AIAA SciTech Forum
9 - 13 January 2017, Grapevine, Texas
55th AIAA Aerospace Sciences Meeting

AIAA 2017-0336

Application of Carbon Nanotubes and Temperature-Sensitive Paint for the Detection of Boundary Layer Transition under Cryogenic Conditions

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For aerodynamic profile tests on aircraft models, transition detection is of great interest. Under ambient flow conditions the infrared technique (IR) is a well-established image-based method for this purpose. In high Reynolds number tests which are conducted at cryogenic temperatures the IR technique is of only limited suitability. In contrast, the image-based Temperature-Sensitive Paint (TSP) technique is well-suited for these conditions. Boundary layer transition detection by means of TSP generally requires an artificial temperature difference between model surface and flow. For wind tunnels operated under cryogenic conditions this temperature difference can be generated by changing the liquid nitrogen injection rate of the working fluid causing a rapid change of the flow temperature. The drawback of this procedure is that during the change of the flow temperature neither the Reynolds nor the Mach number can be kept constant. To overcome this problem, we have recently published an alternative approach where Carbon Nanotubes (CNT) are used to electrically heat the model surface and thus generate a well-defined temperature difference to visualize laminar-turbulent transition. The combination of CNT and TSP, which we call cntTSP, delivered excellent results in different wind tunnel tests from ambient down to 150 K. At lower temperatures the previously used CNT layer failed to work, since the nanotubes were embedded into an acrylic binder material which is known to be unsuitable for cryogenic temperatures. In this paper we describe a new sensor development based on the idea that all paint components are mixed (CNT) or dissolved (TSP) in a polyurethane binder material, which has demonstrated its suitability for cryogenic testing in previous tests. After pre-testing CNT and TSP in the laboratory, a cryogenic wind tunnel experiment was conducted in the pilot facility of the European Transonic Windtunnel (PETW) with the aim to visualize the laminar-turbulent transition on a two-dimensional model for Reynolds number $Re_c \leq 10\times10^6$. A comparison between the results of the standard temperature-step method of the working fluid and of the new approach based on the model surface heating by means of CNT will be presented and discussed.

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