



On the onset of turbulence in natural convection on inclined plates

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ABSTRACT

The problem of determination of the turbulence onset in natural convection on heated inclined plates in an air environment has been experimentally revisited. The transition has been detected by using hot wire velocity measurements. The onset of turbulence has been considered to take place where velocity fluctuations (measured through turbulence intensity) start to grow. Experiments have shown that the onset depends not only on the Grashof number defined in terms of the temperature difference between the heated plate and the surrounding air. A correlation between dimensionless Grashof and Reynolds numbers has been obtained, fitting quite well the experimental data.

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1. Introduction

Natural convection on heated inclined plates has been widely studied, both analytically and experimentally, aiming mainly to determine the Nusselt number and, in turn, the heat transfer, for it being of great interest in many applications ranging for example from small electronic components to huge solar panels. Other applications are not only concerned with the magnitude of the heat transfer but with the flow regime, as explained below. In fact, one of the tasks in the design process of optical telescopes is to determine the thermal control needed to maintain the images of mirrors and their relative positions within the required tolerances, regardless of variations in the environmental conditions. The design of almost every telescope element requires a thermal analysis; small temperature differences in the optical devices or mounting structures might affect the alignment and mirror figures [1].

Apart from the thermal behavior of the telescope parts themselves, the quality of images is also affected by ambient temperature. The turbulence encountered by the light rays in the local telescope environment degrades its optical performance. This phenomenon is called ‘seeing’, and consists of optical aberrations produced by density non-homogeneities in the air along the optical path. The refraction index of air changes due to thermal gradients so that the wavefront incident on the mirror is randomly distorted, and therefore, images are altered. In particular, the seeing effect in the telescope mirror is called ‘mirror seeing’.

Mirror seeing is therefore the result of natural convection on the mirror surface, for it being warmer than the surrounding air.

The effect is generated in the region where the temperature fluctuations are the largest and most intermittent, that is, just above the viscous conductive layer. The seeing effect has been qualitative and quantitatively studied [2,3], and a number of experiments have been carried out to measure it [4].

As it is well known [5], when a vertical or inclined plate is warmer than the environment, an ascending thermal boundary layer is formed. Its initial development is laminar, but at some distance from the leading edge turbulent eddies are formed and the transition to a turbulent boundary layer begins. Further up the flow become fully turbulent. Most of the image degradation in telescopes occurs in a thin but very turbulent layer above the surface. So, in order to minimise the mirror seeing effect, the air flow over the mirror has to be laminar, the optical effects being this way small and, what is more important, predictable. Therefore, part of the thermal feasibility study of a telescope should consist of determining whether the convective flow is going to be laminar or turbulent, in this last case being necessary to cool down the mirror to diminish the difference of temperature between mirror and air to keep the laminar regime. It has to be noticed that this mirror seeing effect is much more important in solar telescopes, for the primary mirror being directly facing to and absorbing energy from Sun, what could heat the surface noticeably. Although the study of the transition from laminar to turbulent regime in natural convection over inclined surfaces has many applications and is of great importance in many other fields, this work has been carried out in the context of the thermal study of a solar telescope (like the balloon-borne telescope Sunrise, flown from Esrange, the Swedish Space Corporation Balloon Facility, in June 8th, 2009 [6]). It was of great interest to determine when the transition from laminar to turbulent in a heated inclined surface occurred, aiming with this

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