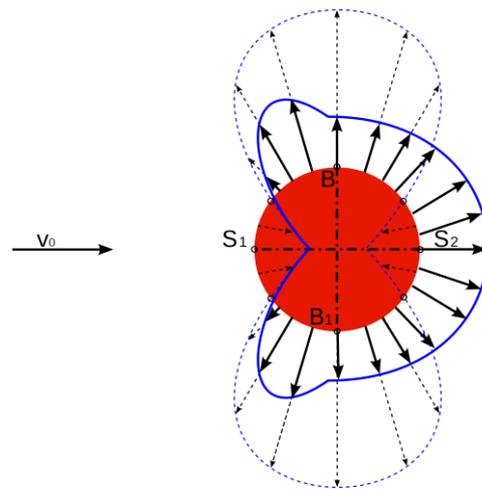


Fig. 7 D'Alembert paradox – symmetric (dashed) vs real (full line) asymmetric pressure distribution

4. Nineteenth Century

In the middle of the nineteenth century, first **Claude-Louis Navier** (1785-1836) in the molecular level and later lord **George Gabriel Stokes** (1819-1903) from continuous point of view succeeded in creating governing equations for real fluid motion. Thus, creating a matching between the two school of thoughts: experimental and theoretical. The *Navier-Stokes equations*, which describes the flow (or even Euler equations), were considered unsolvable during the mid-nineteenth century because of the high complexity. This problem led to two consequences. Theoreticians tried to simplify the equations and arrive at approximated solutions representing specific cases. Examples of such work are Hermann von **Helmholtz's** concept of *vortexes* (1858), **Lanchester's** concept of *circulatory flow* (1894), and the **Kutta-Joukowski** circulation *theory of lift* (1906).

Navier-Stokes equations describe the motion of a fluid and are used nowadays in many practical applications. However, theoretical understanding of the solutions to these equations is incomplete. In particular, solutions of the equations often include turbulence, which remains one of the greatest unsolved problems in physics, despite its immense importance in science and engineering. Even much more basic properties of the solutions to the equations have never been proven. For the three-dimensional system of equations, and given some initial conditions, mathematicians have not yet proved that smooth solutions always exist, or that if they do exist, they have bounded energy per unit mass. This is called *the Navier–Stokes existence and smoothness problem*. The Clay Mathematics Institute in May 2000 made this problem one of its seven Millennium Prize problems in mathematics. It offered a US\$1,000,000 prize to the first person providing a solution for the problem.



In 1858 **Hermann von Helmholtz** (1821-1894) published his seminal paper "*On integrals of the hydrodynamic equations which express vortex motion*" where he established his three "laws of vortex motion". This work established the significance of vorticity to fluid mechanics and science in general and the laws are used still in fluid dynamics, though they are modified slightly from Helmholtz's original version. Equations require ideal fluids, i.e. fluids that are free from

viscosity and perfect continua. Helmholtz's equations are a paradigm case of mathematical idealizations in physics.

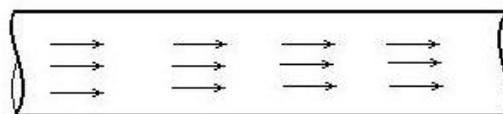
The experimentalists, at the same time proposed many correlations to many fluid mechanics problems, for example, resistance by **Darcy**, **Weisbach**, **Fanning**, **Ganguillet**, and **Manning**. The obvious happened without theoretical guidance, the empirical formulas generated by fitting curves to experimental data (even sometime merely presenting the results in tabular form) resulting in formulas that the relationship between the physics and properties made very little sense.

At the end of the nineteenth century, the demand for vigorous scientific knowledge that can be applied to various liquids as opposed to formula for every fluid was created by the expansion of many industries. This demand coupled with new several novel concepts like the theoretical and experimental researches of **Reynolds**, the development of dimensional analysis by **Rayleigh**, and **Froude's** idea of the use of models change the science of the fluid mechanics.

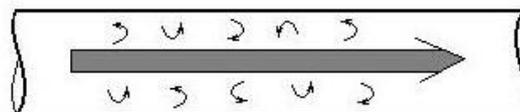
Even though Stokes introduced dimensionless quantity that is used to help predict similar flow patterns in different fluid situations, which is today known as *Reynolds' number*, **Osborne Reynolds** (1842-1912) popularized its use in 1883 when he published the classic pipe experiment. Reynolds number is defined as the ratio of inertial forces to viscous forces, and consequently quantifies the relative importance of these two types of forces for given flow conditions.



Reynolds numbers frequently arise when performing scaling of fluid dynamics problems, and as such can be used to determine dynamic similitude between two different cases of fluid flow. Reynolds also proposed what is now known as *Reynolds-averaging* of turbulent flows, which is today actively used in numerical fluid dynamics. *Reynolds decomposition* is used for *Reynolds-averaging*, which is a mathematical technique to separate the average and fluctuating parts of a quantity.



Laminar Flow ($Re < 2100$)



Turbulent Flow ($Re > 4000$)

Fig. 8 Correlation of Reynolds' number to flow type in pipe



William Froude (1810-1879) and his son Robert (1846-1924) combined mathematical expertise with practical experimentation and developed laws of model testing which are used today. They developed a method of studying scale models propelled through water and applying the information thus obtained to full-size ships. He discovered the laws by which the performance of the model could be extrapolated to the ship when both have the same geometrical shape. A similar technique later was used by pioneers in aerodynamics. Near Froude's home, near Torquay, a model-testing tank was built. He discovered that the chief components of resistance to motion are *skin friction* and *wave formation*.



Fig. 9 Modern model-testing tank



Ernst Mach (1838-1916) explored the field of supersonic velocity. Mach's paper on this subject was published in 1877 and correctly describes the sound effects observed during the supersonic motion of a projectile. Mach deduced and experimentally confirmed the existence of a shock wave which has the form of a cone with the projectile at the apex. The ratio of the speed of projectile to the speed of sound is now called the *Mach number*. It plays a crucial role in aerodynamics and hydrodynamics.



Jean Léonard Marie Poiseuille (1797-1869) was interested in the flow of human blood in narrow tubes. In 1838 he experimentally derived, and in 1840 and 1846 formulated and published, Poiseuille's law (now commonly known as the *Hagen–Poiseuille* equation, crediting Gotthilf Hagen as well), which applies to non-turbulent flow of liquids through pipes, such as blood flow in capillaries and veins. It describes a physical law that gives the pressure drop in an incompressible and Newtonian fluid in laminar flow flowing through a long cylindrical pipe of constant cross section. The *poise*, the unit of viscosity in the CGS system, was named after him.

5. Twentieth Century

Perhaps the most radical concept that effects the fluid mechanics is of **Ludwig Prandtl's** (1875-1953) idea of boundary layer which is a combination of the modeling and dimensional analysis that leads to modern fluid mechanics. Therefore, many call Prandtl as the father of modern fluid mechanics. This concept leads to mathematical basis for many approximations. Thus, Prandtl and his students **von Karman, Meyer, and Blasius** and several other individuals as **Nikuradse, Rose, Taylor, Bhuckingham, Stanton**, and many others, transformed the fluid mechanics to today modern science. **Prandtl** was a pioneer in the development of rigorous systematic mathematical analyses which he used for underlying the science of aerodynamics, which have come to form the basis of the applied science of aeronautical engineering. In 1904 he delivered a ground-breaking paper, "*Fluid Flow in Very Little Friction*", in which he described the boundary layer and its importance for drag and streamlining. The paper also described *flow separation* as a result of the boundary layer, clearly explaining the concept of *stall* for the first time. In the 1920s he developed the mathematical basis for the fundamental principles of subsonic aerodynamics in particular; and in general up to and including transonic velocities. His studies identified also *thin-aerofoils*, and *lifting-line theories*. The *Prandtl number* was named after him, which is defined as the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity.

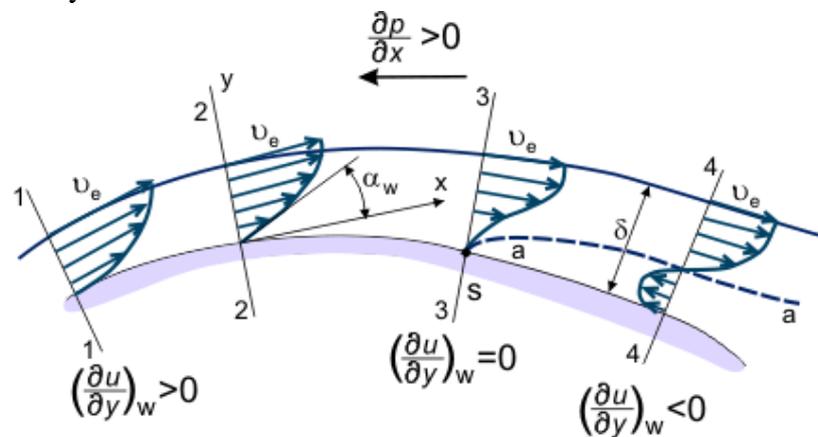


Fig. 10 Boundary layer and flow separation



Theodore von Kármán (1881–1963) was a Hungarian-American mathematician, aerospace engineer and physicist who was active primarily in the fields of aeronautics and astronautics. He is responsible for many key advances in aerodynamics, notably his work on supersonic and hypersonic airflow characterization. Von Kármán made his first notable contribution to the study of supersonics in 1932 when he developed a new mathematical approach to studying airflow and supersonics that is now known as the *Kármán-Moore theory* which is still used today. By the end of his distinguished career, he had published more than 200 papers, advanced scientific collaboration from world leading scientists, developed many unique theories of

aeronautical and space science, and played an important role in the creation of supersonic aircraft and ballistic missiles.

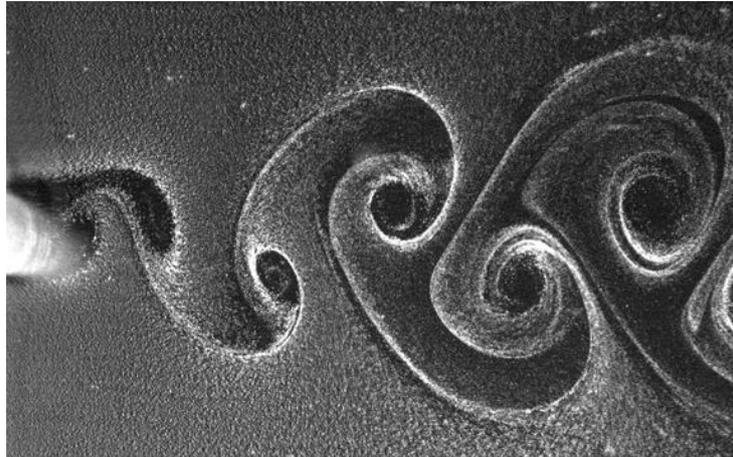
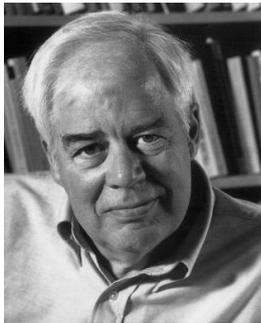


Fig. 11 Von Kármán vortex street experiment



Paul Richard Heinrich Blasius (1883–1970) was a German fluid dynamics physicist. He was one of the first students of Prandtl who provided a mathematical basis for boundary-layer drag but also showed as early as 1911 that the resistance to flow through smooth pipes could be expressed in terms of the Reynolds number for both laminar and turbulent flow. One of his most notable contributions involves a description of the steady two-dimensional boundary-layer that forms on a semi-infinite plate that is held parallel to a constant unidirectional flow.

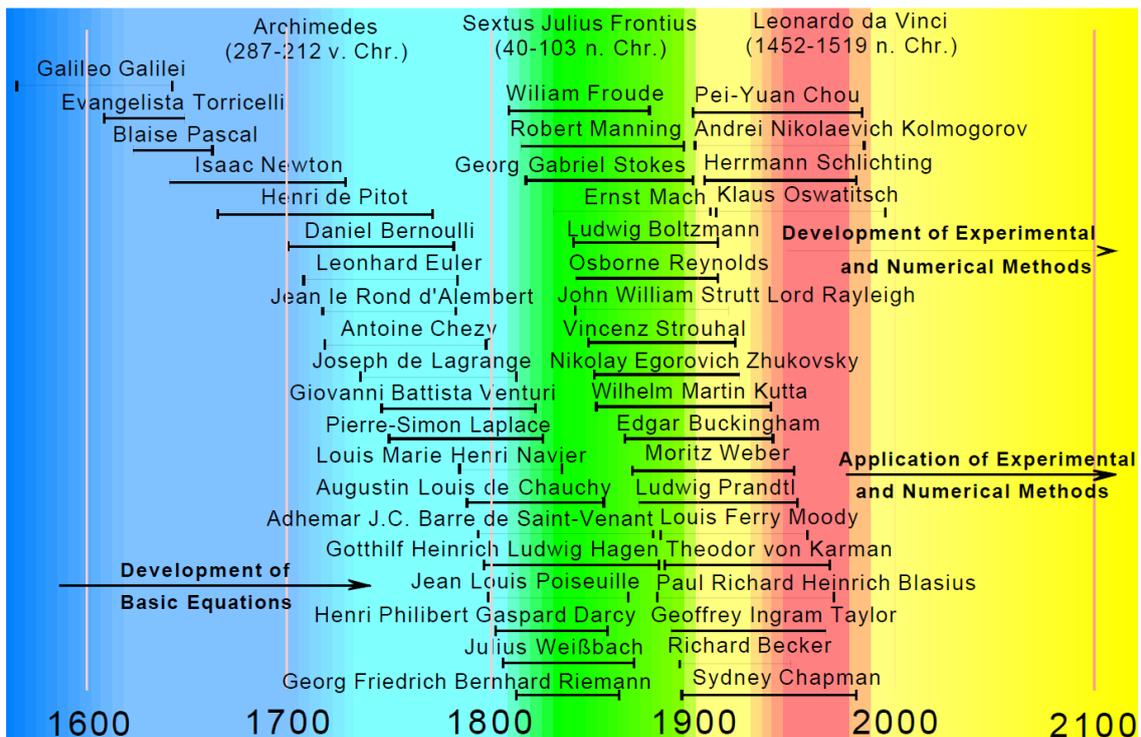


Fig. 12 Historical timeline of fluid mechanics [3]

6. The Switch from Art to Science

It took a number of years for the boundary layer theory to travel outside the small circle of Prandtl and his students at Göttingen. Prandtl's paper, written in German naturally, contained a wealth of information: the concept of boundary layer, the resulting approximations, the mechanism of separation, and flow control strategies to delay flow separation. Researching pace picked up just prior to and certainly after World War II. But engineering schools for the most part continued to teach hydraulics, with scant attention to the Navier-Stokes equations. Only when those schools, particularly in the United States, decided that a quantum shift from engineering technology to engineering science education was in order, did fluid mechanics replace hydraulics in undergraduate engineering curricula. The key impetus for that switch was an important report, the *Grinter Report*, prepared by a committee of the American Society of Engineering Education set to evaluate the future of engineering education in general. In May 1952, ASEE President S. C. Hollister charged that committee to recommend the pattern or patterns that engineering education should take in order to keep pace with the rapid developments in science and technology, and to educate men who will be competent to serve the needs of and provide the leadership for the engineering profession over the next quarter-century. So, fluid mechanics as taught today centers around first principles and the art of rational approximations: integral methods, inviscid flow, boundary-layer approximation, asymptotic analysis, etc. The wind tunnel continues to validate as well as complements the analytical results. But the digital computer may change all that. Today the full equations can be numerically integrated for almost any laminar flow. Turbulent flows are a different beast of course. Only trivial geometries and very modest Reynolds numbers can be tackled via direct numerical simulations. Few decades from now, however, turbulent flows may be approached as readily as their laminar counterparts [3].

7. The Computer Age

Since the 1940s, analytical solutions to most fluid dynamics problems, especially those arising in aerodynamics, were readily available for simplified or idealized situations. However, it was soon realized that a wide range of problems still need to be solved especially with the increasing demands of the industry. This was an incentive for the inception of asymptotic/semi-analytical methods. These methods included perturbation techniques (asymptotics) and scale similarity analysis which found appreciable applications for viscous flow problems and inviscid compressible flow. Numerical methods, on the other hand, were known since the time of Newton in the 1700s. Methods for the solution of ordinary differential equations or partially differential equations were conceptually conceived, but only on paper. With the absence of the personal computer, there was no way for the application of these techniques.

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. In 1960 the underlying principles of fluid dynamics and the formulation of the governing equations (potential flow, Euler, RANS) were well established. The new element was the emergence of powerful enough computers to make numerical solution possible – to carry this out required new algorithms. The emergence of CFD depended on a combination of advances in computer power and algorithms. Today, the fundamental basis of almost all CFD problems are the Navier–Stokes equations, which define any single-phase fluid flow.

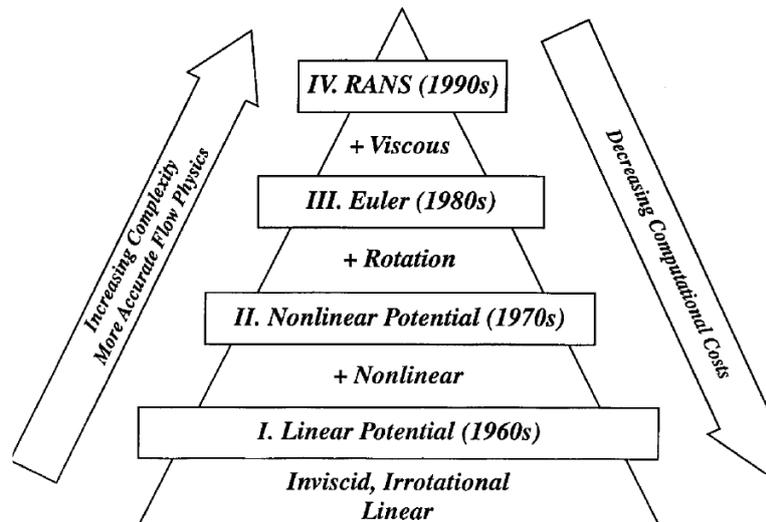


Fig. 13 Development of CFD methods [5]

8. The Future

Worldwide commercial and government codes are based on algorithms developed in the '80s and '90s. These codes can handle complex geometry but are generally limited to 2nd order accuracy and they cannot handle turbulence without modeling. Unsteady simulations are very expensive, and questions over accuracy remain. CFD has been on a plateau for the past 15 years (F1 cars, ships, aircrafts, etc.). Rapid advances in computer hardware should make non-modelled or at least less-modelled turbulent simulations feasible within the foreseeable future for industrial problems at high Reynolds numbers. To realize this goal, we require high-order algorithms, sub-grid scale models, and massively parallel implementation [5].

In 2013, Mukhtarbay Otelbaev of the Eurasian National University in Astana, proposed a solution for the Navier–Stokes existence and smoothness Millennium Prize problem [6]. As an attempt to solve an important open problem, the proof was immediately inspected by others in the field, who found at least one serious flaw. At the time of writing this paper, Otelbaev is attempting to fix the proof, but other mathematicians are skeptical.

9. Conclusion

History of fluid mechanics is formed by numerous great minds who contributed with their observations, experiments, theories and formulations. Some of them are mentioned in this work, and there are lot of others important contributors not mentioned here. The story isn't finished yet as fluid mechanics transformed from art to science introducing many problems, some of which still remain unsolved. The initial thrust of the theory can be attributed to Archimedes that laid the basis of the fluid statics. His famous word "Eureka" today describes the sudden, unexpected realization of the solution to a problem. After his discovery, there was a longer pause in theory progression, though not in practice (ships, city water-supply systems, etc.). It is understandable since the complex nature of problems needed mathematical laws and postulates which were not yet derived. Omnipresent laws discovered by Galilei, Pascal, Newton, D. Bernoulli, d'Alembert and Euler advanced mathematics theory to the level that could tackle problems of fluid kinematics. And they have all tried since fluid problems represented great challenge, and sometimes the competitive process lead to new discoveries (Johann Bernoulli vs brother and son, d'Alembert paradox). After the closure of

inviscid and steady problems, there was, and still is, a whole new area ready to investigate – fluid dynamics. Navier and Stokes separately derived the equations of viscous fluid dynamics which are used today. Until the unfolded usage of numerical mathematics those equations were tagged as unsolvable, and in that time many experimentalists emerged. Reynolds and Froude are the ones to thank for deducing the complete experimental process of smaller models with scaling of results to real sizes, which is also still used today with ship basins and aero tunnels. Fortunately, rapid development of computing power and computing algorithms made numerical analyses possible, and thus enabled experiments of viscous problems to be virtually simulated. Unfortunately, increasing the complexity i.e. needing more accurate flow physics requires extreme resources of computing power. Laminar flows are thus easy to simulate accurately, but turbulent flows are representing demanding numerical problem which is at this moment difficult to directly simulate. In order to decrease computational cost of turbulent simulations, many models for turbulence approximations have been introduced, none of which can generally guarantee sufficient certainty for replacing experiments, at least not for expensive matters such as ships, aeroplanes, shuttles etc. The future of fluid mechanics obviously is the evolution of computational fluid dynamics (CFD) and computer power and algorithms which could accurately simulate viscous turbulent flows.

APPENDIX A

The Turbulent History of Fluid Mechanics

by Naomi Tsafnat, May 17, 1999.

It all started with Archimedes, way back in BC,
Who was faced with an interesting problem, you see...

The king came to me, and this story he told:
I am not sure if my crown is pure gold.
You are a wise man, or so it is said,
Tell me: is it real, or is it just lead?

I paced and I thought, and I scratched my head,
But the answer eluded me, to my dread.
I sat in my bath, and pondered and tried,
And then... "Eureka! Eureka! I found it!" I cried.

As I sat in my tub and the water was splashing,
I knew suddenly that a force had been acting.
On me in the tub, it's proportional, see,
To the water that was where now there is me.

Of course, Archimedes caused quite a sensation
But not because of his great revelation;
As he was running through the streets of Syracuse
He didn't notice he was wearing only his shoes.

The great Leonardo – oh what a fellow...
No, not DiCaprio, Da Vinci I tell you!
He did more than just paint the lovely Mona,
He also studied fluid transport phenomena.

Then came Pascal, who clarified with agility,
Basic concepts of pressure transmissibility.
Everyone knows how a barometer looks,
But he figured out just how it works.

How can we talk about great scientists,
Without mentioning one of the best:
Sir Isaac Newton, the genius of mathematics,
Also contributed to fluid mechanics.
One thing he found, and it's easy as pie,

Is that shear stress, τ , equals $\mu \, dv/dy$.
His other work, though, was not as successful;
His studies on drag were not all that useful.
He thought he knew how fast sound is sent,
But he was way off, by about twenty percent.

And then there was Pitot, with his wonderful tubes,
Which measure how fast an airplane moves.
Poiseuille, d'Alembert, Lagrange and Venturi –
Through his throats – fluid pass in a hurry.

Here is another hero of fluid mechanics,
In fact, he invented the word “hydrodynamics”.
It would take a book to tell you about him fully,
But here is the short tale of Daniel Bernoulli:
Everyone thinks is just one Bernoulli...
It is not so! There are many of us, truly.
My family is big, many scientists in this house,
With father Johan, uncle Jacob and brother Nicolaus.
But the famous principle is mine, you know,
It tells of the relationship of fluid flow,
To pressure, velocity, and density too.
I also invented the manometer – out of the blue!

Yes, Bernoulli did much for fluids, you bet!
He even proposed the use of a jet.
There were others too, all wonderful folks,
Like Lagrange, Laplace, Navier and Stokes.

Here is another well-known name,
A mathematician and scientist of great fame:
He is Leonard Euler, I'm sure you all know,
His equations are basis for inviscid flow.

He did more than introduce the symbols π , i , e ,
He also derived the equation of continuity.
And with much thought and keen derivation,
He published the famous momentum equation.

Those wonderful equations and diagrams you see?
They are all thanks to Moody, Weisbach and Darcy.
Then there was Mach, and the road that he paves,
After studying the shocking field of shock waves.

Rayleigh studied wave motion, and jet instability,
How bubbles collapse, and dynamic similarity.
He was also the first to correctly explain.
Why the sky is blue – except when it rains.

Osborne Reynolds, whose number we know,
Found out all about turbulent flow.
He also examined with much persistence,
Cavitation, viscous flow, and pipe resistance.

In the discovery of the boundary layer
Prandtl was the major player.
It's no wonder that all the scientists say,
He's the father of Modern Fluid Mechanics, hooray!

It is because of Prandtl that today we all can
Describe the lift and drag of wings of finite span.
If it weren't for him, then the brothers Wright
Would probably never have taken flight.

And so we come to the end of this story,
But it's not the end of the tales of glory!
The list goes on, and it will grow too
Maybe the next pioneer will be you?

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