The Effect of Thin Liquid Films on Boundary-Layer Separation and Laminar-Turbulent Transition

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(i) Motivation

When an aircraft flies through rain or heavy clouds, a thin film of water forms on the surface of the wings. This may result in significant alteration of the stability properties of the boundary layer. Also, the boundary layer may become more susceptible to flow separation. In the flow past a modern aircraft wing two instability modes, Tollmien-Schlichting waves and cross-flow vortices, lead to laminar-turbulent transition. In this project our main concern is the effect of Tollmien-Schlichting waves. Furthermore, the water dynamics is naturally linked to icing and thus further understanding of the early stages of the accumulation of liquid becomes even more far-reaching.

(ii) Research

The liquid film forming on the wing might be responsible for an increase in the drag coefficient and a decrease in the lift capabilities of the aircraft. We first determine the flight conditions when the film thickness becomes comparable to the thickness of the viscous near-wall layer in the triple deck model. We then extend the asymptotic theory of viscous-inviscid interaction to incorporate the dynamics of the liquid film and provide suitable physical arguments for the relative importance of inertia and viscous forces in the film and in the relation to the boundary layer in the air above.

In this asymptotic framework, we then conduct a linear stability analysis study and interpret the effects of the liquid film height on important quantities of the flow such as pressure and skin friction. A key part of the effort is dedicated to highlighting how the liquid film interacts with the rest of the flow and how some of the classical results are altered under the presence of this additional layer.

The setup then allows us to construct a state-of-the-art computational platform to tackle the nonlinear aspects of the problem. Furthermore, we aim study of the evolution of Tollmien-Schlichting waves within this flow and elaborate on their impact when the liquid film is present.

(iii) Application for industry

The core elements of the study have a direct implication for the aerodynamic industry. Adverse weather conditions and the effects of water layers (and subsequently ice) are yet to be addressed comprehensively due to the difficult nature of the multi-scale and multi-physics systems. Gaining further insight into these problems is of utmost importance in the near future. Additionally, we direct all our investigations to concrete geometrical configurations of interest, as we determine the effect of the film on the possible boundary layer separation near the wing and flap junction, as well as surface roughness elements.