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RECENT EXPERIMENTAL STUDIES CONDUCTED AT ONERA ON THE INFLUENCE OF SURFACE IMPERFECTIONS ON BOUNDARY-LAYER TRANSITION

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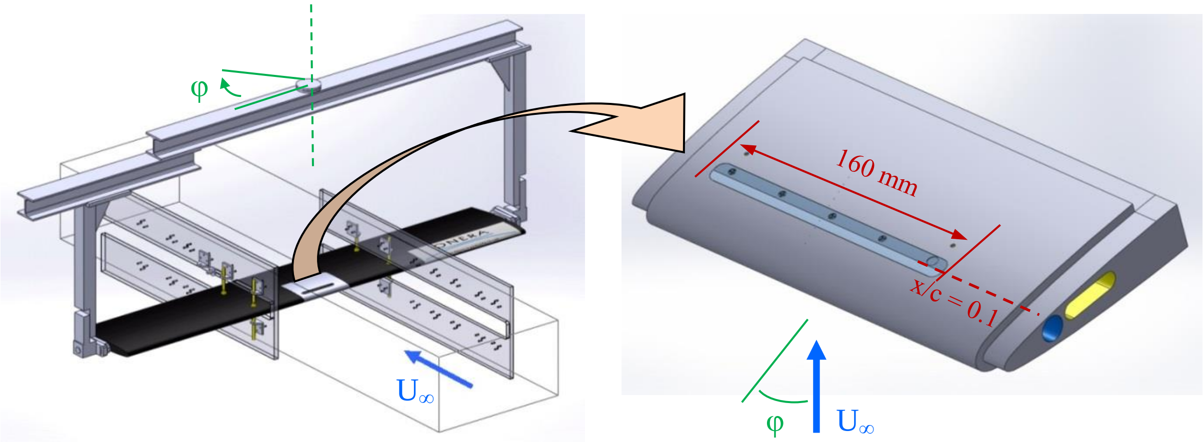
ABSTRACT

For future aircraft, one of the most promising ways to tackle future ecological and economic challenges is to use NLF (Natural Laminar Flow) wings which keep the boundary layer laminar as far as possible along the chord in order to decrease the skin-friction drag and thus, the fuel consumption. Using this approach, it rapidly becomes obvious that the roughness of the wing surface is a key parameter and that the effects of manufacturing irregularities (rivets, junctions, etc) on the boundary layer have to be understood. ONERA has a long-time expertise in this field and has provided useful models and experimental data concerning the effect of two-dimensional imperfections such as Forward Facing Steps (FFS), Backward Facing Steps (BFS), gaps or waviness on the laminar-turbulent transition [1-4]. From a numerical standpoint, the influence of these imperfections can be determined with a simple method using laminar Navier-Stokes computations and classic linear stability analysis. The purpose of such a method is to provide the N-factor modification induced by the imperfection with respect to the smooth case in the form of a ΔN model calibrated for different geometrical parameters and different aerodynamic conditions. Then the transition location shift can be estimated using conventional tools like the e^N method [5-6]. Of course, such models need experimental data to be calibrated. Moreover, this approach is not relevant for isolated roughness elements for which tridimensional effects may result in non-normal mode growth [7]. In this case, empirical criteria based on experimental data seem to be the most convenient approach in order to provide simple guidelines regarding the surface tolerances [8-9]. The purpose of this paper is to provide an overview of recent experimental studies conducted at ONERA regarding the influence of surface imperfections on boundary-layer transition. The large available database could usefully be used for validation of numerical models and simulations.

Two different experimental configurations were used to investigate the effects of two different kinds of surface imperfections:

1. The first configuration consists of a two-dimensional model based on an ONERA-D symmetric profile (with a chord length c = 0.35 m and span s = 2 m) as illustrated in Figure 1. A metallic insert was designed and integrated to the leading-edge region in order to fit the model with localized surface imperfections (gaps and holes) on the upper side at x/c = 10%. The angle of attack α as well as the sweep angle φ of the model can be adjusted in order to address different transition scenarios.
2. The second configuration consists of a metallic flat plate (with a length l = 1.2 m and a thickness t = 38 mm) equipped with a trailing-edge flap and a leading-edge

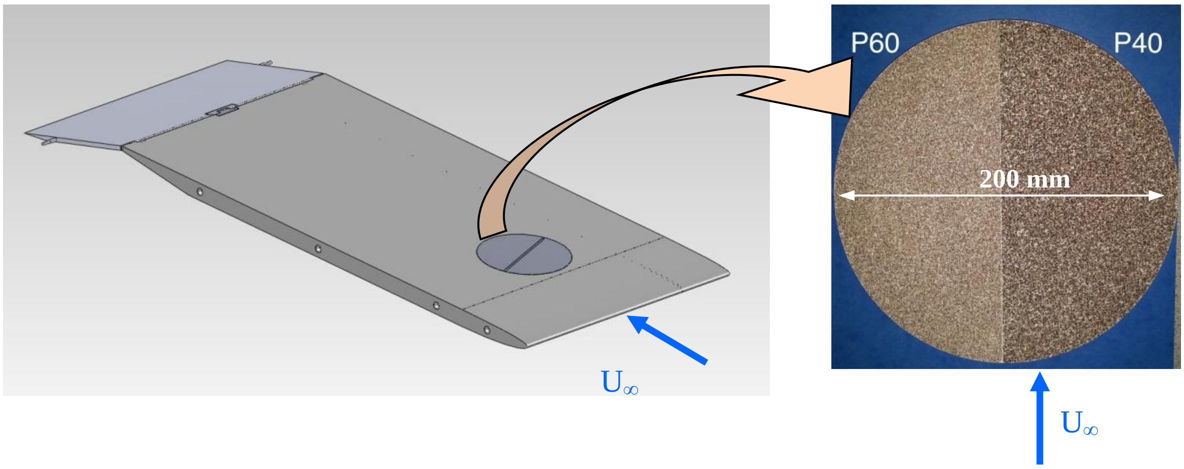
specifically designed to minimize the suction peak. A circular insert (with a diameter $d = 0.2$ m and a center located at $x_c = 0.31$ m) was designed and integrated to the flat region of the model just downstream of the leading-edge in order to change the surface-roughness value (basically metallic circular inserts covered with different grades of sand papers) as illustrated in Figure 2.



a) b)

Figure 1 - a) The ONERA-D model mounted inside the test section of the TRIN1 wind tunnel ($\varphi = 0°$) and b) detailed view of the metallic insert with several surface defaults (5 different holes in the picture).

Both configurations were mounted inside the subsonic open-return TRIN1 wind tunnel located at ONERA Toulouse which features a relatively low turbulence level $0.05\% < Tu < 0.15\%$ (integrated frequency-band: [3 Hz-10 kHz]) depending on the free-stream velocity U_∞ which ranges from 5 to 80 m/s. This facility operates at ambient conditions and is well-suited for transition studies. The test section is 0.35 m high (at the inlet), 0.6 m wide and 2.5 m long. All the velocity measurements inside the boundary layer were carried out using constant-temperature hot-wire anemometry.



a) b)

Figure 2 - a) The flat plate model and b) detailed top-view of the circular insert with different surface-roughness values (2 different sand papers in the picture).

The first configuration enables the investigation of the critical Reynolds number depending on the geometric parameters of localized surface imperfections (depth h and width b for gaps;

depth h and diameter d for holes): critical Reynolds number models will be given in the full paper as well as tripping limits for different transition scenarios. The second configuration enables the investigation of the influence of surface roughness on the transition for a TS-dominated transition scenario. The results showed a clear dependency between the critical velocity (local velocity for which transition is triggered at a given location downstream of the insert) and several geometric parameters such as the streamwise extent of the roughness insert or the roughness value. The perspectives of ONERA on this topic are to validate our models for compressible flows and for sucked boundary layers in connection with HLFC (Hybrid Laminar Flow Control) systems [10]. These new experiments will also be introduced.

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