PROGRESS REPORT(*)

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OPTIMUM LIFTING WINGS IN NEWTONIAN FLOW

by

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1. INTRODUCTION

The object of this investigation is a general analysis of optimum two-dimensional or three-dimensional lifting wings in hypersonic flow. Physically, Newtonian theory is employed. Mathematically, the methods of the calculus of variations are used in order to optimize the lift-to-drag ratio for given geometric constraints. This quantity is important in that the range and the maneuverability of a hypersonic cruise vehicle, a hypersonic glide vehicle, and a reentry vehicle increase linearly with it. Since flat-top wings are naturally suited to produce high lift-to-drag ratios at hypersonic speeds, particular attention is devoted to these wings under the assumption that the free-stream velocity is parallel to the flat top.

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2. DIRECT METHODS (Ref. 1)

An investigation of the lift-to-drag ratio attainable by a slender, affine wing at hypersonic speeds is presented under the assumptions that the pressure distribution is Newtonian and the skin-friction coefficient is constant. Analytical expressions are derived relating the drag, the lift, and the lift-to-drag ratio to the geometry of the configuration.

The class of flat-top wings whose upper surface is parallel to the free stream is considered. After it is assumed that the chordwise thickness distribution is a power law and the spanwise thickness distribution is proportional to some power of the chord distribution, the effect of the thickness ratio and the power law exponents on the lift-to-drag ratio is investigated.

It is shown that a set of values of the thickness ratio and the power law exponents exists which yields a maximum lift-to-drag ratio. Specifically, the optimum thickness ratio is such that the friction drag is one-third of the total drag; the optimum chordwise power law exponent is one, meaning that a linear thickness distribution is the best in the chordwise sense; and the optimum spanwise power law exponent is one, meaning that a thickness distribution proportional to the chord distribution is the best in the spanwise sense. For a friction coefficient $C_f = 10^{-3}$, the maximum attainable lift-to-drag ratio is 5.29.

4. INDIRECT METHODS IN TWO INDEPENDENT VARIABLES (Ref. 3)

The problem considered in Refs. 1 and 2 is investigated again with reference to the class of three-dimensional, slender, flat-top wings not necessarily affine. By means of the indirect methods of the calculus of variations in two independent variables, it is proved that the solutions of Refs. 1 and 2 are variational solutions.

5. SIMILARITY LAWS (Ref. 4)

In the previous investigations, the maximum lift-to-drag ratio was determined assuming that no constraints are imposed on the configuration. In a practical design, requirements may be imposed on the lift, the planform area, the frontal area, the volume, the root chord, the span, and the root thickness. Since the number of possible variational problems is practically without limit, economy of thought leads one to pose the following questions: (1) Is there any similarity law which permits one to determine the optimum chordwise contour of a wing of arbitrary spanwise contour from the known optimum chordwise contour of a reference wing? and (2) Is there any similarity law which permits one to determine the optimum spanwise contour of a wing of arbitrary chordwise contour from the known optimum spanwise contour of a reference wing? The answer to these questions can be found in Ref. 4 where two similarity laws are derived.

The Similarity Law for Chordwise Contours permits one to determine the optimum chordwise contour of a wing of arbitrary spanwise contour and chord distribution from the known optimum chordwise contour of a reference wing (a wing of constant trailing edge thickness and constant chord); the aerodynamic and geometric quantities of the latter must be replaced by appropriate proportional quantities of the former, with the proportionality constants depending only on the prescribed spanwise contour and chord distribution.

The Similarity Law for Spanwise Contours permits one to determine the optimum spanwise contour and chord distribution of a wing of arbitrary chordwise contour from the known optimum spanwise contour and chord distribution of a reference wing (a wing with a linear chordwise thickness distribution); the aerodynamic and geometric quantities of the latter must be replaced by appropriate proportional quantities of the former, with the proportionality constants depending only on the prescribed chordwise contour.

REPORTS

1. MIELE, A., Lift-to-Drag Ratios of Slender Wings at Hypersonic Speeds, Rice University, Aero-Astronautics Report No. 13, 1966.

2. MIELE, A., One-Dimensional Approach to the Maximum Lift-to-Drag Ratio of a Slender, Flat-Top, Hypersonic Wing, Rice University, Aero-Astronautics Report No. 14, 1966.

3. MIELE, A., Two-Dimensional Approach to the Maximum Lift-to-Drag Ratio of a Slender, Flat-Top, Hypersonic Wing, Rice University, Aero-Astronautics Report No. 15, 1966.

4. MIELE, A., Similarity Laws for Lifting Wings of Minimum Drag at Hypersonic Speeds, Rice University, Aero-Astronautics Report No. 16, 1966.