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On impulsively started convection: The case of stagnation point flow

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ABSTRACT

Transient convection in incompressible planar and axisymmetric point flow is analyzed numerically in this work, and the thermal boundary layer response to surface sudden heating and cooling in the two settings is presented and compared over a range of Prandtl number between 0.5 and 100. A comparison between surface sudden cooling and heating is performed and different criteria are established as to when surface sudden heating and cooling are equivalent in terms of the transition time. With no initial thermal boundary layer (surface and fluid are at the same temperature), the transition time from the initial steady state to the final steady state upon surface sudden cooling or heating is found to be a constant regardless of the surface heating or cooling extent above or below the initial surface temperature, and is dependent only on the Prandtl number. With the existence of an initial thermal boundary layer, the transition time is dependent upon the heating or cooling extent, the initial surface temperature, the Prandtl number and whether heating/cooling is towards building-up or demolishing the thermal boundary later. It takes longer time when surface sudden heating or cooling is towards demolishing the thermal boundary layer than building it up. With symmetric surface sudden cooling or heating above or below the far-field fluid temperature, the transition time is independent on the surface cooling or heating extent and is a function of only the Prandtl number. A considerable difference in the thermal boundary layer response in the two settings is found. The transition time from the initial to the final steady state in axisymmetric stagnation point flow is less than that in plane stagnation flow under the same conditions.

1. Introduction

Unsteady convection arises in many engineering systems such as heat exchangers, wave rotors, shock tubes, nuclear reactors, high power laser flow loops and pulsed combustion engines. The use of steady heat transfer correlations in such systems can result in considerable errors in both direction and magnitude of heat transfer. Predictions of the transient thermal response as well as the transition time are thus crucial in the design and operation of unsteady systems and systems in transition. Unsteady convection in external flow has been investigated extensively in the literature to study the transient thermal response of systems with sudden changes in the far-field fluid temperature [1,2], and sudden changes in the surface temperature or surface heat flux [3–10]. The common feature of these investigations is the fact that transient convection in external flow is modelled as a two-dimensional flow over a semi-infinite flat surface or a wedge using the boundary layer assumptions. The evolution in time of the system thermal response starts from an initial steady state condition where the surface is exposed to a heat flux q''_o, or the far-field fluid and the surface are initially at a temperature of T_∞ and T_s respectively, that may or may not be equal. Either the far-field fluid temperature, the surface temperature or the surface heat flux is suddenly changed, and the transition from the initial steady state to the final steady state is examined in terms of variations in temperature and convective heat transfer coefficient. With the assumptions of incompressible flow and constant fluid properties, the velocity flow field is unchanged in this case. The Keller-Box numerical method detailed in [11] is used in the investigations [1,2]. An implicit-explicit numerical method is implemented in [3,4], while integral approaches are adopted in [5–9] and approximate series solutions are developed in [10] for the extreme cases of very short and very large times. All of these studies illustrate the importance of the accurate prediction of the thermal response in unsteady systems including the time varying heat transfer coefficient and the changes in heat transfer direction during the transition period as well as the transition time from the initial steady state until the final steady state is reached.

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