Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Advanced Method for Computing Flow Around Wings with Rear Separation and Ground Effect

Klaus Jacob*
German Aerospace Research Establishment (DFVLR)
Göttingen, Federal Republic of Germany

Introduction

In order to predict the flow around the wing of an aircraft at high incidence and low speed (takeoff and landing), it is crucial to account for the viscosity effects, including separation. A few years ago, a method of computing the flow with rear separation for a restricted class of wings was published.[1] The total iterative procedure contains a three-dimensional lifting surface method for inviscid incompressible flow and a two-dimensional airfoil method for viscous flow at low Mach numbers, including a displacement model for separated flow. In comparison with experiments, the results of the method were encouraging, but some deficiences were found. Meanwhile, some important improvements and an extension of the method to include the ground effect have been achieved. The advanced method is presented in detail in Ref. 2 together with many results. In this note, a very brief description is given and a few results are shown.

The Method

For a clean wing with moderate to high aspect ratio and low sweep, the flow at each section is assumed to be approximately two-dimensional. But, compared to a wing of infinite span, the effective basic flow at each section is somewhat changed due to the different vortex systems of the finite and infinite wings. This change, i.e., the induced velocity difference Δw, depends on the spanwise lift and pitching moment distributions $\gamma(\eta)$ and $\mu(\eta)$ of the wing.

If the lift and moment distribution is known, the effective basic flow at each section can be computed by reverse application of a lifting surface method. On the other hand, if the basic flow is known at each section, the lift and moment distribution can be computed by applying to each section a two-dimensional airfoil method including the boundary layer and separation and a compressibility correction. So, starting with a first approximation of $\gamma(\eta)$ and $\mu(\eta)$, the viscous flow can be calculated by connecting these two computations and recycling until convergence of the lift distribution is found. A reasonable first approximation for $\gamma(\eta)$, $\mu(\eta)$ may be obtained by standard application of the lifting surface theory, at least for the lower angles of attack α_g. For higher α_g, the results from the previous α_g can be used as first approximations, if α_g is increased stepwise.

The effective basic flow velocity vector at a section (η = constant) is $V(\eta,x) = V_\infty + \Delta w(\eta,x)$, with Δw being the difference of the velocity vectors induced by the vortex systems of the finite and infinite wings, respectively. The basic flow velocities at different points of the section (for instance, at the quarter chord and trailing edge) differ little from each other or from V_∞. So, in the first version of the method[1] the basic flow was assumed to be a parallel flow with $|V| = |V_\infty|$ and $\alpha = \alpha_g - \Delta\alpha$, where $\Delta\alpha$ is a mean value of the induced angle differences at the quarter chord and trailing edge. But it turned out that this is a good approximation only for the lower angles of attack and for the center part of the wing. Compared to experiments for high α_g, the computed total lift was too high and, at the outer part of the wing, there was a noticeable difference in the pressure distributions. For these reasons, the basic flow model has been refined in two respects: 1) instead of $|V_\infty|$, the absolute value of the basic flow velocity at the quarter chord $|V(\eta,x_q)|$ is used and 2) the different directions of V at the quarter chord and trailing edge are taken into account by replacing the parallel flow by a curved basic flowfield with given flow angles at the quarter chord and trailing edge. By these refinements, considerable improvement with respect

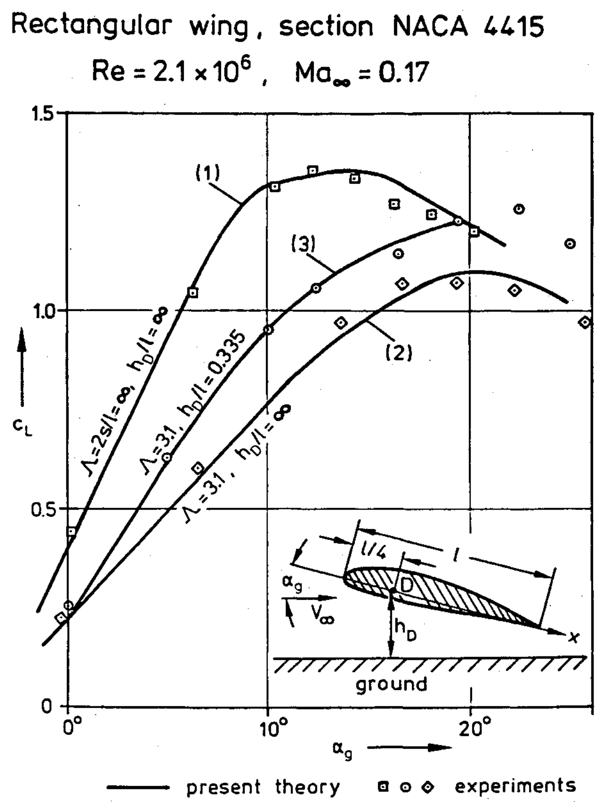

Fig. 1 Lift from theory and experiment for airfoil section (curve 1) and rectangular wing (curves 2 and 3) without and with ground effect.

Received June 8, 1986; revision submitted July 28, 1986.

*Dr.-Ing, Institut für Theoretische Stroemungsmechanik.

to the pressure distributions, total lift, drag, and pitching moment has been gained.

The first version of the method was limited to unbounded flow. The flight at high incidence, however, is of special interest for takeoff and landing, i.e., near the ground. To satisfy the kinematic flow condition at the ground, the well-known reflected image concept was applied to both the lifting surface theory and the two-dimensional airfoil method. This led to an extension of the theory for computation of the viscous flow around a wing in the vicinity of the ground.

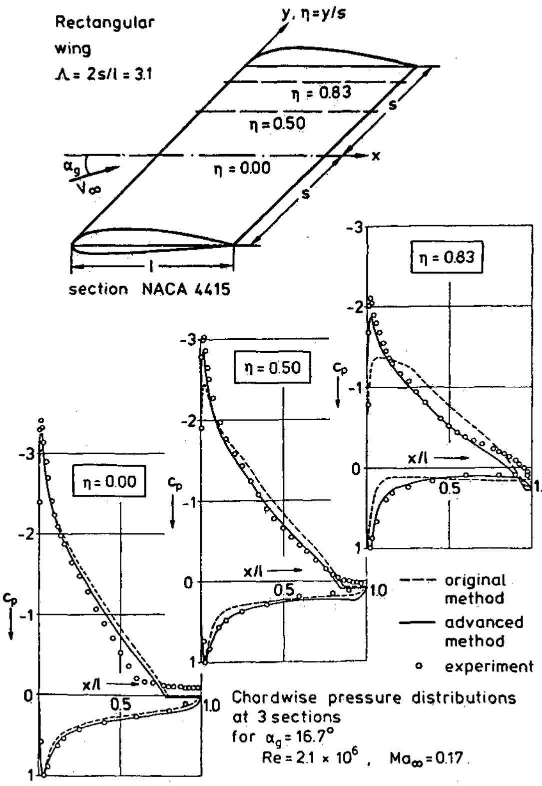

Fig. 2 Pressure distributions at different sections of the rectangular wing (without ground effect).

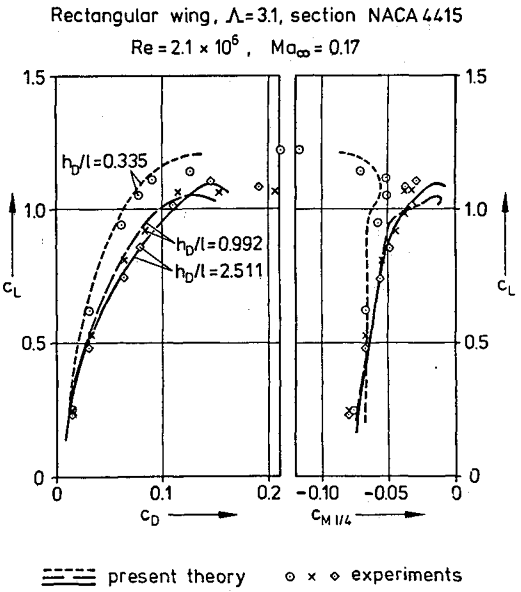

Fig. 3 Drag polars and pitching moment of the rectangular wing for three different ground distances h_D.

Results

Figure 1 shows the total lift coefficient c_L vs angle of attack α_g for the infinite wing (curve 1) and for a finite-rectangular wing of aspect ratio $\Lambda = 3.1$ without ground effect (curve 2) and with ground effect (curve 3). All of the computed results compare well with the experiments. The considerable effects of the finite span and of the ground are well predicted, even for rather high angles of attack. Chordwise pressure distribu-

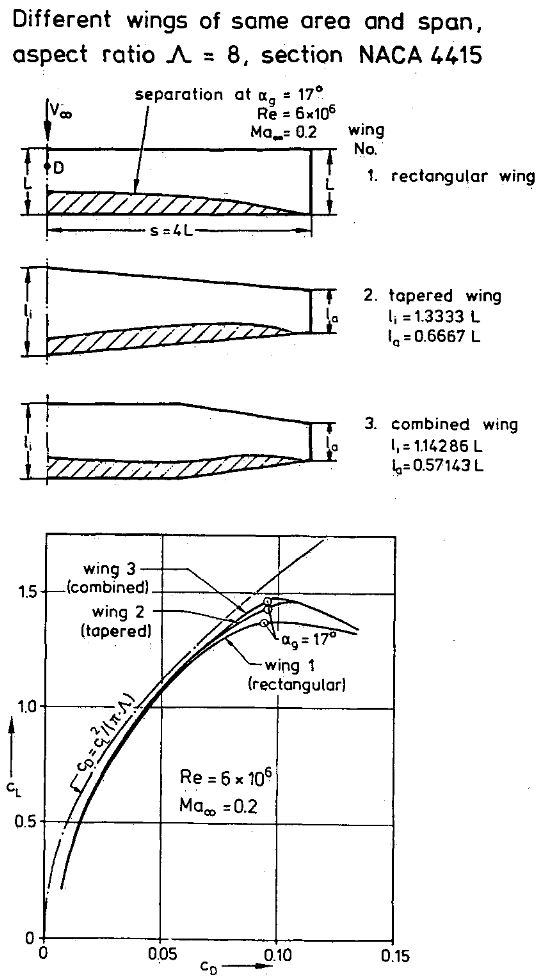

Fig. 4 Computed separation and drag polars for three different wings.

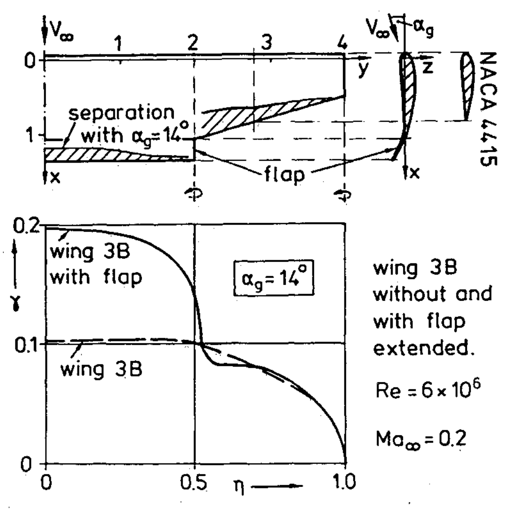

Fig. 5 Computed separation and spanwise lift distribution for a wing with flap.

tions for three different wing sections are compared in Fig. 2 at $\alpha_g = 16.7$ deg, i.e., near maximum lift. Some rear separation is found at the inner sections. At the outer section, one can clearly see the improvement gained with the advanced method. Figure 3 shows some results for the rectangular wing at three different ground distances h_D. Again, the theoretical predictions are satisfactory. It should be noted that the lowest $c_{L\max}$ is found for the medium distance $h_D/1 = 0.992$. So, when this wing approaches the ground, the maximum lift decreases until the ground distance is lower than the wing chord.

Finally, Figs. 4 and 5 exhibit some of the theoretical results for more general wing geometries. In Fig. 4, separation lines and total lift-drag characteristics are compared for three different wing shapes. The results indicate wing 3 to be the best at high lift. In Fig. 5, a variant of wing 3 (with an unswept leading edge) is investigated with and without an attached flap on the inner half of the wing. With a flap, a strong gradient of the spanwise lift distribution γ is found near the flap tip. The corresponding trailing vortex induces some rear separation at the outer wing and reduces separation at the outer part of the flap.

A slotted flap was not used because, at present, the computer program is limited to single-element airfoils. The next step will be an extension to multicomponent high-lift systems.

References

[1] Jacob, K., "Computation of the Flow Around Wings with Rear Separation," DFVLR, Göttingen, FRG, Rept. FB82-22, July 1982.

[2] Jacob, K., "Advanced Method for Computing the Flow Around Wings with Rear Separation and Ground Effect," DFVLR, Göttingen, FRG, Rept. FB86-17, Jan. 1986.