A Simplified Laboratory Model Flow for the Turbulence Structure of Atmospheric Low Level Jets – PART I: Hypothesis

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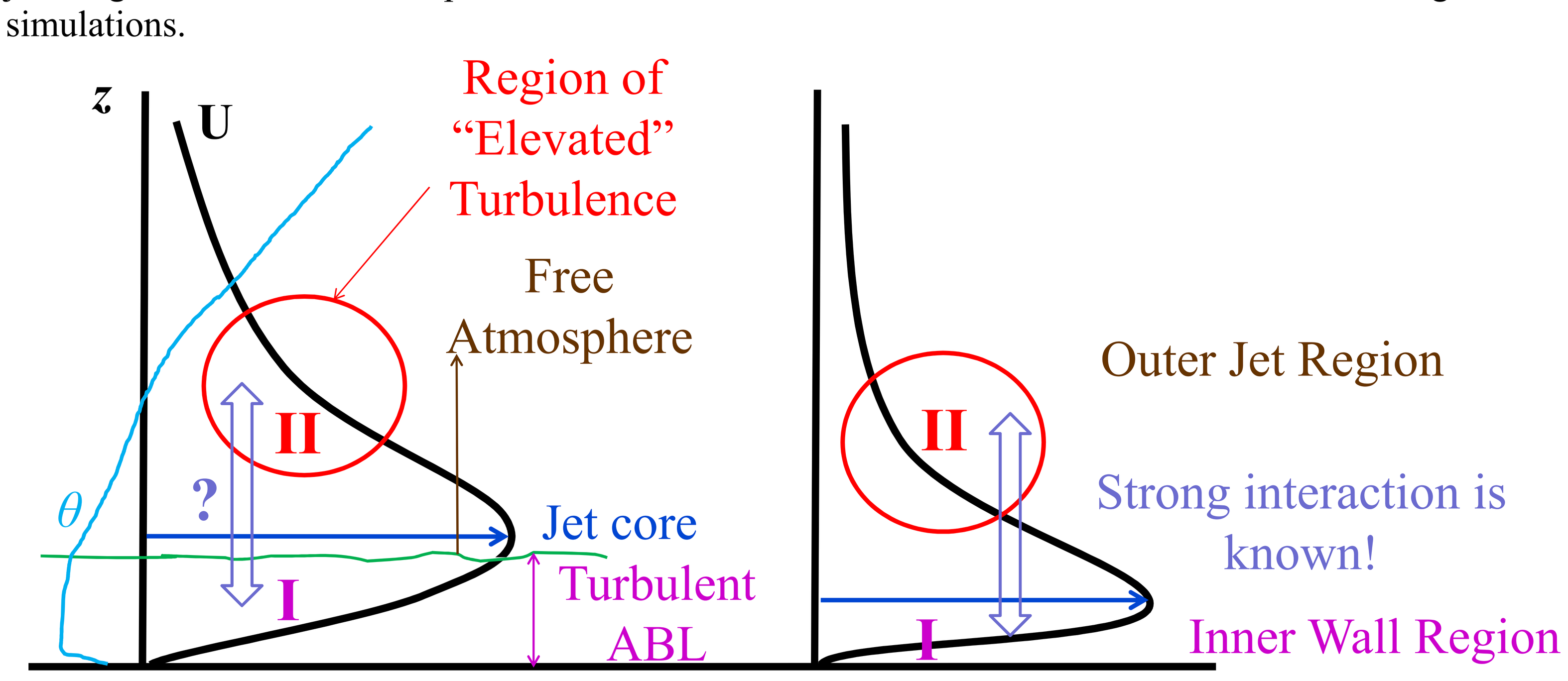
CAIPEEX Phase IV

Introduction

Low-level-jets (LLJs) occur in many parts of the globe [1] and are characterized by a wind speed maximum, called the jet core, occurring close to the surface with wind speed decreasing in the vertical direction on either side of this maximum [2]. LLJs in the atmosphere are generated by a variety of different mechanisms and may be expected to influence the atmospheric boundary layer (ABL) flow due to their proximity to the surface. The two prominent mechanisms leading to the occurrence of LLJs are the collapse of daytime boundary layer towards the end of the day leading to supergeostrophic wind speed maximum (Nocturnal LLJ) near the surface [3] and the large scale flow during Indian monsoon setup consistent with the convective heating in the lower troposphere [4] leading to the Monsoon LLJ. It is not unreasonable to expect that once the LLJ is established, essential features of the vertical structure of shear-dominated turbulence in the jet (see FIG. 1A) will be more or less identical irrespective of the mechanism by which the jet is generated. Our attempt is to model this vertical structure of LLJ turbulence using laboratory simulations.



(A) Canonical Atmospheric Low Level Jet **(B) Laboratory Model Wall Jet**

FIG. 1. Schematic vertical profiles of the mean horizontal wind and possible interaction amongst different flow regions for (A) LLJ and (B) Wall jet flow.

Upon surveying a variety of know flow archetypes in the laboratory fluid mechanics literature, it is found that the so-called turbulent wall jet flow bears striking resemblance with the features observed in the LLJs. Turbulent wall jet is a basic flow of fundamental interest for turbulence researchers because of its two-scale character [5]. The inner layer of the plane wall jet is genrally considered to be similar to that of the turbulent boundary layer, while the outer layer resembles that of a plane free jet [6]. The interaction of turbulence in the outer layer with that in the inner layer creates a complicated flow field that influences the streamwise development of the wall jet [7]. The purpose of this poster is to highlight the correspondences between the vertical profiles of mean and turbulence quantities and propose the wall jet flow as a laboratory analogue of the vertical structure of turbulence in LLJs.

Hypothesis

It is proposed that the laboratory turbulent wall jet flow can be treated as an analogue of the turbulence structure of LLJ flows. This is relevant especially for Monsoon LLJ studies and laboratory modeling with emphasis on the possible interaction of elevated turbulence with the boundary layer flow [8] (see FIG. 2A) in the LLJ in the light of already-known strong interaction of outer jet region and near-wall inner region in the wall jets [9] (see FIG. 2B).

Before presenting results from the literature and from the present experiments towards supporting the present hypothesis, an important point needs to be addressed. One main difference between the Monsoon LLJ and laboratory wall-jet flow is that the Monsoon LLJ is continuously forced by the large scale flow and is therefore maintained over large spatial extents [4]. Also the heated surface of the Earth during the daytime results in convective forcing on the jet flow. The simplest laboratory wall jet on the other hand, slowly decays downstream due to friction at the wall being the only external dissipative force. Also there is no convective forcing when the plate is not heated. The connection between these two flows can then be understood as relaxation of the former to the latter when the forcing is switched off. That is the isothermal wall-jet flow represents an asymptotic state to which the LLJ would evolve to if the forcing is removed and the flow is allowed to relax. In such a hypothetical relaxation, one may expect the convective features to die out rather rapidly (timescale of about an hour or so) and the shear-related features to persist. Thus if we are able to link experimentally observed features of the wall-jet in the laboratory to some of the salient features of the LLJ, then it would lend support for our hypothesis. In this sense, studying wall-jet flow in a laboratory is expected to provide insight into the features of the LLJ observed in the atmosphere.

Wall jet setup at FDL, IITM, Pune

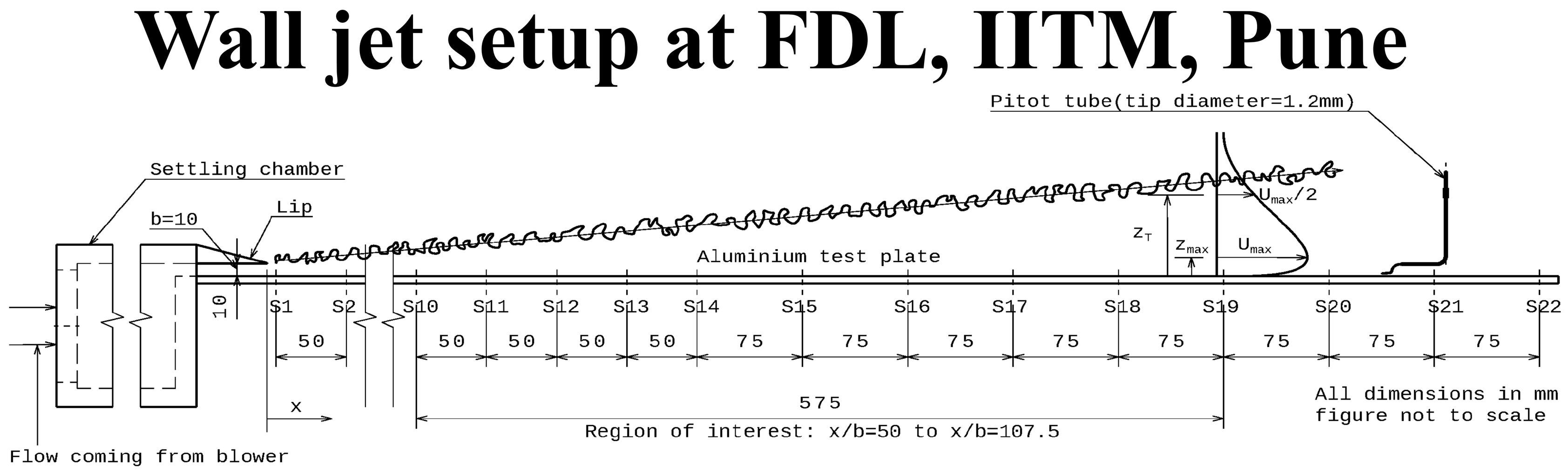


FIG. 2. Experimental wall jet setup at the FDL, IITM, Pune.

In the Fluid Dynamics laboratory (FDL) at IITM, Pune, we have developed the wall jet setup. Schematic side view of this setup is shown in FIG. 3. A flat, straight, polished aluminium test surface, 2 feet wide, 5 feet long and 6 mm in thickness, serves as the test surface along which a two dimensional jet is blown. A speed-controlled blower discharges air flow into a settling chamber which consists of a honeycomb, a set of suitable screens and a well-designed two-dimensional nozzle (width L=300 mm) whose exit slot height b is fixed at 10 mm. A sharp aluminium lip is fitted at the exit of the nozzle to ensure well-defined initial conditions. Wall shear stress is directly measured using Oil-film interferometry (OFI) [10]. Mean velocity measurements are performed using a Pitot tube (OD of 1.2 mm) and an ethanol-based projection manometer. Turbulence profiles are measured using custom-made hotwire anemometry probes operated with the Streamline Pro system from Dantec Dynamics, Denmark. Spanwise measurements are performed to check two-dimensionality of the mean flow.

Mean velocity and TKE profiles

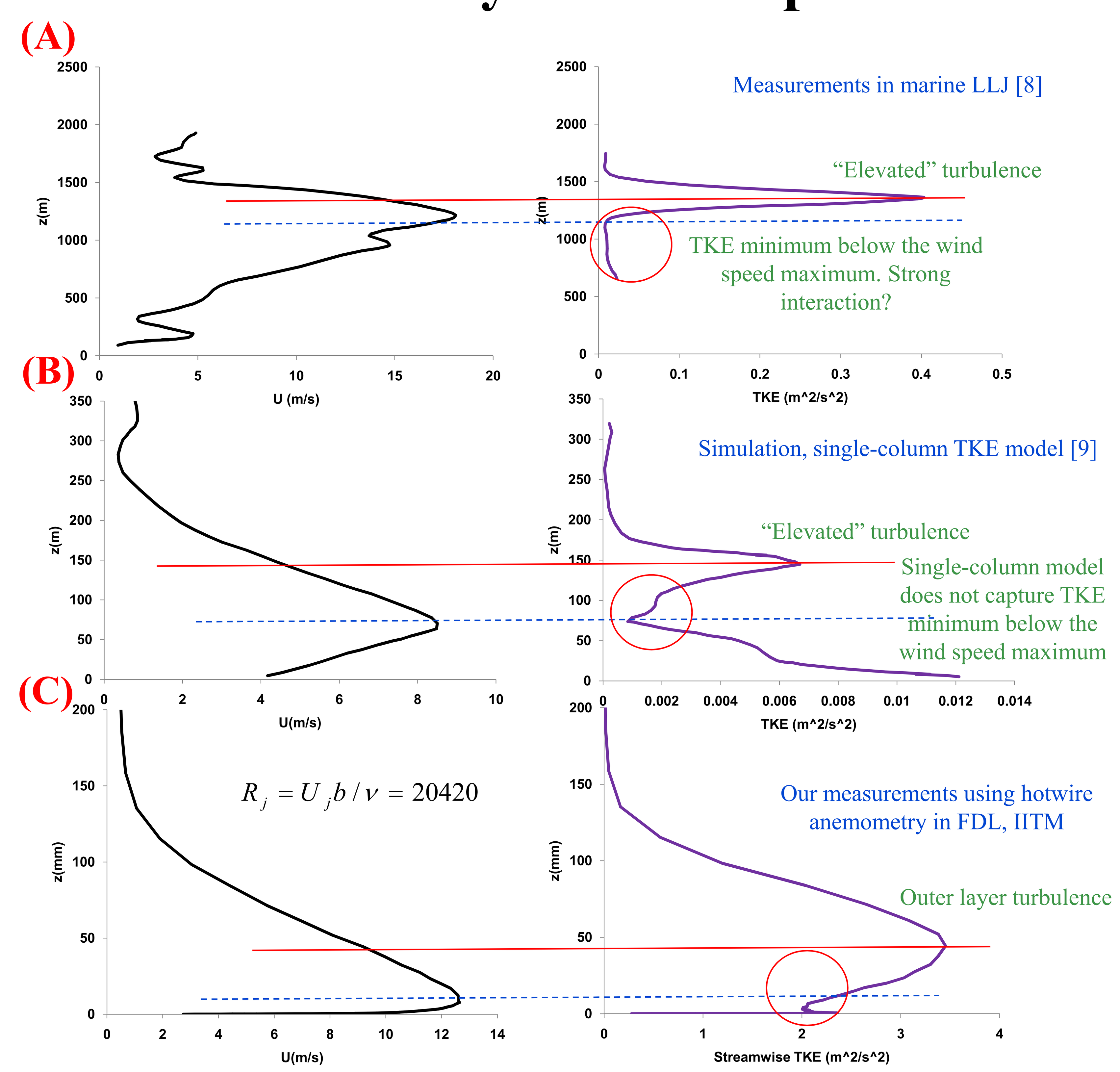


FIG. 3. Comparison of mean velocity and TKE profiles from (A) observations in a marine low-level jet [9], (B) single-column model simulations [10] and (C) our laboratory model wall-jet measurements using hotwire anemometry.

Results and Discussion

Figure 3 shows the comparison of vertical profiles of the mean wind and the turbulence kinetic energy (TKE) in three different flows namely (A) the experimental aircraft measurements of the marine low-level jet over the Baltic sea [8], (B) numerical simulations of the LLJ flow using single-column TKE model [9] and (C) laboratory measurements using hotwire anemometry in our turbulent wall-jet setup at FDL, IITM, Pune. It is clear that the profiles of the mean wind (left panels) exhibit striking resemblance amongst each other. Staring from the ground the mean wind speed increases with height until a maximum value of wind speed is attained. Beyond this location, the wind speed decreases with height. The location of the wind speed maximum relative to the thickness of the flow value appears to be somewhat different in atmospheric and laboratory flow. However, this is simply due to the geometric difference in the effective height of the source of momentum in these flows; the essential dynamical properties remain identical. This is seen even more dramatically in the profiles of the TKE (right panels) that also bear striking resemblance to each other. Starting from the surface, the TKE shows a near-wall peak corresponding to the buffer layer TKE production peak subsequent to which it reduces to a minimum value around the location where the wind speed reaches its maximum value. Note that the TKE minimum actually occurs *below* the wind speed maximum in LLJ observations and laboratory wall jets; this feature is not captured by the single column TKE model simulations. Beyond the wind speed maximum, the TKE increases dramatically in the outer jet-like region of the flow. This region is called the region of "elevated turbulence" in LLJ flows [9] and the dominant mechanism for this maximum is the shear production of turbulence. Thus the vertical structure of turbulence in turbulent wall jets is remarkably similar to that in the LLJs and the former may well serve as a laboratory analog of the latter. This is expected to provide insight in to the structure of turbulence in LLJs which is not accessible to any of the remote sensing instruments. We plan to study wall jets in detail in the FDL at IITM, Pune.

Acknowledgements

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