Transition to rivulets in a highly sheared liquid film on an airfoil

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This work deals with the prediction of the breakup of a sheared liquid film into rivulets. It is motivated by the needs of the aeronautic industry, for the study of the icing of aircraft components. When an aircraft flies through icing clouds or rain, supercooled water droplets impinge on its wings and form ice if these aerodynamic surfaces are not thermally protected. Usual anti-icing systems involve heating the leading edge of the airfoil. As they are unable to freeze, the droplets tend to coalesce and form a continuous thin water film. This runback water flows to downstream regions, driven by pressure and shear forces due to the external airflow around the airfoil, and its thickness varies streamwise. When a critical thickness is reached, surface tension effects become dominant, and it is energetically favorable for the film flow to break up into rivulets. The presence of rivulets affects the performance of the anti-ice system because it decreases the effective area of heat and mass transfer between the water, the airfoil surface, and the external airflow.

It is therefore fundamental to be able to predict where the water film will break up into rivulets on an airfoil, and which rivulet pattern will be adopted. This can be tackled through different approaches: the film flow and rivulets can be fully computed, taking into account the contact angle force in the lubrication equations, and studying the stability of the contact line, e.g. [1]. But this approach is time consuming, and a macroscopic approach is usually preferred in ice accretion / anti-icing codes. In this type of approach, a wetness factor is computed and there is no explicite calculation of the rivulets. Al-Khalil [2] and da Silva et al. [3] have used the Minimum Total Energy (MTE) criteria to predict transition to rivulets in their respective codes. This criteria allows determining if there will be transition or not. For that, the total energy (kinetic + surface tension) of the film is compared to the energy of an optimum rivulet configuration. The MTE approach has been extensively validated for falling films, but almost never for sheared films because of the lack of experimental data. In addition, the MTE modeling of rivulets in anti-icing codes has never been validated in isothermal conditions.

In this work, the MTE model is implemented for an isothermal water film flow on a NACA0012 profile. As an example, the critical film thickness for rivulet transition h_0 predicted by the MTE model is plotted in Fig.1 as a function of the shear stress τ at the film interface. In the case of the NACA profile, the distribution of τ is estimated through single phase computations of the airflow. The results are compared to the experimental measurements of Kai et al. [4] who provide a complete mapping of the water film thickness on a NACA0012 profile subject to shear flow (Fig.2). An emphasis is given to the prediction of the critical film thickness for transition to rivulets, as well as the spacing λ between rivulets and their diameter.

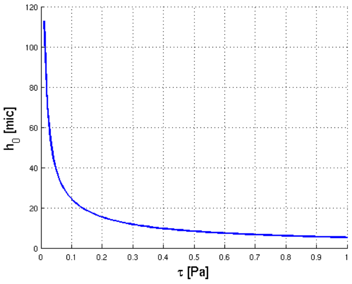

Fig. 1. Critical film thickness for transition to rivulets h_0 predicted by the MTE criterion.

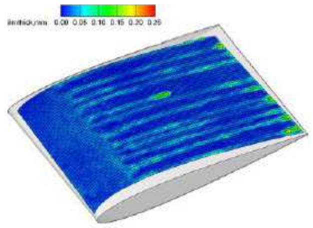

Fig. 2: Rivulet transition on a NACA0012 profile captured by Kai et al. (2014).

References

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