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New Supersonic Wing Far-Field Composite-Element Wave-Drag Optimization Method

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NASA and industry recently ended the High Speed Civil Transport program. The objective of the High Speed Civil Transport program was to develop critical technologies to support the potential development of viable supersonic commercial transport aircraft. The aerodynamic design development activities benefited greatly from the use of the prior design, analysis, and prediction methods as well as the understanding of the fundamental physics inherent in an efficient supersonic aircraft design. It was recognized that the critical strengths of the aerodynamic processes included the blending of the computational power offered by computational fluid dynamics methods with the fundamental knowledge and rapid design development and assessment capabilities inherent in the existing linear aerodynamic theory methods. Nonlinear design optimization studies are typically initiated with an initial optimized linear theory baseline configuration design. In this paper, a new supersonic linear theory wave-drag optimization methodology using far-field wave-drag methodology is introduced. The method is developed using the class-function/shape-function transformation concept of an analytic scalar wing definition. The methodology is applied to an arrow-wing planform to illustrate its versatility as well as to demonstrate the usefulness of the class-function/shape-function transformation analytic wing concept for aerodynamic design optimization.

I. Introduction

NASA and industry recently ended the High Speed Civil Transport (HSCT) program. The objective of the HSCT program was to develop critical technologies to support the potential development of viable supersonic commercial transport aircraft. The initial phases of the HSCT program used the extensive database of methods and knowledge and expertise from the U.S. Supersonic Transport (SST) program and the subsequent NASA-sponsored Supersonic Cruise Research studies. The aerodynamic design development activities benefited greatly from the use of the prior design, analysis, and prediction methods as well as the understanding of the fundamental physics inherent in an efficient supersonic aircraft design. The emerging advanced computational fluid dynamics (CFD) methods greatly enhanced the supersonic design and analysis process and enabled substantial improvements in achievable aerodynamic performance levels. It was recognized that the critical strengths of the aerodynamic processes included the blending of the computational power offered by CFD methods with the fundamental knowledge and rapid design development and assessment capabilities inherent in the existing linear aerodynamic theory methods. The primary objectives of this paper are twofold. First, the far-field composite-element (FCE) supersonic wave-drag optimization method will be developed and introduced. Second, the use of the universal parametric geometry representation method, the class-function/shape-function transformation technique (CST) [1–3], for wing design optimization will be demonstrated.

II. Planar Linear Theory Analyses Versus CFD Analyses

"Linear theory is long on ideas but short on arithmetic, CFD is long on arithmetic but short on ideas."† Although linear theory can provide some unique insights and ideas, it does require understanding of both the numerical and physical limitations of the theory. However, CFD can provide both answers and visibility for flow solutions and flow conditions far beyond the capability of linear theory. By using both CFD and linear theory and exploiting the benefits of each, we can have the ideas and the arithmetic with the added bonus of increased synergistic understanding and design capability.

Since the advent of the use of the powerful CFD design and analysis methods, the value of linear theory methods is often questioned. During the development cycle of a new airplane concept, an important question to be answered is how much detail and computational sophistication is required. The answered offered to this question in [4] is, "In the spirit of Prandtl, Taylor and von Kármán, the conscientious engineer will strive to use as conceptually simple an approach as possible to achieve his ends."

Being old or restrictive does not imply being useless. In fact, many of the contributions derived from linear theory are still useful today: 1) elliptic load distribution for minimum induced drag; 2) thin-airfoil theory; 3) conformal transformations; 4) supersonic area-rule wave-drag calculation; 5) transfer-rule wing/body optimization; 6) Sears–Haack, Haack–Adams, and Karmen ogive minimum wave-drag bodies of revolution; 7) conical flow theory; 8) reverse-flow theorems; 9) supersonic nacelle/airframe integration guidelines; 10) supersonic favorable interference predictions and concepts; 11) sonic boom prediction; 12) understanding sonic boom configuration design factors; 13) supersonic trade and sensitivity studies; and 14) baseline configuration for nonlinear design optimization.

Let us examine the fundamental differences in the results of linear theory analysis tools and in the results of corresponding nonlinear CFD analysis. Linear theory underestimates compression pressures and overestimates expansion pressures. In addition, linear theory disturbances are propagated along freestream Mach lines and therefore may not adequately predict shock formations. Linear theory with planar boundary conditions does not predict interferences between lift and volume. These differences typically are not significant effects for long, slender, thin configurations at low lift coefficients, which correspond to the geometric characteristics of low-drag supersonic configurations.

Linear theory equations as well as related direct solution formulations can provide direct insights and understanding into the effects of geometry on the nature of the flow phenomena. Because of

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†Private communication with R. T. Jones, about 1975.