



A century of fluid mechanics: 1870–1970 / Un siècle de mécanique des fluides : 1870–1970

## Turbulence from 1870 to 1920: The birth of a noun and of a concept



*La turbulence de 1870 à 1920 : la naissance d'un nom et d'un concept*

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### ABSTRACT

We consider here the works of French, British, and German researchers in fluid mechanics from 1870 to the beginning of the twentieth century. Our aim is to understand how the term “turbulence” introduced by William Thomson in 1887, which was not used by the main researchers of the time, including Joseph Boussinesq, Osborne Reynolds, Lord Rayleigh, Horace Lamb in the first editions of his book, became classical in the 1920s. We trace the first introductions of the terms “turbulence”, “turbulent flow” in the works of relatively unknown researchers between 1889 and 1903, until it reaches the vocabulary of mainstream researchers in fluid mechanics and physics. Our result is that the shift was in 1906–1908, when the term was used in the 1906 edition of the book of Horace Lamb, and in Lanchester's book, followed by a series of papers of German researchers before the First World War.

The use of the word “turbulence”, a word used for a long time for crowds or for children, in a scientific context, corresponds to the introduction of a new concept, a new understanding of a scientific phenomenon clearly identified as being different from laminar motion. The study of the use of this term is also the study of the diffusion of a new concept among researchers of the time.

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### R É S U M É

Nous considérons les travaux de chercheurs français, britanniques, allemands en mécanique des fluides, de 1870 au début du vingtième siècle. Notre objectif est de comprendre comment le terme « turbulence » introduit par William Thomson en 1887, qui n'a pas été utilisé par les principaux chercheurs de l'époque, incluant Joseph Boussinesq, Osborne Reynolds, lord Rayleigh, Horace Lamb dans les premières éditions de son livre, est devenu classique dans les années 1920. Nous recherchons les premières occurrences des termes « turbulence » et « écoulement turbulent » dans les travaux de chercheurs mineurs du domaine entre 1889 et 1903, avant qu'ils n'apparaissent dans le vocabulaire des spécialistes du domaine en mécanique des fluides et en physique. Notre conclusion est que la transition se situe dans les années 1906–1908, lorsque le terme a été utilisé dans l'édition de 1906 du livre de Lamb, et dans celui de Lanchester, suivis par une série d'articles par des chercheurs allemands avant la Première Guerre mondiale.

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L'utilisation du mot « turbulence », un mot employé depuis longtemps pour des foules ou des enfants dans un contexte scientifique, correspond à l'introduction d'un nouveau concept, à une nouvelle compréhension d'un phénomène scientifique, clairement différencié des écoulements laminaires. L'étude de l'utilisation du terme est aussi l'étude de la diffusion d'un nouveau concept parmi les chercheurs de l'époque.

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## 1. Introduction

The field of turbulence is an important subpart of fluid mechanics and of condensed matter physics; a Web of Science search reveals that more than 46,000 papers were published between 1995 and 2016 with “turbulence” or “turbulent” in the title, with 2884 for the year 2015 alone. Turbulence is found for high Reynolds number flows, and is characterized by erratic motion, intermittency, 3-D vortices and filaments, irreversibility, chaos, unpredictability [1–5]. Turbulence is ubiquitous in nature and is found, e.g., in the ocean [6], the atmosphere [7], geosciences [8], and also in climate models [9].

In the field of engineering, many models are used, based on the averaging of the Navier–Stokes equations, since the seminal work of Osborne Reynolds [10] at the end of the nineteenth century. Since these equations are non-linear, averaging introduces small-scale fluxes that need to be related to averaged quantities through a so-called closure. The classical closure is the one at the basis of eddy-viscosity models, and is due to Joseph Boussinesq [11]. The fact that the Boussinesq's eddy-viscosity closure was introduced in 1872 (the 1877 paper is a written report of a presentation done in front of the French Academy of Science in 1872), 25 years before the introduction of Reynolds averages, has been discussed in a paper published in this journal [12], in a thematic issue devoted to Joseph Boussinesq [13].

In the same paper, we were also surprised to see that neither Boussinesq nor Reynolds have used the word “turbulence” in their publications. In his publications in fluid mechanics, Boussinesq used “tumultuous movements”, “eddy agitations”, “liquid eddy theory” (in French, “mouvements tumultueux”, “agitation tourbillonnaire”, “théorie des tourbillons liquides”) [14,11,15]. Osborne Reynolds also used many different words: “sinuous paths”, “sinuous motion”, “irregular eddies”, “sinuous or relative disturbance” [16,10].

This shows that these two important researchers of the end of the nineteenth century did not use the word *turbulence*, while it is extremely classical nowadays and used in a very large number of academic works. Between these two periods, there is a transition to be studied. In the present paper, we are interested in the diffusion of the term “turbulence” in the scientific literature: its first introduction apparently in 1887 by William Thomson (later Lord Kelvin), its adoption and generalization in the early twentieth century. It is seen as the birth of a new concept, since its adoption as a noun is also the recognition of a new subfield of fluid mechanics.

## 2. From 1887 to 1903: introduction of the term in fluid mechanics by William Thomson, but no by mainstream followers

### 2.1. Early times, regular flows versus nonlinear or sinuous motion

As recalled by Olivier Darrigol [17], as early as 1822 Navier made some distinction between “linear” and “nonlinear” flows, and a decade later Saint-Venant made distinctions between “regular” and “tumultuous” flows. There was later much interest in the transition between the two regimes, a search of a mechanism explaining this transition, and of a criterion to characterize the “sinuous” or “irregular” or “unsteady” regime. Such characterization was made possible with the introduction by Osborne Reynolds of what was later called the “Reynolds number” in 1883 [16]. In 1884, shortly after his long experimental paper describing the transition to turbulence in a channel flow, Osborne Reynolds delivered a speech on “the two manners of motion of water” at an evening meeting of the Royal Institution of Great Britain, published in 1887 [18]. In this speech, he proposed an interesting analogy between hydrodynamics and the movement of troops. A small army has easily order and discipline in the movements of its troops; a large army has greater chance of disorder. For him, “direct or steady motion” is similar to a disciplined army, and “sinuous or unsteady motion” is like a troop whose motion is a “scramble”. With such analogy between fluids and human behavior, Reynolds was close to using the word “turbulence”.

### 2.2. Introduction of the term “turbulence” by William Thomson in 1887

The word “turbulence” had been used for a long time, either in the French (*turbulence*), English (*turbulence*) or German (*Turbulenz*) languages, to describe agitation and disorder. Coming from the Latin *turbulentia*, meaning perturbation, trouble, it had been used since several hundred years for animals, crowds, or children. The adjective “turbulent” came from the Latin *turbulentus* and was used for agitated, troubled, noisy phenomena. Hence the troops used as analogy by Reynolds could have been characterized as turbulent when they are scrambled. However, Reynolds did not use the term.

The adjective “turbulent”, used as an image for an agitated natural phenomenon, was used in several scientific papers, for waves [19], or rivers [20]. The word “turbulence” was used as an image for a molten lava flow of the Stromboli by Charles

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