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THE LIFE AND WORK OF OSBORNE REYNOLDS

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Biographical Overview

- Osborne Reynolds was born on August 23rd, 1842. He came of a clerical family. His great-grandfather and grandfather were rectors of the Parish of Debach-with-Boulge in Suffolk, England.
- His father, the Rev. Osborne Reynolds, was a Fellow of Queens' College, Cambridge, Headmaster of Dedham Grammar School, Essex, and also Rector of Debach.

The family home at Debach



Early education

 Reynolds' early education was undertaken mainly by his father, who was an extremely able mathematician with a keen interest in mechanics.

Practical training

- The young Osborne Reynolds showed an early aptitude and liking for mechanical matters and, at the age of nineteen, entered the workshop of Mr. Edward Hayes of Stony Stratford, a *well known inventor and mechanical engineer*.
- He remained with Edward Hayes for over a year obtaining practical experience in the manufacture and *fitting out of coastal steamers*.
- During this period, to use his own words, `my attention (was) drawn to various mechanical phenomena, for the explanation of which I discovered that a knowledge of mathematics was essential'.

University Education and Professional Training

- He therefore decided to go to Cambridge to take a degree course in mathematics.
- His university studies were highly successful.
- He graduated in 1867 and was immediately afterwards elected to a *Fellowship at Queens' College*.
- He then entered the office of a well known *civil* engineer, Mr. John Lawson, of London.

The young Osborne Reynolds



Appointment as Professor at Owens College Manchester

- In 1868 at the age of 25 Osborne Reynolds applied for and was elected to the newly instituted Chair of Engineering at Owens College Manchester – later to become the Victoria University of Manchester.
- In his application for the post he stated:-

'From my earliest recollection I have had an irresistible liking for mechanics and the physical laws on which mechanics as a science are based. In my boyhood I had the advantage of the constant guidance of my father, also a lover of mechanics and a man of no mean attainment in mathematics and their applications to physics'.

Some members of the Appointing Committee



Tenure of the Chair

- Osborne Reynolds remained as Professor of Engineering at the University of Manchester until 1905.
- He died on February 21st, 1912 at Watchet in Somerset at the age of sixty-nine.

Degrees and Honours

- He was awarded the degree of *M.A. by the University of Cambridge* in 1880 and elected an Honorary Fellow of Queens' College Cambridge in 1882.
- In 1877, he became a *Fellow of the Royal Society* and in 1888 received the *Royal Medal*.
- He was elected a *Member of the Institution of Civil Engineers* in 1883 and was awarded the *Telford* Premium in 1885.
- The University of Glasgow conferred the Honorary Degree of LL.D. on him in 1884.
- In 1888 he was elected President of the Manchester Literary and Philosophical Society and received the Dalton Medal in 1903

His Inaugural Lecture

THE

PROGRESS OF ENGINEERING

CONSIDERED WITH RESPECT TO

THE SOCIAL CONDITION OF THIS COUNTRY.

A LECTURE

INTRODUCTORY TO THE SESSION 1998-9, AT OWENS COLLEGE, MANCHESTER.

BY

OSBORNE REYNOLDS, B.A.,

PROFESSOR OF ENGINEERING; FELLOW OF QUEENS COLLEGE, CAMBRIDGE.

CAMBRIDGE: MACMILLAN AND CO. MANCHESTER: THOS. SOWLER AND SONS. MDCCCLAVIIL

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Academic Career

- Osborne Reynolds' considerable mathematical ability was supplemented by an almost *uncanny insight* into the physical fundamentals of a problem.
- Shortly after coming to Manchester, he began a series of original researches which led, during the next thirty-five years, to the publication of many papers of outstanding interest covering a phenomenally wide range of physical problems and engineering applications.
- They laid the foundations for much of the subsequent work on turbulent flow, hydraulic modelling, hydrodynamic lubrication, and many other matters.



Rankine

Osborne Reynolds was greatly influenced by the eminent Scottish engineerscientist Rankine whose books on a range of engineering topics were a major source of inspiration to him.



Reynolds' Early Work

- At the time Reynolds arrived in Manchester in 1868 Owens College was housed in a building in Quay Street in central Manchester.
- Little was available to Reynolds then in the way of laboratory facilities. Initially, he was restricted to research involving experiments of a very simple kind which could either be done at home or outdoors.
- We see this clearly reflected in the emphasis of his early work.

The Quay Street Building (1868)



Move to the New Building (1873)



The Manchester Literary and Philosophical Society

- In November 1869, just over a year after his appointment, Osborne Reynolds became a member of the Manchester Literary and Philosophical Society.
- At that time the President of the Society was the distinguished Manchester scientist James Prescott Joule.

James Prescott Joule



Osborne Reynolds' first paper

 It was under the encouraging eye of Joule that Reynolds read his first paper to the Literary and Philosophical Society in March 1870 on '*The stability of a ball above a jet of water'*.



Suspension of a ball on an air jet



Studies of 'Out-of-door Physics' (1870-1881)

- This stream of Reynolds' work, was described in the terms used above by *his most famous student, J.J. Thomson*.
- The papers on this aspect of his work, deal with matters concerned with:
 comets, the solar corona and the aurora;
 terrestrial magnetism;
 the electrical properties of clouds;
 the bursting of trees struck by lightning;
 the destruction of sound by fog;
 the refraction of sound by the atmosphere;
 the action of rain in calming the sea;
 the action of an oil film on water in preventing waves;
 other phenomena involving surface tension and capillary action.

Sir J.J. Thomson – Discoverer of the Electron



Some Experimental Studies The Solar Corona

 Using simple apparatus, Reynolds produced a corona resembling a solar corona by discharging electricity from a brass ball at high voltage in a partially evacuated receiver.

Reynolds' Equipment



A Reproduction of Reynolds' Experiment



The Action of Raindrops in calming the Sea

 In a presentation to the Manchester Literary and Philosophical Society, 'On the action of rain to calm the sea' Reynolds showed by experiment that vortex rings produced by droplets of rain cause water to be carried well below the surface very effectively, leading to the damping of wave motion.

This is what we see after a drop of water falls in a pool.



Reynolds' illustration of vortex motion below the surface



Formation of a Hailstone

- Reynolds pointed out that hailstones are formed by the *aggregation of small frozen particles* resulting from coalescence with more rapidly descending larger particles.
- He ingeniously produced artificial hailstones by chilling a flow of air laden with tiny droplets of water using an ether spray.

A Perfect Hailstone



Reynolds' Experiment



A reproduction of Reynolds' experiment – no longer in use due to present day health and safety restrictions!



The bursting of trees struck by lighting

- This he explained in terms of the boiling of sap within a tree due to the sudden discharge of electricity through it.
- He demonstrated the effect by discharging an electrical condenser through water in a small glass capillary tube.



The water in the U tube, boils rapidly and the glass tube explodes into fragments.

A reproduction of Reynolds' experiment


The Effect of Oil in Destroying Waves

- In a paper read to the British Association in 1880
 'On the effect of oil in destroying waves on the surface of water', Reynolds attributed this to the presence of a film on the surface capable of withstanding tension which moves as the wind flows over the surface.
- The effect is a dynamic one; instead of wave motion occurring in the water, the surface remains plane and *turbulent eddies are formed below it*.

Letter from Osborne Reynolds to a colleague, <u>Horace Lamb, describing his 'experiment'</u>

Fin Paule His i what I have found 9. kor 1042 B.A. Report 1000. Transactions of Section A 5. Do the Effect of Oil in distroying Wares on the Surface of Wahr By Part. Ochome Mapurta De "This paper contained a short account of on surretigation from which it appears that the effect of Oil on the surface Mowatts to prevent wind wares and distary wares alsong incetting was owing to the tempuce tindeon of the water such Which the oil spread varying invessely as the thectoren of the oil, thus introducing longuited stiffren into the oil - Sheet which presented the bil lating up the langestical notion of the water hereath - leveral ather phenomena Wire also mentioned. The author hopes shouth to kalelish a full accomt of the investigation -X. The Eddies here reperred to use described me 6.10 of my paper in The phil- Truns - 10015 "Direct. There is also in another paper on Surpace Tension and Capillany Action B.A. Report 1881 p. 524 -This is all I can lay any hards on , but I think There is a paper in The het & Phel which I will look alf - I have found only note on W. Grundy's point. It is as follows." 20 may 1002 - Vil on Water -This as follows. 20 may 1002 - Vil on Water -This morning there was a strong loss Wind - Threw Jone Frets of ill out of a smelt while near the construction of the out of a smelt while near the les side of Del. Grinietzy pond. The oil fell in reatheres. Orops and mised a large patien of paismatic colours. for a moment or two I was taken aleask by the Just that the sil did not sam to deating the actifie litt are moving suy syl from the prismatic porteti I saw it surrounded with proputty calm water I instantly same that Thead Thead The Suprestedy a proof that when the luger if oil has acached ito many Theokness, at which it with openad, then do wold not affect the waves - Mestability of the Oiled Surface. Where the water was calred by the oil lowerds the windward side thise was a provement in the Surface while indicated relies helow , that is to say the disturbance do not appear to be suguedan like our writing disturbance but as through they suight ne cult freque some directoped dus turbance below. D. R.yulto

Sir Horace Lamb



The formation of vapour bubbles in water at ordinary temperature – Cavitation



A reproduction of his experiment



The Dilatancy of Granular Materials

Reynolds applied the term 'dilatancy' to the property possessed by a quantity of granular material to alter its volume in accordance with a change in the arrangement of its grains.

His illustration of this in terms of the piling of spheres in two different ways is shown next.

Diagram to illustrate the dilatancy of granular materials



The pile of spheres in cubical formation occupies a volume greater than that of the same number and size of spheres when piled in the second way.

His experiment to Demonstrate Dilatancy

- Reynolds went on to illustrate this by characteristically simple means.
- If an india-rubber bottle with a glass neck is filled with water and the bag is then squeezed, water will be forced up the neck.
- But if the bottle is full of granular material and water, the effect of squeezing, up to a point, is to draw water down from the neck into the bag, because the grains have adopted an arrangement in which the volume of the interstices has been increased.

Apparatus for demonstrating dilatancy of granular materials



An outdoor experiment at the seaside

- A familiar phenomenon explained by Reynolds was that which is observed when one places a foot on firm moist sand on the sea-shore.
- An area around the foot appears to become dry. However, when the foot is raised, the sand beneath is found to be abnormally wet.
- The pressure of the foot has increased the volume of the interstices between the grains of sand below it and water has been drawn in to occupy the additional voids.

Research on the Physics of Gases (1874-1879)

- This is a stream of Osborne Reynolds' work which is not widely known about these days. It was, however, of considerable interest within the Victorian scientific community and it was probably for his early efforts in this area that Reynolds was elected a Fellow of the Royal Society in 1877.
- The kinetic theory of gas was being developed by Maxwell at that time.

Clerk Maxwell



Forces Exerted by the Communication of Heat

- Reynolds was interested in the forces exerted by the *communication of heat* to a surface immersed in *a rarefied gas*.
- Such forces he attributed to *molecular influences* and utilised his ideas on this to afford an explanation of the operation of the *Crookes light mill*.

The Crookes Light Mill



The Force on a Spider Thread

- Reynolds argued that the extremely low pressure of the gas in the light mill was necessary because of the comparatively large size of the vanes and that similar results ought to be obtainable at higher pressure with smaller vanes.
- This he proved by experiments with fibres of silk and a 'spider line' applying radiant heating on one side to cause them to move.

Reynolds' Experiment



Thermal Transpiration – The Dimensional Properties of Gases

- Reynolds' interest in the Crookes light mill was perhaps the initial stimulus for his thoughts on the so-called *'thermal transpiration' of gases,* a pioneering study in nano-fluid dynamics!
- The results of his investigation on this topic were presented in 1879 in one of the longest and most original of his papers entitled 'On Certain Dimensional Properties of Matter in the Gaseous State'.
- In this, he showed by *theory and experiment* that not only would a difference of pressure cause a gas to *flow from one side of a porous plate to the other*, but so also would a difference of temperature,.

Reynolds' Experiment



The Test Section



The Kinetic Theory Model of Gases

- Reynolds considered his investigation of thermal transpiration to have very profound implications, affording a *proof that gas is not a continuous medium*.
- His description and explanation of observed behaviour involved the dependence of the *density of the gas in relation to the size of the passages* in the porous medium, and so depended on what he called the '*dimensional properties of gases*'.

Work on Applied Hydrodynamics (1872-1891)

- Osborne Reynolds had developed an interest in problems connected with the *propulsion* and *dynamics of ships*, particularly screw steamers, a number of years prior to going to Manchester, probably dating back to his apprenticeship with Edward Hayes at Stony Stratford. This led to a long involvement in the safety of ships.
- His attention later turned to waves and currents and the laws relating the scaling of experiments to study flow in rivers, estuaries and foreshores.
- He also became interested in the development of multistage *centrifugal pumps and turbines*.

Ship Propulsion and Dynamics

- The first fruits of the interest in ships were his publications in 1873 and 1874 on the racing of screw propellers.
- By showing this to be the result of the admission of air Reynolds was among the first to recognize the important influence which air can exert on a mass of water in which it is dissolved or occluded.
- The conclusions which he reached later concerning the racing of screws and the steering of screw-steamers, (1875), were largely based on pioneering experiments made with two models, one 2 feet 6 inches long driven by a spring and the other 5 feet 6 inches, driven by steam.

The steering of screw steamers



Modelling of rivers and estuaries

- 1887 marked another of Reynolds's pre-eminent contributions. 'On certain laws relating to the regime of rivers and estuaries, and on the possibility of experiments on a small scale'.
- Reynolds's first scale model was of the Mersey; it had a flat bed and vertical sides representing the shape of the estuary at high tide; the horizontal scale was 2 inches to a mile (1/31800) and the vertical scale 1 inch to 80 feet (1/960), giving a vertical exaggeration of approximately 33:1.
- Tides were generated by a hinged tray at the seaward side of the model. Reynolds noticed that only one period – about 40 seconds – gave a correct imitation of the tidal phenomena in the actual Mersey: 'a result', he says, that might have been foreseen from the theory of wave motions.

Scaling rule

- Reynolds established the rule that if the horizontal scale is 1/x and the vertical scale is 1/y, the logical corollary is that the velocity-scale should be 1/√y and the timescale for tidal periods √y/x. This was a major advance and opened up great possibilities for modelling flow in rivers and estuaries.
- In addition Reynolds astutely observed that his tidegenerator also accurately shaped the sand he had placed in the model (to ensure the correct mean depth of water at high tide) to mirror the principal features of the natural estuary.

Bed formation and other features of models of estuaries

On a 30 ft. tide, distance between the contours represents about 1.1 miles.

SERIES 11. WITH LAND WATER



Tank J. Experimental Longitudinal Section III. Righ Water Level The of Main Control Jank Low, Water Level The of Main Control Jank Low, Water Level The of Main Control Jank Low, Water Level The of Main Control Jank Britania Sale, Main Control Chapter (Control Chapter (



Vertical Scale + fire Model 1/2 of an Estuary having a SO Mute.)

Pumps and Turbines

- In matters of innovation and invention Reynolds was never motivated by financial gain. He did, however, take out *a number of patents*. The patent for '*improvements in turbines and centrifugal pumps*', the specification for which is dated 1875 was an important one.
- It reads, in many respects, like a research-paper and at the same time demonstrates Reynolds' great powers as an *engineer and inventor*.

Reynolds' illustration of the idea of multi-staging



Display of Reynolds' multistage pumps, steam turbine and dynamometer



Reynolds' Two-stage Steam Turbine (1875)



Miniature Froude Dynamometer with Reynolds' Improvements



William Froude



Reynolds theory of hydrodynamic lubrication

- The stimulus for this was the important experimental research on 'The friction of lubricated journals' carried out for the Institution of Mechanical Engineers by Beauchamp Tower, in 1883 and 1884.
- Reynolds' famous contribution 'On the theory of lubrication...' appeared in the Philosophical Transactions of the Royal Society in 1886.
- In this very lengthy and detailed paper, Reynolds not only formulated and integrated the hydrodynamics equations but also, by allowing for the variation of viscosity with temperature, obtained close agreement with the observed pressures.

Diagrams to illustrate the action of lubrication

Under the heading 'General view of the action of lubrication', he evolves the basic concepts involved by first considering two plane surfaces.



Demonstration of the pressure distribution in a journal bearing -Hydrodynamic Lubrication



The Analogy Between Heat Transfer and Momentum Transfer

- In 1874 (nine years before the appearance of his famous paper on transition from laminar to turbulent flow and the critical Reynolds number), Reynolds produced a short paper, 'On the extent and action of the heating surface of steam boilers'.
- In this he pointed out that heat is removed from such a surface not only by molecular action but also by the *turbulent eddies* present in the flow which mix hotter fluid with cooler fluid.
- This led him to infer an *analogy* between *heat-transfer* and *skin-friction*.
- Almost half a century was to pass before these ideas were taken up by others and the analogy was extended by authorities such as *Taylor, Prandtl* and *von Kármán*.
The Reynolds Number

- In 1883, Osborne Reynolds published his renowned paper entitled 'An experimental investigation of the circumstances which determine whether motion of water shall be direct or sinuous and of the law of resistance in parallel channels'.
- This paper proved to be a classic in the literature of the science of fluid motion and had a profound effect on the development of fluid mechanics in the widest sense.
- It contained the enunciation of the dimensionless group, the *Reynolds Number*, a unifying parameter of fundamental importance in fluid mechanics.

Reynolds' experiment to try to understand the mechanism of turbulence production in a shear flow

He created relative motion in horizontal tube between two immiscible fluids.





Visualisation of Laminar and Turbulent Flow

- In 1877 Reynolds had described methods for rendering the internal motions of a fluid visible by means of *colour bands*. This he did with particular reference to various kinds of *vortex motion*.
- He was to use this technique again in the experiments on *laminar and turbulent flow in pipes* reported in his 1883 paper.

The Reynolds Tank

The well known illustration from his paper showing the apparatus.



The Apparatus

- The apparatus used, which is so effectively portrayed by the illustration, consisted of a *glass-sided tank*, 6 feet long, 18 inches deep and 18 inches wide.
- Inside the tank was a glass tube with 'a trumpet mouth of varnished wood, great care being taken to make the surface of the wood continuous with that of the glass'.
- On one side, the tube was connected to an iron pipe equipped with a valve which could be controlled by means of a long lever.
- On the other was the *device for introducing a streak* of dye into the trumpet.
- A *float* connected to a *pulley and dial arrangement* was used to register the *water-level* in the tank.

Two of Reynolds' students photographed with the Original Equipment on display at the Centenary Symposium Exhibition in 1968



The Experiments

- The experiments, first made in 1880, consisted of filling the tank with water, allowing several hours for conditions to become steady, then *opening the valve, at first only slightly.* The colour-band established itself as a *beautifully steady streak*.
- On opening the value further and increasing the flow through the tube, a point was reached, when 'the colour band would all at once seem to mix up with the surrounding water, apparently filling the rest of the tube with a mass of coloured water'.
- However, 'On viewing the tube by the (fluctuating) light of an electric spark, the mass of colour resolved itself into a mass of *more or less distinct curls*, showing eddies'.

Illustration from Reynolds' paper







Reynolds tank experiment with laminar flow



Reynolds tank experiment with turbulent flow



The Condition for Transition from laminar to turbulent flow

- Reynolds proceeded to measure the velocity for onset of eddies using three glass tubes of different diameter, in each case varying the water temperature.
- To a first approximation, *the values of Reynolds number based were found to be the same* (about 13000) for each of the tubes and for all the water temperatures. (about 13000).

The Lower Critical Reynolds Number

- Reynolds next set out to find the critical condition below which flow in pipes is *always* stable even if strong disturbances are present, referring to this as the '*inferior limit*'.
- To do this, he used equipment which allowed water to flow in a disturbed state from the mains supply through a length of pipe and *measured the pressure-drop* over a five-foot length near the outlet.

Apparatus for determining the frictional pressure drop in pipes



Experimental Results

- He found that below a certain point the fluid levels in the differential manometer connected to the pressure-holes *ceased to fluctuate*: this coincided with a change in the character of the flow and provided visual evidence of the attainment a *critical velocity below which it was stable*.
- This he later determined by *plotting the mean velocity* against the pressure-gradient.
- Pipes of two different diameters were tested. The result was to demonstrate that the critical velocities for the two were in fact so related as to imply *the same critical value of Reynolds number* (about 2000). Below this value the disturbances in the flow were damped out.

Pressure drop-flow rate plots



Hydrodynamic Similarity Law

- A comprehensive programme of measurements of the frictional pressure drop provided a detailed picture of the resistance to turbulent flow in pipes, showing the pressure drop coefficient in these pipes to be a unique function of Reynolds number.
- In fact Reynolds established that this function could be reliably described by a simple power law. Thus

$$f = C \operatorname{Re}^{-n}$$

 For very smooth lead tubes he found that n = 0.27. For smooth metal pipes it was slightly smaller (about 0.2) and for very rough pipes n tended to zero.

Evaluation of the 1883 Paper

 In his Presidential Address to the British Association in Montreal in 1884, Lord Rayleigh paid this tribute to the work reported the previous year by Osborne Reynolds:

... Professor Reynolds has traced with much success the passage from the one state of things to the other, and has proved the applicability under these complicated conditions of the general laws of dynamical similarity as adapted to viscous fluids by Professor Stokes, a subject which is certainly second to none in scientific as well as practical interest.

Lord Rayleigh



Reynolds's Dynamical Theory of Turbulent Flow

- Rayleigh anticipated that Osborne Reynolds would go on to make further important contributions to the understanding of turbulent flow.
- Eleven years were to elapse before this major breakthrough was made.
- It came with Reynolds' contribution in 1894 'On the Dynamical Theory of Incompressible Viscous Fluids and the Determination of the Criterion'.

Reynolds' description of his approach

 It was the culmination of twenty-five years of research and came as a result of Reynolds conducting

'a more rigorous examination and definition of the geometrical basis on which the analytical method of distinguishing between molar-motions and heat-motions in the kinetic theory of matter is founded; and of the application of the same method of analysis, thus definitely founded, to distinguish between the meanmolar-motions and relative-molar-motions, where, as in the case of steady-mean (turbulent) flow along a pipe, the more rigorous definition of the geometrical basis shows the method to be strictly applicable'.

 The origins of this method of analysis date back to Reynolds' interest in the properties of gases at the outset of his career.

Results of the Theory

- Expressed in modern terms, Reynolds sought to write the components of velocity in a turbulent flow in terms of mean and fluctuating quantities and to perform *averaging of the momentum equations*. This showed that these equations contained additional terms which could be thought of as *apparent stresses due to turbulence*.
- He then derived equations for the kinetic energy of the mean motion and the kinetic energy of the turbulent motion and noticed that they contained terms, the turbulent energy production terms, which represent the total exchange of energy between the mean motion and the kinetic energy of the turbulence.
- Reynolds went on to examine the conditions under which the turbulence energy could be sustained. Using the turbulence energy equation and considering a control volume for which the turbulent diffusion of turbulent energy would integrate to zero, he arrived at a condition for `*the inferior limit*' based on the idea that the total turbulence *production must equal the total turbulence dissipation*.

Osborne Reynolds in 1896



Professor Reynolds Teaching (drawn by one of his students)

Feb 10 th 1902 Limit of Blasticity PX strain Feb 12- 1902 : b:x = 0 =0 dx dp d-Professor Keynolols as seen from the sallers

Professor Reynolds Demonstrating



Professor Reynolds Lecturing



Osborne Reynolds with staff and students in 1903



Portrait of Osborne Reynolds by John Collier (1903)



Concluding remarks

- The success of Osborne Reynolds in identifying the fundamental dimensionless parameter which characterises the behaviour of flowing fluids was without question a pioneering achievement which many people regard as his most valuable scientific legacy.
- His experimental work on the circumstances under which flow in pipes is either laminar or turbulent coupled with his dynamical theory of turbulent flow have together provided the *true foundations for the subsequent development of engineering fluid mechanics*.

Acknowledgment

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Use by others of the term 'Reynolds Number'

- According to Nicholas Rott of Stanford University, in his note on history of the Reynolds number, Arnold Sommerfeld made the first reported reference, to the Reynolds number in 1908 when he presented a paper on hydrodynamic stability.
- In the equation known today as the Orr-Sommerfeld equation, he introduced a 'pure number' which he called 'the Reynolds number'.
- The terminology introduced by Sommerfeld has not changed ever since, and the use of the expression 'Reynolds number' has spread into all branches of fluid mechanics.

- Prandtl's role in the history of the Reynolds number, as revealed in his collected works, begins with his paper in 1910 on the Reynolds analogy. There he makes reference to 'the Reynolds number known in hydrodynamics'.
- In his 1913 encyclopedia article, Prandtl wrote more explicitly "The forementioned quantity, a nondimensional number, is named after the discoverer of this similarity, Osborne Reynolds, and is called the Reynolds number".

- The work of Blasius reported in 1912 is the first that was fully devoted to the extraction from experiments of a function that, according to Reynolds' similarity law, depends only on the Reynolds number.
- In the extended version his paper in 1913 Blasius wrote that the Reynolds law "has not penetrated, as of today, into the pertinent fields of engineering".
- His paper became influential in leading to a change in aeronautical and mechanical.

 The general acceptance of the term and of the notion of Reynolds' ideas similarity came later in hydraulic engineering, in spite of the fact that a textbook on hydraulics by von Mises appeared in 1914 that fully exploited Reynolds similarity. In England, Stanton, who studied under Osborne Reynolds and received his Bachelor of Science degree in Engineering at Manchester in 1891, was well aware of the significance of Reynolds' work.

Thomas Edward Stanton

