Massive turbulent separation: an investigation of shear-layer interfaces.

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Abstract The massively separated flow behind a backward-facing ramp is investigated using particle image velocimetry, in the perspective of designing active separation control. Beyond the usual one-point statistical analysis, we address the issue of the characteristic length scales corrugating the interfaces that characterize the turbulent separation. Our preliminary results give evidence the multi-scale nature of these interfaces. This fact might hold promise for new sizing criteria for fluidic actuators intended to alleviate separation effects.

INTRODUCTION

The detrimental effects of fluid separation on performances of industrial systems are well known, as the long-lasting efforts of the fluid dynamics community for characterizing and effectively reducing such phenomenon. In this study, the separation of an incompressible, turbulent flow on a diffuser (25° ramp) is being analyzed, with particular focus on dynamic characteristics of the separated region which might be key parameters in active flow control [1] (e.g. turbulent length and time scales). Such canonical flow (or assimilated ones) has been extensively studied and controlled in the past (e.g. see [2] and references therein). Anyway, a large scatter of actuation frequency has been reported, meaning that mechanisms underlying flow separation and its control are still misunderstood, and might be strongly dependent on boundary and initial conditions. Here we address this issue by investigating the length scales corrugating the interfaces that characterize turbulent separation. Interfaces are indeed of great importance in a number of flow processes such as mixing or combustion. In a recent work of Chauhan et al. [3], the turbulent/non-turbulent interface (TNTI) in a boundary layer was detected with a threshold on a local turbulent kinetic energy (TKE). Further statistical analysis demonstrates that TNTI has rich, multi-scale dynamics which governs turbulent/non-turbulent exchanges. Our work starts from this approach and aims at extending it to turbulent separation.

EXPERIMENTAL SET-UP

Experiments are performed in a subsonic Eiffel wind tunnel of PRISME Laboratory, at Université d'Orléans, France. The facility has a 2 x 0.5 x 0.5 m test section. It can reach a maximum free-stream velocity of 50m/s, with residual turbulence intensity of 0.5% in most of the test section. The diffuser (see Figure 1) is centered on the longitudinal axis of the test section and directly fixed on its floor. It is composed of three elements: 1) a leading egde of circular profile; 2) a flat plate where turbulent boundary layer grows; 3) a descending, 25° ramp of height h ≈100mm. Downstream of the ramp, the flow relaxes on the floor of the test section. The ramp model is just 94mm wide, limited by vertical end plates. Low aspect ratio and lateral walls have sizeable 3D effects on flow [4], [5], which however are not of primary interest in the framework of the present study. A PIV set-up is designed as to cover the entire ramp and the region downstram of it. Two LaVision VC-Imager cameras (4032 x 2688 pixels) are placed side by side. Each is equipped with a 105mm Nikon AF DC Nikkor lens, for a total field of view of about 500 x 180 mm and a magnification of 68 μm per pixel. Correlation is performed by a multipass algorithm with a final interrogation window of 32 x 32 pixels and 50% overlap.

METHODOLOGY

In the separated flow downstream of the edge of the ramp, we firstly identify the interface separating the turbulent shear-layer from the recirculation region (region where $U_{m,n} < 0$). In addition, we detect the upper boundary of the shear-layer as a TNTI. Extending the approach developed in [3], we introduce a local turbulent kinetic energy $\tilde{k}$ computed over a 3 x 3 grid as

$$\tilde{k} = \frac{1}{9} \sum_{m,n=-1}^{1} \left[\left(u_{m,n} - U_\infty\right)^2 + \left(v_{m,n} - V_\infty\right)^2 \right].$$

$u_{m,n}$, $v_{m,n}$ are the istantaneous values of respectively streamwise (x axis) and wall-normal (y axis) velocity components computed from PIV, and U_∞ and V_∞ are their free-stream ones. A threshold criterion on $\tilde{k}$ is used to discriminate between turbulent regions and non-turbulent ones. Figure 2 reveals a typical example of interface detection on an instantaneous PIV field. Corrugations of the two interfaces show evidence of multi-scale dynamics, with much smaller scales compared to the recirculation length.

CONCLUSIONS AND PERSPECTIVES

During our conference presentation, we will provide an extended investigation based on statistics (e.g. mass and momentum fluxes, mean and fluctuating brush) conditioned by the identified interfaces. This will be completed by a modal decomposition of interfaces in order to get a scale-by-scale analysis of interface corrugation. These elements will provide useful information about which scales (small or large) should be excited in order to efficiently change the turbulent separation and to accordingly size the actuators.

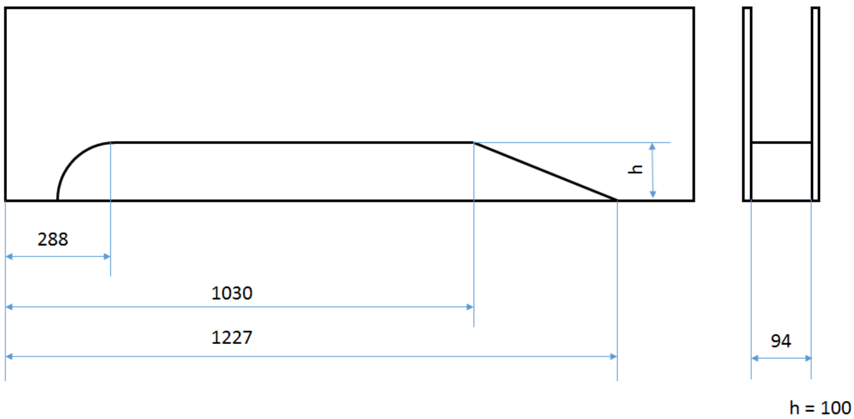

Figure 1. Details of the ramp in mm (not to scale).

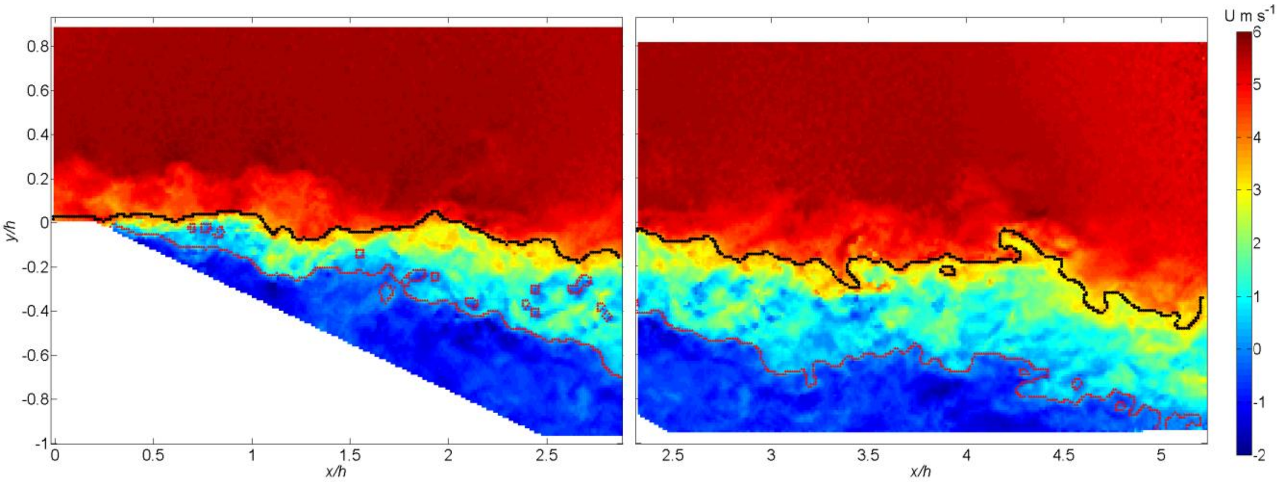

Figure 2. TNTI (black online) and recirculation region interface (red online) obtained from an instantaneous PIV field.

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