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DANIEL BERNOULLI – A LIFE DEDICATED TO SCIENCE

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Abstract

Daniel Bernoulli, doctor, mathematician, teacher of metaphysics and natural philosophy, remained one of the most symbolic figures in the history of science. His name is commemorated by the equation he discovered, a specific example of the conservation of energy known nowadays as Bernoulli Principle. Friend but also rival of Leonhard Euler, Bernoulli is the author of some publications about hydraulics and mathematics. Just as importantly, he had abilities in other fields, earning a PhD in botany and anatomy and his master degree in philosophy. Our article is a journey in the private and professional life of the great Daniel Bernoulli.

***Key words**: Bernoulli equation, fluid mechanics, incompressible flow, kinetic energy, mathematics potential energy.*

INTRODUCTION

Daniel Bernoulli was born in the city Gorningen, The Netherlands, on February 8, 1700 (Figure 1) (https://mathshistory.st-andrews.ac.uk/Biographies/Bernoulli_Daniel/pictdisplay/) He is part of the Bernoulli Dynasty, a family of proeminent mathematicians. Son of Johann Bernoulli, one of the early developers of calculus, nephew of Jacob Bernoulli, an early researcher in probability theory, with two mathematician brothers Nikolas and Johann II, Daniel was described by W.W. Rouse Ball as "by far the ablest of the younger Bernoulli's". He had a complicated relationship with his father who insisted that Daniel should be a merchant as his grandfather, a strategy that his own father tried with him. Daniel resisted to this idea and by the age of 13, Johann accepted this fact but refused Daniel being a mathematician so he decided that his son should study medicine. Their relationship didn't become easier by the time past, reaching to compete for the first prize on a scientific contest. After this Johann forbade his son to come to his house and they remained argued until his dead.

Not surprisingly with such history in his family in mathematics, Daniel made rapid progress in this field although he also studied medicine. In this way, his career is based on many fields having achievements in mathematics, medicine but also hydrodynamics. He is well known for the equation he discovered, known nowadays as Bernoulli Principle, which remained one of the most important findings from those times.

Figure 1. Daniel Bernoulli (1700-1782)

STUDIES

Having science running through his veins, Daniel was an excellent student gaining his baccalaureate in 1715 and his master's degree at Basel University in 1716. He respected the wish of his father and studied medicine at Heidelberg in 1718, Strasbourg in 1719 and then returned to Basel University in 1720. In return, his father was the one who thought him about calculates and mathematics. By 1720, his father had introduced Daniel to what would later be called "conservation of energy". In 1721, at the age of 21, Daniel Bernoulli graduated as a doctor with a thesis on the mechanics of breathing in which included a part of his soul passion, mathematics. Later on, he will be encouraged by the English physician, William Harvey - the first who observed that the human heart worked like a pump- to combine these two fields in order to discover the rules that govern the movement of fluids.

Apart from his usual abilities, Daniel studied the oscillation of air in organ pipes and defined the simple nodes and the frequencies of oscillation of a system. He showed that the movements of strings of musical instruments are composed of an infinite number of harmonic vibrations all superimposed on the string.

Bernoulli showed up a lot of interest in the Newton's theories and methods and using the principle of conservation of energy gave an integral of Newton's basic equation. He also studied the movement of bodies in a resisting medium using these methods (O'Connor and Robertson, 1998).

CAREER

After he took his PhD, Daniel hoped to get a job at Basel University with no success, but he continued to study mathematics in this time. In 1723, Daniel moved to Venice, Italy where he learned practical medicine. One year later, he received an offer from Empress Catherine I of Russia to teach mathematics at the Imperial Academy in St. Petersburg. Bernoulli hardly accepted the offer, mostly because his older brother, Nikolas, accompanied him but unfortunately, he died of tuberculosis the following year. From that time, Daniel was extremely unhappy and wanted to return home, moment when his father sends there one of his students Leonhard Euler, who later will become not only friend of Bernoulli but also a rival. A temporary illness in 1733 was the perfect reason for Daniel to return to Basel University, where after a few failures he held successively the chair of medicine, metaphysics and natural philosophy until his death.

Although he was increasingly interested in the exact sciences, he began to publish a series of articles dealt with physiology. Two of his most important physiologic writings were treatises on muscular mechanics (1728) and the mechanical work done by the heart (1737) (Fye, 2009).

In 1738, he published his masterpiece named "Hydrodynamica", which includes all of his experiments and discoveries, his reputation being established after the publication of this book (Figure 2) (The Turner Collection, Keele University 1973).

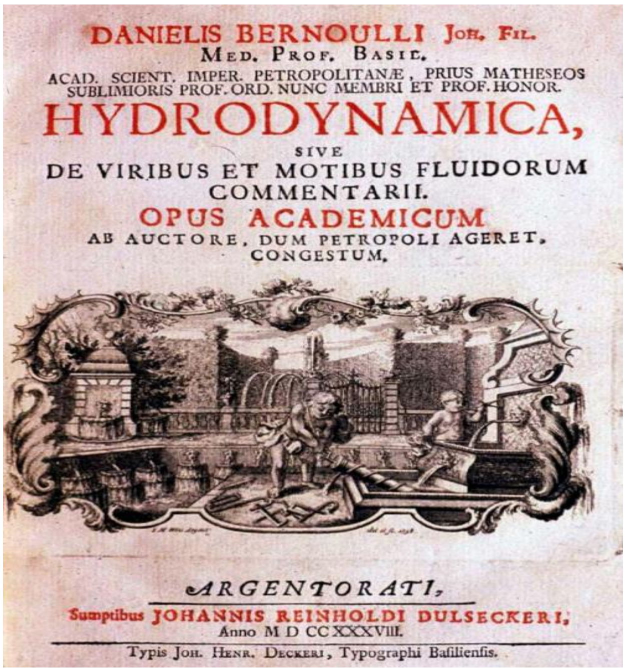
DANIELIS BERNOULLI JOH. FIL.
MED. PROF. BASIL.
ACAD. SCIENT. IMPER. PETROPOLITANÆ, PRIUS MATHESEOS SUBLIMIORIS PROF. ORD. NUNC MEMBRI ET PROF. HONOR.
HYDRODYNAMICA,
SIVE
DE VIRIBUS ET MOTIBUS FLUIDORUM COMMENTARII.
OPUS ACADEMICUM
AB AUCTORE, DUM PETROPOLI AGERET, CONGESTUM.
ARGENTORATI,
Sumptibus JOHANNIS REINHOLDI DULSECKERI, Anno M D CC XXXVIII.
Typis JOH. HENR. DECKERI, Typographi Basiliensis.

Figure 2. "Hydrodynamica" by Daniel Bernoulli

EXPERIMENTS AND DISCOVERIES

Bernoulli was a brilliant mind, showing a great ability in performing various experiments but also interpreting the results. All this journey in the world of experiments was accentuated by several people who encouraged him, one of the most important being Euler the one who refined Bernoulli's mathematics.

At first, Bernoulli tried to combine the two fields he activated, as he was advised and with Euler were interested to discover more about the flow of fluids. More particularly, they wanted to know the connection between the blood speed and its pressure.

To investigate this, Daniel used as materials a pipe and an open-ended straw. He punctured the wall of the pipe and discovered that the height to which fluid rose up the straw was strongly correlated with the pressure of the fluid in the pipe (Quinney, 1997) (Figure 3) (The Turner Collection, Keele University 1973).

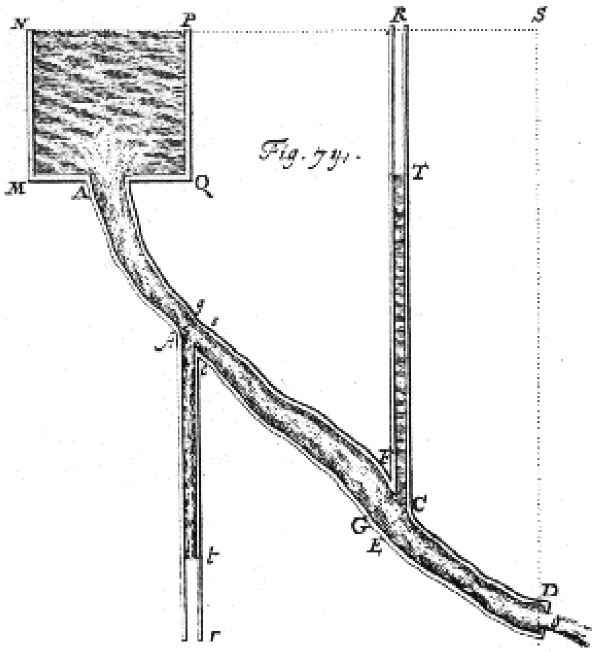

Figure 3. Bernoulli's diagram to illustrate how pressure is measured

This simple experiment didn't remain in the dark, so soon all the physicians were measuring patient's blood pressure by introducing point-ended glass tubes directly into their arteries. This practice remained valid until one Italian doctor discovered a less painful method, 170 years later. Although, this method of measuring pressure is still used in modern aircrafts to measure the speed of the air passing the plane.

Surprisingly enough, Bernoulli wrote a paper in a totally different field from his usual abilities. In 1738, he published "Exposition of a New Theory on the Measurement of Risk", a work which included the idea that St. Petersburg paradox was the base of the economic theory of risk.

Bernoulli taught us to measure risk with the geometric mean and recommended minimizing risk by spreading it across a set of independent events (bet-hedging). He also defined the situations in which one should avoid risk against the situations in which the risk should be chosen (Stearns, 2000).

Bernoulli noticed that when making decisions involving some uncertainty, people did not always try to maximize the monetary gain but most the utility. The paper influenced economic theory, portfolio theory and evolutionary biology.

Another discovery which could more be named an anticipation of James Clerk Maxwell work, the one who explained the origin of temperature, is *the kinetic theory of gases*. The kinetic theory relates the independent motion of molecules to the mechanical and thermal properties of gases. In chapter X of Hydrodynamica (1738), Bernoulli mentioned for the first time that gases consist of numerous particles in rapid random motion and he assumed that the pressure of a gas is produced by the direct impact of the particles on the walls of the container (https://www.britannica.com/science/atom/Kinetic-theory-of-gases).

Bernoulli's biggest merit was that he is the first who has explicitly established the kinetic origin of the pressure. Starting from the idea that the heat is the external manifestation of molecules' oscillatory motion, Bernoulli explains the pressure of the gas as a result of collision between molecules and cylinder's walls (Figure 4) (Cernica and Pasincovschi, 2018).

In 1760 Daniel Bernoulli wrote an article related the smallpox. In his time there was much controversy around inoculation (the action of immunizing someone against a disease by introducing infective material, microorganisms, or vaccine into the body.), a practice that could protect people but could also be deadly. He showed that inoculation was advantageous if the associated risk of dying was less than 11% and that the inoculation could increase life expectancy at birth up to three years (Bacaër, 2011).

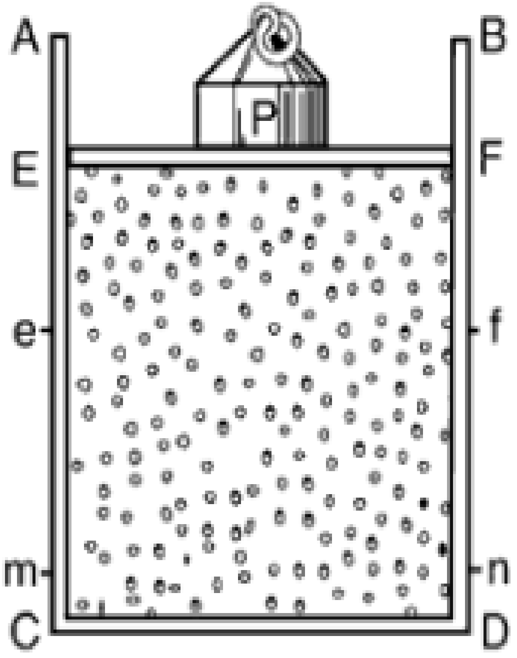

Figure 4. The pressure of gas according to Bernoulli

BERNOULLI'S EQUATION

Along all of these important experiments, the most valuable discovery that he made remain what we entitled today as Bernoulli's Principle.
Bernoulli's equation is obtained by applying the principle of conservation of energy, according to which the variation of the kinetic energy of a system in a given time interval is equal to the sum of the mechanical work of the forces acting on the system in the same time interval.
Bernoulli's equation for steady frictionless flow written along a streamline, can be integrated between any two points 1 and 2 as

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} \qquad (1)$$

or can be write as general form:

$$z + \frac{p}{\gamma} + \frac{v^2}{2g} = \text{const.} \qquad (2)$$

Each term in the equation (2) has the dimension of length and represents some kind of "head" of a flowing fluid as follows: *z* is the elevation head; *p/γ* is the pressure head; *v2/2g* is the velocity head (Cengel and Cimbala, 2006).
Bernoulli's theorem implies, therefore, that if the fluid flows horizontally so that no change in gravitational potential energy occurs, then a decrease in fluid pressure is associated with an increase in fluid velocity.
Also, this equation can be written as a sum of specific energies:

$$zg + \frac{p}{\rho} + \frac{v^2}{2} = \text{const.} \qquad (3)$$

We recognize gz as potential energy, *p/ρ* as flow energy and *v2/2* as kinetic energy, all per unit mass. Therefore, the Bernoulli equation can be interpreted as follow: the sum of the kinetic, potential, and flow energies of a fluid particle is constant along a streamline during steady flow when the compressibility and frictional effects are negligible.
However, it must be stated that the Bernoulli equation can be applied to solve different applications, taking into account the complete list of assumptions for Eq. (1): steady flow; incompressible flow; frictionless flow; flow along a single streamline; between 1 and 2 there are no pumps or turbines on the streamline; no heat transfer between 1 and 2 (White, 2014).
For real fluids, which have non-zero viscosity, Bernoulli's equation (1) also includes the term that quantifies the amount of head losses between the two sections:

$$z_1 + \frac{p_1}{\gamma} + \frac{\alpha_1 v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{\alpha_2 v_2^2}{2g} + h_{t1-2} \qquad (4)$$

where a correction factor regarding the speed distribution in the section was noted with α, and the amount of load losses was noted with ht.
Bernoulli's Principle shows up in a lot of different applications such as:
- To explain how plane wings generate lift.
- To explain how Bunsen burners work.
- Several different flow measurements rely on the equation such as the Pitot-static tube and the Venturi meter: if the fluid is flowing through a horizontal pipe of varying cross-sectional area, for example, the fluid speeds up in constricted areas so that the pressure the fluid exerts is least where the cross section is smallest. This phenomenon is sometimes called the Venturi effect, after the Italian scientist G.B. Venturi (1746 – 1822), who first noted the effects of constricted channels on fluid flow.
- He made fundamental contributions to hydrodynamics, including the basic principle

that allows airplanes to fly and that governs the design of sails and boat hulls.

OTHER SCIENTIFIC CONTRIBUTIONS

Daniel Bernoulli was a man of science, a special presence in the world of mathematics, hydraulics and medicine, having lots of publications and awards.

He never forgot about his big passion and in 1724 published “Mathematical Exercises” which includes four parts.

He won ten prizes from the Paris Academy of Sciences for different topics:

- In 1740 for works with Euler on Newton’s theory of the tides.
- In 1743 and 1746 for essays on magnetism.
-In 1747 for a method to determine time at the sea.
-In 1751 for an essay on ocean currents.
-In 1753 for the effects of forces on ships.
-In 1757 for proposals to reduce the pitching and tossing of a ship in high seas.

He is part of the International Air &Space Hall of Fame at the San Diego Air and Space Museum, which commemorate people that have contributed to the advancement of aerospace flight, due to the fact that his method of measuring pressure was used to measure the speed of the air passing the plane.

He was elected as a fellow of the Royal Society.

Bernoulli was the first who stated the principle of superposition in 1753, according to Leon Brillouin, a French physician.

He had a weighty contribution to the theory of statistics, being the first author who used the continuous method for solving statistical problems.

He was elected to most of the leading scientific societies of the leading scientific societies of his day including those in Bologna, St Petersburg, Berlin, Paris, London, Turin, Zurich and Mannheim.

CONCLUSIONS

Daniel Bernoulli (1700-1782) was born into a Swiss family of eleven famous scientists, being a virtual dynasty of that period but spent most of his life working at the Academy in Petersburg, where he produced 47 scientific works. Son of Johann Bernoulli, one of the eight gifted mathematicians of the legendary family published his theory of hydraulics in his famous "Hydrodynamics" (1738), the most significant treatise on physical mechanics to appear in the 18th century. His theorem is the principle of energy conservation for ideal fluids in steady, or streamline, flow and is the basis for many engineering applications. He had lots of experiments, discoveries and publications in different fields making important contributions to science.

Daniel Bernoulli dedicated his whole life to science. He never gets married and had no children, although he had an attempt on getting married with a woman who turned out being very mean with money. He respected simplicity of lifestyle, living for his work. He passed away to eternity age 82 on March 17, 1782 in his sleep in Basel, Switzerland.

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