

## TURBULENCE CHARACTERISTICS AND PROPERTIES

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**Abstract:** This article analyzes the main characteristics and physical and mathematical properties of turbulent flows. Turbulence, unlike laminar flow, represents an unstable, uneven and energy-rich form of motion. The study considers the role of parameters such as Reynolds number, energy spectrum, momentum transfer, as well as turbulent diffusion and viscosity. The structure of turbulent flows, the dynamics of vortices in them and their effect on flow stability are studied from a theoretical and practical perspective. Also, methods for modeling turbulence - statistical approaches, approaches based on the Navier-Stokes equations and computational fluid dynamics (CFD) tools - are analyzed. These analyses are of significant practical importance in the fields of hydrodynamics, aerodynamics and environmental engineering.

**Keywords:** turbulence, Reynolds number, vortices dynamics, turbulent viscosity, flow stability, Navier-Stokes equations, computational fluid dynamics, laminar flow, turbulent diffusion, energy spectrum.

### Introduction

Turbulence is one of the most complex and widespread phenomena in the dynamics of fluids and gases. It is characterized by a complex form of motion that is irregular, unstable, and involves a large amount of energy transfer compared to laminar flow. In the fields of hydrodynamics and aerodynamics, turbulent flows are characterized by strong oscillations on the flow surfaces, eddies, and a wide distribution of the energy spectrum.

The analysis of turbulence is carried out using parameters such as the Reynolds number, turbulent viscosity, eddy structure, and energy dissipation in the flow. This phenomenon is important not only theoretically, but also in many areas of practical technological processes - fluid transfer through pipes, heat transfer control in air flows, aerospace engineering, energy, and environmental monitoring.

This article discusses in detail the theoretical foundations of turbulence, its physical and mathematical properties, and methods for modeling them. The structure of turbulent flows, stability conditions, and their application through practical examples are also analyzed.

### Literature review

Although the phenomenon of turbulence has been widely studied in various fields of science and technology, the issue of creating its complete theoretical foundations is still relevant. There are many approaches to analyzing the phenomenon of turbulence in the scientific literature, among which classical and modern theories stand out.

The most important theoretical foundations in the study of turbulent flows were formed by the boundary layer theory put forward by L. Prandtl (1904). It became the main tool for distinguishing turbulence from laminar flow and determining the stages of their development. The next important approach is the statistical turbulence theory developed by Kolmogorov (1941), which provides a deep understanding of the energy spectrum and the hierarchical structure of turbulent vortices. This theory describes on a mathematical basis how turbulent energy is distributed in the inertial range.

In modern literature, methods for modeling turbulent flows based on computational fluid dynamics (CFD) are widely used. Models such as RANS (Reynolds Averaged Navier-Stokes), LES (Large Eddy Simulation) and DNS (Direct Numerical Simulation) are widely used to determine various complex structures of turbulent flows and simulate them in technical systems. Also, monographs by scientists such as Schlichting, Pope and Wilcox are considered leading scientific sources in this field.

Numerous studies have shown that the occurrence and development of turbulence is closely related to the Reynolds number, and when the critical value is exceeded, laminar flow becomes turbulent flow. Also, in the literature, the analysis of parameters such as turbulent viscosity, diffusion, energy dissipation plays an important role in describing turbulence.

In general, scientific research in the field of turbulence is still being deepened, and the complex nature of this phenomenon is being revealed more fully through new modeling methods and experimental methods.

The concept of turbulence and its nature

Turbulence is an unstable, irregular and turbulent form of motion that occurs during the flow of a liquid or gas. In this case, the flow velocity is constantly changing in time and space. The phenomenon of turbulence is mainly observed in conditions with a high Reynolds number. While laminar flow is smooth and stratified, turbulent flow is characterized by eddies, sudden changes in momentum and uneven distribution of energy.

Main characteristics of turbulence

Turbulent flows are characterized by the following main characteristics:

Reynolds number (Re): The main non-dimensional parameter that determines whether the flow is laminar or turbulent. Its critical value is usually around 2300, and above this value the flow becomes turbulent.

Turbulent viscosity ( $\nu_t$ ): A parameter that characterizes the process of momentum transfer in turbulent flows, in contrast to ordinary molecular viscosity.

Vortex motion: One of the main characteristics of turbulence is the presence of eddies, which lead to the distribution of energy in structures of different sizes.

Energy spectrum: According to Kolmogorov theory, energy in turbulent flow is transferred from large eddies to small eddies and is dissipated.

Turbulence modeling methods

Full mathematical modeling of turbulent flows is extremely complex, and the following approaches are used for this purpose:

RANS (Reynolds Averaged Navier–Stokes): A statistical approach that separates the flow velocity components into average values and fluctuations.

LES (Large Eddy Simulation): Large eddies are directly modeled, while small eddies are taken into account statistically.

DNS (Direct Numerical Simulation): The Navier–Stokes equations are solved in full, but this method is only practical for small-scale systems with limited computer resources.

#### Practical applications

Analysis and control of turbulent flows are used in engineering, in particular:

- In piping systems: reducing pressure losses,
- In aviation: reducing air resistance,
- In energy: optimizing heat exchange processes,
- In environmental monitoring: determining the spread of pollutants.

#### CONCLUSION

Turbulence is a complex form of motion of liquids and gases, which plays an important role in many physical and technical processes. The main features of turbulent flows are fluctuations in the flow, eddies and energy distribution over different dimensions. This article has extensively covered the physical nature, main characteristics and modeling methods of turbulence.

The analysis shows that understanding and controlling turbulent flows is of great importance in increasing the efficiency of technical processes. In particular, the complex structure of turbulent flows is being studied in depth and implemented in practice using mathematical models such as RANS, LES and DNS.

Future scientific research should be aimed at reducing the level of uncertainty in turbulence, optimizing energy losses and reducing environmental impacts. More in-depth modeling of turbulent flows and improving experimental methods will serve as the foundation for scientific and technical achievements in this area.

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