3 Some Notes on Drag Reduction in the Near-Wall Region

Ron F. Blackwelder

University of Southern California, Los Angeles, California 90089, U.S.A.

Abstract. The last thirty years has seen an explosion of information concerning the structure of the near-wall region of bounded shear flows. Kline et al. (1967) were one of the first to examine its eddy structure and provide a detailed description using primarily visualization methods. They showed the existence of the ubiquitous low-speed streaks and coined the word "burst" to describe the violent lift-up and mixing. The intervening thirty years have provided many details about this region and its importance to the dynamics of bounded shear flows. It is well known that the eddies in this region control the production of turbulence and the drag due to the boundary. The general structure of the eddies and processes in this region is covered in the next section followed by a discussion of the similarities between this region and transitional flows. The use of suction and actuators for manipulating and controlling the eddies follows.

1 The Structure of the Bursting Process

Since the original work by Kline et al. (1967), many authors have added terminology to the observations in the wall region that has been summarized by Robinson (1991). It has become clear that the entire eddy structure within the wall region is an ongoing process that is quite dynamic and is statistically repeatable. Hereafter, this process will be called the bursting process or bursting phenomenon and denoted by BP. It consists of many individual eddies and events that are summarized in the flow chart presented in Fig. 1. This schematic is obviously a simplification of a complicated process, but provides a beginning point for the discussion. The major components of the BP are streamwise vortices, the low-speed streaks, the inflectional profiles and the resulting instabilities. There is no universal agreement within the community as to the details of the elements within Fig. 1. Many of the differing points of view result from the random environment of the bursting phenomenon. It occurs near the wall in the presence of turbulence having an rms value of 10–12% of the freestream or centerline velocity. This allows fluctuating swings of more than 50% of the local mean flow which makes the BP difficult to study. For example, it is extremely difficult to follow any eddy in the wall region long enough to observe its complete life cycle. Indeed, this turbulent environment may be more correctly viewed as the result of the BP. When the BP is artificially removed, the turbulent intensity decreases significantly.

Another reason for the lack of agreement of the elements in Fig. 1 is because the different eddy structures are observed via many different methods.

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Most of the knowledge about the BP has been obtained from visualization methods, hot-wire/film anemometry and direct numerical simulations. Lately some impressive results have been obtained from particle image velocimetry. However within each type of measurement system, there are almost as many variations as there are investigators. The result is that often different aspects of the eddies are observed in “similar” investigations. For example different initial conditions or threshold levels can yield different views and impressions of the eddies under study. In addition, the BP has a Reynolds number dependence that is not well known. To obtain a near-wall region having sufficient spatial resolution with any of the methods mentioned above, a low Reynolds number is required. Consequently most of the results in the literature have been obtained at a “low” Reynolds number, thus excluding a large range of Reynolds number testing. In addition, the Reynolds number can be viewed as a ratio between the spatial scales of the large eddies of the flow field and

Fig. 1. The proposed sequence of the bursting process. The arrows indicate the sequential events and the ‘?’ indicate relationships with less supporting evidence.