STRUCTURE OF TURBULENT HEAT FLUX IN A FLOW OVER HEATED WAVES

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Technically relevant flow problems are often characterized by complex wall geometries, high Reynolds numbers, and multiple fluid phases, often involving chemical reactions and scalar transport. We chose a reference flow situation that resembles several characteristics of such complex flow situations but, on the other side, connects to the turbulent flow through a flat-walled channel in a systematic way. A rigorous quantitative description of turbulent heat transfer between a wavy surface and the bulk is given by the thermal energy budget (Townsend, 1980). Determining the turbulent heat flux requires simultaneous measurements of temperature and velocity fields. We present a method for simultaneously resolving the fluid velocity and temperature in a flow over heated waves and how the technique can be used to connect structural information with integral quantities for heat transfer studies in turbulent flows.

The fully developed flow between a sinusoidal bottom and a flat top wall in a wide water channel (aspect ratio 12:1) is considered. The wavy PVC bottom wall is covered with a thin layer of Manganin and can be heated resistively, providing constant heat-flux boundary condition. The wave amplitude, a, is twenty times smaller than the wavelength, Λ, causing partial flow separation behind the wave crests [1,3].

Measurements are performed at Reynolds numbers up to 21’000, defined with the bulk velocity and the half-height of the channel. Digital particle image velocimetry (PIV) and liquid crystal thermometry (LCT) are used simultaneously to examine the spatial variation of the velocity and the temperature field.

For the velocity measurements, a dual Nd:YAG laser sheet and a 12-bit monochrome CCD camera (1024 x 1280 px^2) are used. A 3-CCD color camera with telecentric objective and a pixel-resolution of 768 x 572 for each chip, oriented perpendicular to the light sheet plane, aquires - within the same field of view - the spatial color distribution of liquid crystal particles that are illuminated with a pulsed sheet of white light. The RGB information is then be used for simultaneous extracting instantaneous temperature fields. Therefore, the term $\overline{u_i'T'}$ can be assessed, where the second term, $\overline{v'T'}$, is the dominant contributor to the turbulent heat flux. Structural information on the temperature and velocity field and the contribution of different scales to $\overline{v'T'}$ are obtained by a proper orthogonal decomposition (POD) analysis [1,2].

To our knowledge, we propose the first spatially resolving and simultaneous measurements of the velocity and a scalar for a turbulent, wall-bounded flow. Compared with previous studies, the considered range of Re numbers is increased to a limit given by the spatial measurement resolution. A comparison of the eigenfunctions and spectra of eigenvalues at different Reynolds numbers will provide a basis for scaling considerations.

[1] Günther, A., Rudolf von Rohr, Ph. *Exp. Fluids* 33 (2), (2002)
[2] Kruse, N., Günther, A., Rudolf von Rohr, PH., *J. Fluid Mech.* 485, pp. 87-96 (2003)
[3] Hudson J.D., Dykhno, L., Hanratty, T.J., *Exp. Fluids* 20 (4), pp. 257-265 (1996)