Book Review

Missile Aerodynamics

Jack N. Nielsen, Nielsen Engineering & Research, Inc., CA, 1988, 450 pp., $40.00

In the preface it is stated that this book can provide insight and background for missile aerodynamicists. In today's highly computerized world of computational fluid dynamics, is this true? The answer for this book is yes. Today's aerodynamicists can use the text, over 400 figures and more than 500 equations, to aid in understanding important flow parameters and verifying more complex methods. Many of the results apply also to aircraft concepts. As a reference volume it provides excellent definition of symbols and nomenclature, many derivations of equations, and frequent references. This book was a major contribution when it was first published in 1960 and may be even more powerful now. If it lacks anything, it would be additional comparisons of theory with experimental data.

The Introduction provides an explanation of differences between airplanes and missiles. This discussion could have gone a little deeper and described the primary geometric differences that are driven by the need to meet constraints such as aircraft carriage, subsystem packaging, and cost. Additional information would help the new missile aerodynamicist understand why he is working with different geometric parameters than an aircraft engineer.

The book begins to develop as a strong reference in the second chapter as fundamental formulas are collected and described. A most useful summary is provided that classifies and lists assumptions for 13 basic theories used to compute pressure distributions, forces and moments. The utility of this information cannot be underestimated because it provides a means of understanding the range of applicability of these often used theories such as shock-expansion, method of characteristics, slender-body theory, and conical flow theory. Selected theories are also applied to demonstrate their range of applicability. This chapter itself is worth the price of the book.

The third chapter develops and applies a major theory for missile aerodynamics—slender-body theory. It develops zero and finite angle of attack solutions and identifies how general cross-section shapes can be evaluated. Pressure coefficients and force and moment coefficient formulas are established by solving the appropriate potential equations with slender-body assumptions.

Both subsonic and supersonic flows are evaluated. Although the equations are developed with adequate explanation and clearly identified assumptions, no numerical examples or comparisons with data are provided. It would have been more enlightening in the early stages of the book to have selected examples to give the novice some ability to judge accuracy. This chapter is a classic reference for the development of slender-body equations for application to missile geometries.

In Chapter 4 the impact of nonlinear phenomena such as vortices is established. The body of revolution is first analyzed by applying some of the formulas of the previous chapter. Center of pressure estimates for tangent ogives are developed. Pressure distributions are shown for cones, elliptic cones, and bumped cylinders and provide insight into the behavior of surface properties. Vortex phenomena are then introduced by showing the breakdown in pressure coefficient prediction versus data on a circular cylinder. Empirical data is then provided to develop models for the location and strength of vortices. Mathematical models are then developed based upon the vortex singularity to model motion of the body vortices. This is a powerful approach that provides understanding that the mathematical model is an attempt to model a very complex flow phenomenon. The concept of free vortices is introduced and sets the stage for handling component interactions on missiles. Most of the mathematics in this chapter is based upon complex variables. This makes physical interpretation of equations difficult.

This sets the stage for Chapter 5, which addresses wing-body interference. This chapter shows the power of using slender-body theory to develop the interactions between a wing and a body. The change in the lift components and center of pressure between the two are developed and values shown to provide the reader insight into the magnitude of the effect. Analysis for more traditional missile cruciform wing-body arrangements is developed and differences in body and panel loads shown. An excellent summary is provided to compare the resulting equations. Modifications of the results are shown for more realistic missile concepts with short afterbodies or nonslender bodies. Some comparison with data is provided. The examples in this chapter are key to understanding the physical significance of wing and body carryover interference factors.

The role of the wing vortex and how to model it are addressed in Chapter 6. The vortex sheet concept is first developed and then the resulting roll-up to form a single vortex is described. These vortex phenomena are then developed into mathematical models to establish the vortex strengths that influence the local velocity fields or downwash. The treatment of the vortex in the presence of the body is developed with example calculations. The impact and role of multiple vortices are superimposed to provide the understanding of the contribution of each to the total forces on the wing-body combination. The chapter finishes with an excellent presentation of the interactions of the multiple vortices in a cruciform wing arrangement. In general, this is a very strong chapter for understanding fundamental wing vortex behavior.

Once the basics of vortex development are understood the interference of wing vortices with tail surfaces is established in Chapter 7. First, the flat vortex sheet is addressed. This is the situation when the wing and tail are close together. The modification of the pressure field on the trailing surface is also developed for the discrete vortex case when wing and tail are separated by a significant distance. The lift change due to the vortex interaction is then developed using strip theory for one of the classic parameters of aerodynamics, this is, the tail interference factor. An excellent example is given to provide insight into the magnitude of the interference effect. The strength of this chapter lies in the development of the vortex interference factors. A little more physical interpretation of some of the interference factors would be useful.

With the fundamental principles of wing-body-tail aerodynamics well in hand, Chapter 8 develops control effects by beginning with a discussion of control types. Since the all-moveable control is prevalent on missile concepts, this type of control is appropriately addressed at length. Slender-body theories are applied here to develop the effect of carryover in the presence of deflection and an example is used to describe the magnitude of this effect. The equations for the resulting lift ratios are given with no detail on the steps to obtain these somewhat complex expressions. In this case, the lack of detailed equation development is appropriate because it is primarily algebraic manipulation. Planar and cruciform arrangements are addressed and the coupling between adjacent fin panels established. Most of this section describes qualitative effects, but it provides good insight into coupling effects. A discussion of trailing-edge controls leads to a definition of what type of controls can be analyzed with classical theory such as supersonic wing theory, slender-body theory, and simple sweep theory. The overall chapter strength is the development of deflection effects on lift and moments.

Although lift, stability, and control have been addressed up to this point, drag is the subject of Chapter 9. The components of drag (i.e., pressure, base, and viscous) are first discussed and the characteristics of classical drag curves or polars are developed next. This introductory material provides a short, but useful, summary of drag fundamentals. The chapter then develops slender-body solutions for forebody drag. Expressions are developed for nonlifting and lifting cases. Viscous effects are also introduced and nonslender shapes are addressed with a variety of additional theories that model nonlinear effects. Classic theories such as Newtonian, tangent cone, and conical shock-expansion theory are discussed and their accuracy compared. This provides a very convenient reference for understanding the limitations of these drag theories. Optimum body shapes are then derived and numerical examples given. The chapter goes on to develop pressure drag models for wings using supersonic wing theory. Again a good illustrative example is provided. Procedures for minimizing wave drag of combinations of wing-bodies are then described. This discussion is somewhat lengthy but it does qualitatively develop some drag reduction procedures such as area ruling.

Base drag receives a thorough treatment. Since its prediction is primarily empirical, much time is spent describing some of the phenomena that affect base drag. Several useful curves and data sets are provided to help the reader understand this subject more clearly.

The rest of the chapter is devoted to skin friction. Initially, a discussion of phenomena is provided before the development of some of the fundamental models and parameters. Examples are carried through to give insight into the magnitude of shear stresses and skin-friction coefficients. Extensive references are cited to help with the development of some of the theoretical results and provide additional database sources.

The book finishes with Chapter 10 and stability derivatives. First, the notation is developed. Then a very thorough development of a complete set of stability derivatives is accomplished. This is followed by the identification of the most important derivatives for static stability, damping, and dihedral effects. Expressions to compute these derivatives are then developed in terms of inertia coefficients. The nomenclature here can be a little cumbersome but the points are made clearly. An invaluable part of this chapter is the table of apparent mass coefficients for a variety of shapes. For anyone who has tried to do stability analyses on unusual shapes or fin arrangements, this is a major time-saver. These apparent mass coefficients are used to develop specific derivatives for a planar and cruciform, triangular wing arrangement. Further discussion considers wing-bodies, arbitrary number of fins at a cross section, variable body radius, arbitrary aspect ratio, and empennage interference. The large number of examples provides the reader with insight into the primary factors affecting the magnitudes of these stability derivatives.

In conclusion, this book is an excellent reference for both the beginning and experienced aerodynamicist. I recommend it as a required reference for any practicing aerodynamicist working on either missile or airplane applications.

Robert J. Krieger
McDonnell Douglas Astronautics Company,
St. Louis, MO