

Preface

In physics, engineering, and other aspects of science, dimensional analysis is a tool to find or check relations among physical quantities by using their dimensions. The dimension of a physical quantity is the combination of the basic physical dimensions (usually mass, length, time, electric charge, and temperature) which describe it; for example, speed has the dimension length/time, and may be measured in meters per second, miles per hour, or other units. Dimensional analysis is necessary because a physical law must be independent of the units used to measure the physical variables in order to be general for all cases.

Dimensional analysis is routinely used to check the plausibility of derived equations and computations and to form reasonable hypotheses about complex physical situations. These situations can be tested by experiment or by more developed theories of the phenomena, and to categorize types of physical quantities and units, which are based on their relations. These relations may depend on other units or dimensions if any. Providing a concise and accessible overview of key concepts in dimensional analysis, this book uses cases and examples in engineering and science to show the practical use of dimensional analysis and self-similarity methods in solving complex problems. The text presents all of the mathematical steps along with the main equations. The appendix includes two detailed case studies.

Isaac Newton, who referred to it as the “Great Principle of Similitude,” understood the basic principle of dimensional analysis. Nineteenth-century French mathematician Joseph Fourier made important contributions based on the idea that physical laws like $F = MA$ should be independent of the units employed to measure the physical variables. This led to the conclusion that meaningful laws must be homogeneous equations in their various units of measurement, a result that was eventually formalized by Edgar Buckingham with the π (Pi) theorem. This theorem describes how every physically meaningful equation involving n variables that can be equivalently rewritten as an equation of $n - m$ dimensionless parameters, where m is the number of fundamental dimensions used. Furthermore, and most importantly, it provides a method for computing these dimensionless parameters from the given variables.

A dimensional equation can have the dimensions reduced or eliminated through nondimensionalization, which begins with dimensional analysis, and involves scaling quantities by characteristic units of a system or natural units of nature.

The similarity method is one of the standard methods for obtaining exact solutions of Partial Differential Equations (PDEs) in particular non-linear forms. The number of independent variables in a PDE is reduced one-by-one to make use of appropriate combinations of the original independent variables as new independent variables, called “similarity variables.”

Solving Boundary Layer problems in Fluid Mechanic and Fluid Dynamics, when encountering non-linear partial differential equation beyond order two, will require usage of Dimensional Analysis and Similarity Method. We have introduced few examples of such problems (i.e. Blasius Equation in Appendix-E). Another example of such usage is in the area of dealing with mathematics and physics of Soliton Wave Partial Differential Equation and their non-linearity behavior. Such issues also can be encountered in physics of laser driven pellet for inertial confinement application and strong shock associated with pellet implosion, where the self-similarity of second kind approach may be used (i.e. Guderley Problem), which is also demonstrated in this book.

In some cases Dimensional Analysis does not provide an adequate approach to establish a solution of a certain eigenvalue problem in nonlinear form which gives rise to the need to discuss similarity method as another approach. In particular, simple cases dealing with reduction of a partial differential equation to an ordinary differential equation in an ordinary way that we have learned in any classical text of same type. In more complex scenarios dealing with boundary-value problem for system of ordinary equations with conditions at different ends of an infinite interval, construction requires a self-similar solution that is more efficient way of solving such complex boundary value problem for the system of ordinary equations directly. In a specific instance, the passage of the solution into a self-similar intermediate asymptotic allows not to have a need to return to the partial differential equations, indeed, in many cases, the self-similarity of intermediate asymptotic can be established and the form of self-similar intermediate asymptotic obtained from dimensional considerations.

The mathematical topics of chaos and fractals are presented both in the body of the book and in the appendices. The chaos and fractals are particularly appropriate in this regard: they are timely—many ideas in these fields were first conceived during the students’ lifetimes; they are applicable—fields as diverse as medicine, business, geology, art, and music have adopted ideas from these areas; and they are beautiful—there is something in the gorgeous computer generated images of objects such as the Mandelbrot set, Julia sets, the Koch snowflake, and others that capture students’ interest and enthusiasm.

Although the book does not provide any exercises at the end of each chapter, throughout the book numerous examples are provided for the appropriate chapter and sections. Thus, the reader will have ample practical examples of dimensional problems instead of facing a cut and dry abstract approach as existing books of this subject follow.

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Engineers and Scientists

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