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BOOK REVIEW

The gas dynamics of explosions by John H. S. Lee

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This small, erudite monograph is a natural extension of Professor Lee's earlier text *The Detonation Phenomenon* (Cambridge University Press, 2008), in which he describes and explains the physical and chemical processes responsible for the self-sustained propagation of detonation waves, a subject on which Professor Lee is recognised as an international authority. The detonation of a solid, liquid or gaseous explosive charge produces a volume of high temperature, high pressure gas that rapidly expands creating a compression wave in the ambient atmosphere, known as a blast wave. Professor Lee's latest text is essentially an archival presentation and description of the various analytical techniques that have been used to determine the physical properties of blast waves as functions of space and time, and this has been done in an exemplary manner.

Chapter 1 provides an excellent review of the thermodynamic and gas dynamic relationships that are essential for understanding the properties of shock and detonation waves. Although the presentation of these relationships is concise, the mathematical progress is always clearly explained, unlike some professorial texts in which there are gaps left as challenges to students. There are no references given in this chapter as each new topic is introduced, and such an inclusion would be helpful to readers who are new to this field of study. Classical symbols and nomenclatures are used, which makes the mathematical text easy to follow, although it seems unusual to use D as the shock velocity and y as the hydrostatic overpressure to ambient pressure ratio. The equations are well displayed when set out in their own lines, but when minor equations are used within the text the fonts are often reduced in size, sometimes making them difficult to read.

Chapter 2 presents a collection of the classical shock wave solutions that have been obtained by assuming the shock to be weak. In every branch of physics and engineering analytical solutions to problems are normally only possible by making assumptions about the magnitudes of the properties involved and their relationships. By assuming the shock to be weak, i.e., the shock Mach number $M_S \approx 1$, the entropy change across the shock is small and the shock can be treated as an isentropic compression wave. Using this assumption, solutions have been obtained by Chandrasekhar, Friedrichs, Witham and Oswatitsch, all of whom are referenced and their solutions are concisely, but fully presented with clarity. This is aided, where appropriate, by the inclusion of illustrations presenting the solutions in the $x - t$ plane. What is perhaps missing is any significant commentary on the validity of the weak shock solutions. How large can the shock Mach number be before there is a significant difference between the results of the solution and experimental observations?

Chapter 3 is devoted entirely to the consideration of shock propagation along a tube of non-uniform cross-sectional area. The three classical solutions by Chester, Chisnell and Whitham are each presented clearly and in detail. The way in which pressure perturbations generated by the area changes are transmitted along the characteristics is described, and provides an understanding of the flow that is not always available from numerical simulations, which is the way in which such flows nowadays are usually studied. It is shown that all three solutions give very similar results, but these are not compared with experimental observations.

Chapter 4, Blast Wave Theory, describes and extends the attempts of Taylor, von Neumann and Sedov to find what is known as the point source solution. This is one of the simplest problems in fluid dynamics to define, namely described

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the physical properties of the wave produced by the instantaneous release of a finite amount of energy at a point in a uniform atmosphere, and yet it has proved to be one of the most intractable problems to solve. Taylor attempted this in the early 1940s when the possibility of producing a nuclear explosion was first conceived, and he achieved a solution by assuming the hydrostatic pressure behind the shock to be large, relative to the ambient pressure, i.e., $M_S \gg 1$. Using the results from this solution, together with measurements from a single photograph of the Trinity explosion, Taylor was able to calculate the energy yield of that first nuclear explosion, to the embarrassment of the US authorities, who still considered that information to be highly classified. As a result, Professor Taylor was refused admission into the USA for several years. Again, the equations for these solutions are clearly set out in a manner that is easy to follow, assisted by appropriate illustrations, although it may be noted that the curves in Figs. 4.6 and 4.7 are not labelled.

Chapter 5 describes the solutions for homentropic explosions, such as in a uniform cross-sectional shock tube, for which the shock propagates at a constant velocity, leaving the gas in the region behind the shock in a state of constant entropy. As a result, the isentropic relationships can be used and the number of dependent variables reduced from three to two.

Chapter 6 describes the solutions that can be obtained if it is assumed that the ratio of specific heats $\gamma \approx 1$. This results in the gas behind the shock wave being concentrated in a thin layer and is called the snow-plough approximation. It is shown that even if $\gamma = 1.4$ some solutions provide useful results and insights. The derivations and applications of this approach are well referenced. It is shown how, in some cases, a Lagrangian approach may be more productive, of which more below.

Brinkley and Kirkwood were the first to develop approximation techniques to describe the propagation of a non-steady shock wave. The original presentations by these authors are brief and difficult to follow, but have been expanded and simplified in subsequent publications. The description of these techniques presented in Chapter 7 is probably the most complete and clearest of any available. This work illustrates some of the advantages of studying the physical properties of blast waves in Lagrangian coordinates, in which the properties are followed along a particle trajectory. After passing through the primary shock, the entropy of the fluid particle remains constant until it is traversed by the second shock. However, the second shock is usually so weak that the entropy change it causes is extremely small. As a result, along the particle trajectories, the simple thermodynamic relationships can be applied and the physical properties defined by two, rather than three, dependent variables.

It is also shown that each particle trajectory can be considered as a piston which drives the subsequent wave. This has led to a technique, known as the piston-path method, which has been used for several decades to successfully calculate the physical properties of blast waves produced by centred explosions. A particle trajectory or piston-path can be obtained by high-speed photography of a particle-flow-tracer established close to a charge shortly before detonation. The properties of the wave produced by this piston can be calculated using numerical techniques that provide results throughout the distance–time plane in exact agreement with measurements made by electronic sensors.

Chapter 8 describes the attempts that have been made, since the early work of Sakurai and Oshima, to develop analytical methods to describe the propagation of blast waves that have decayed to the point that self-similar solutions are no longer possible. Much of this work has been done by Bach and Lee, and the descriptions presented here are undoubtedly the clearest and most complete available from any source. It is pointed out that these analytical methods have their "pros" and "cons", but further evaluation is not provided.

The final chapter is devoted to the presentation of analytical solutions that have been attempted to provide a description of the properties of imploding blast waves. This is a challenging field whether using analytical, numerical or experimental methods. Expanding blast waves rapidly tend to become circular in cross section in two dimensions and spherical in three dimensions. This is because any localised advance of the shock implies an increase of pressure, causing a transverse pressure gradient that is quickly dispersed at the local sound speed. In contrast, imploding shocks are inherently unstable, and this instability can be triggered by the minutest of irregularities in the early stages of the implosion. As a result, it has not been possible to achieve the high pressure and temperature that have been predicted at the focal point of an imploding shock. At one time it was hoped that pressures and temperatures could be achieved by imploding shocks that would trigger nuclear fusion at the laboratory scale.

The text includes a minimal amount of commentary, discussion and evaluation, something that only someone with the stature and experience of Professor Lee can provide. As a result, a newcomer to the field of blast wave physics may find it difficult to distinguish those parts of the text that are primarily interesting mathematical exercises from those parts that are essential for our understanding of the physical processes within a blast wave. For example, it is stated that the decaying shock expanding in two or three dimensions leaves the ambient gas in a state of radially decreasing entropy. This is the feature of a blast wave that distinguishes it from many other fluid flows. It means that if one or even two physical properties of the flow are measured as function of time or distance, it is not possible to precisely calculate the magnitude of the other physical properties. It is this feature that makes the study of blast waves so challenging. After the passage of a blast wave the pressure rapidly returns to its ambient value, but the residual entropy gradient means that the gas is left in a state of radially decreasing temperature and radially increasing density. It is the buoyancy effects of this density gradient that causes the upward and inward flow, bearing dust and detonation products, resulting in the classical mushroom cloud with its toroidal cap and long, thin stem.

Just as the entropy gradient presents a challenge in the study of blast waves, there are other features for which exact solutions are possible, and which provide precise agreements with measurements over a wide range of shock strengths. This is particularly the case with the Rankine–Hugoniot relationships that are presented in the text. Rankine and Hugoniot independently solved the conservation of mass, momentum and energy equations for a compressible gas, and showed that two states were possible, but were not aware of the shock phenomenon which we now know separates these two states. The ratios of all the physical properties on the two sides of a shock can be exactly calculated in terms of the shock Mach number, which is the easiest and most accurate measurement of a blast wave that can be made. As a result, electronic sensors used to measure the properties of blast waves are usually calibrated by measuring the shock velocity, and using the appropriate Rankine–Hugoniot relationship to calculate the magnitude of the property immediately behind the shock.

There is another reliable and simplifying feature of blast waves that is not mentioned in the text and that is the scaling laws of Hopkinson [1] and Sachs [2]. Hopkinson showed that the distance at which a blast feature occurs is proportional to the cube root of the energy release, or the charge mass, and Sachs showed how distances and times within a blast wave can be scaled to account for differences in the ambient pressure and temperature. Hopkinson's law has been shown to be valid over a wide range of charge mass, from milligrams to megatons, and Sach's laws have been shown to be valid over the range of ambient pressures and temperatures encountered on the surface of the Earth. The availability and reliability of these laws means that it is easy to compare measurements of blast properties from charges of different masses detonated in different ambient conditions. In this way, results from small-scale experiments can be confidently used to predict the properties of blast waves from much larger explosions.

In summary, *The Gas Dynamics of Explosions* is a unique and valuable collation and presentation of the analytical methods that have been used to calculate the physical properties of blast waves. This has been done with mathematical clarity, which in most cases is superior to that of the original publications. These analytical methods often provide an insight into the physical processes within a blast wave that is not provided by numerical simulation techniques that are nowadays most commonly used to study these processes. The text provides an excellent reference source for researchers studying blast waves and an excellent primer to those who are new to the field. It is a natural sequel to Professor Lee's earlier work, *The Detonation Phenomenon* (Cambridge University Press, 2008), and an essential companion to C. E. Needham's *Blast Waves* (Springer, 2010).

References

1. Hopkinson, B.: British Ordnance Board Minutes, 13565 (1915)
2. Sachs, R.G.: The Dependence of Blast on Ambient Pressure and Temperature. BRL Rept. 466, Aberdeen Proving Ground, Maryland, USA (1944)