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# ASSESSMENT OF BURSTING DETECTION METHODS WITH LES DATABASE OF TURBULENT CHANNEL FLOWS*

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**Abstract:** Validated by comparison with DNS, numerical database of turbulent channel flows is yielded by Large Eddy Simulation (LES). Three conventional techniques: *uv* quadrant 2, VITA and mu-level techniques for detecting turbulent bursts are applied to the identification of turbulent bursts. With a grouping parameter $\tau_E$ introduced by Bogard & Tiedemann (1986) or Luchik & Tiederman (1987), multiple ejections detected by these techniques which originate from a single burst can be grouped into a single-burst event. The results are compared with experimental results, showing that all techniques yield reasonable average burst period. However, *uv* quadrant 2 and m*u*-level are found to be superior to VITA in having large threshold-independent range.
**Keywords:** channel flow, turbulent, burst detection, LES

## 1. INTRODUCTION

Turbulent burst, one kind of coherent structure in the wall region, carries most turbulent kinetic energy, and is responsible for Reynolds stress production and passive scalar transport. Take sediment transport for example, Gyr & Schmid [1] showed that the movement of sediment near bed is mainly affected by the lift and breakup of low-speed streaks in the near-wall region. Nino et al. [2] found that sediment motion is closely associated with the turbulent bursts. Quantitatively, Cao[3] worked out a sediment model based on the spatial and temporal scales of turbulent bursting borrowed directly from steady flows. However, these scales may vary in unsteady circumstances. In view of sediment motion in coastal areas, more fundamental understanding of turbulent bursting in unsteady flows is of great importance.

Several techniques were devised to detect bursts, among which are *uv* quadrant 2, VITA and mu-level techniques etc. There is at least one adjustable parameter in each of them which renders them to give different or even conflicting results. Some attempts were made to explain the cause, and new techniques, such as wavelet transform, were invented for the bursts detection [4]. Bogard & Tiedemann[5] introduced a grouping parameter to combine multiple ejections. Luchik & Tiederman [6] extensively studied *uv* quadrant 2, VITA and m*u*-level techniques. To the author's knowledge, there is limited work for detecting the turbulent bursts based on numerical data processing[7]. In order to single out a best technique suitable for sampling burst by this approach, we have tested the same three conventional methods, i.e. *uv* quadrant 2, VITA and m*u*-level techniques, by using validated LES databases, and found that *uv* quadrant 2 and m*u*-level are superior to VITA in having large threshold-independent range.

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## 2. LES DATABASE OF TURBULENT CHANNEL FLOWS

In LES, turbulence is decomposed into geometry-dependent large-scale part $\bar{f}$ and relatively universal small-scale part $f'$ by filtering process, i.e. $f = \bar{f} + f'$. The large-scale motions are solved numerically while the small-scale ones are modeled with so-called Sub-Grid Scale (SGS) models. Furthermore, $\langle \bar{f} \rangle$ stands for horizontal as well as temporal averaging and $\bar{f}'$ for $\bar{f} - \langle \bar{f} \rangle$.

In this paper, SGS model is Smagorinsky eddy viscosity model with Van Driest's damping function. The Fourier sharp cutoff filter and Pseudo-spectral method are used in horizontal direction with periodical boundary conditions. A finite difference scheme is used in normal direction on a non-uniform staggered mesh. A Poisson's equation is solved for $P$. An Adams-Bashforth scheme is utilized for time evolution.

To validate the code, a channel flow with Reynolds number $Re_\tau = 180$ (based on friction velocity and half channel width) is simulated with the time step of 0.001 and integral of 30 non-dimensional time units. 64 modes are used in streamwise and spanwise direction, respectively, and 64 non-uniform grid points are distributed between two walls. The computational box is $2.5\pi \times 2 \times 1.5\pi$ in the order of streamwise, normal and spanwise.

Figure 1 shows the mean velocity profile in semi-log coordinates Turbulence intensities are demonstrated in Fig.2. and the stresses in Fig.3. It can be seen that the computational result agrees well with the wall turbulence theory or DNS of Kim, Moin and Moser [8].

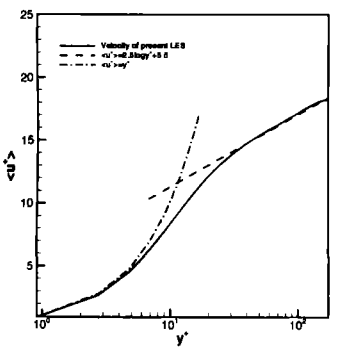


Fig. 1 Mean-velocity profiles

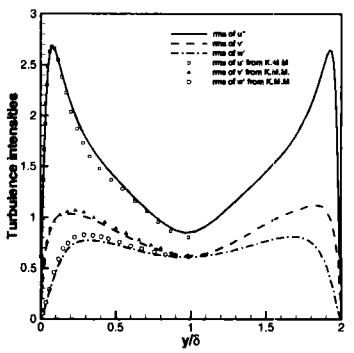


Fig. 2 Turbulence intensities

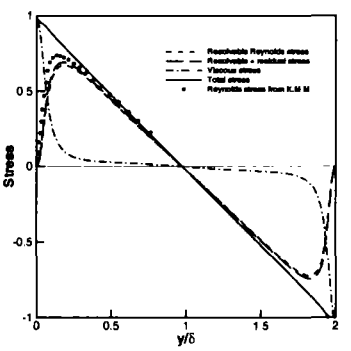


Fig. 3 Stress distributions

## 3. BURST DETECTION

### 3.1 Bursts detection techniques based on conditional sample

In this study, three conventional techniques, the *uv* quadrant 2, VITA and m*u*-level techniques were tested. The details concerning them are presented in Table 1 ($\bar{u}', \bar{v}'$ are streamwise and normal velocity fluctuations. The subscript *rms* means the root-mean-square. $(\bar{u}'\bar{v}')_2$ denotes $\bar{u}'\bar{v}'$ in quadrant 2. $L, k, H$ are thresholds and $\tau$ average time interval.).

Luchik and Tiederman[6] have made comparisons among them, stating that the average burst periods detected by them are in accordance with flow visualizations with grouping parameter used. However, there were still differences among them. When time series is long enough (for example, more than 200 burst periods sample time), *uv* quadrant 2 technique is the best one.

**Table 1**

| | Characteristics | Sampling function |
|---|---|---|
| *uv* quadrant 2 | Detecting events associated with an ejection, i.e. $\bar{u}'<0,\bar{v}'>0$ | $D(t)=\begin{cases}1, (\bar{u}'\bar{v}')_2 > H\bar{u}'_{rms} \\ 0, \quad \text{otherwise}\end{cases}$ |
| VITA | Detecting accelerations in streamwise velocity associated with high levels of $\bar{u}'\bar{v}'$. | $D(t)=\begin{cases}1, Var > k\bar{u}'^2_{rms} \text{ and } d\bar{u}'/dt>0 \\ 0, \quad \text{otherwise}\end{cases}$ <br> $Var=\frac{1}{\tau}\int_{t-\tau/2}^{t+\tau/2}\bar{u}'^2(t)dt-\left[\frac{1}{\tau}\int_{t-\tau/2}^{t+\tau/2}\bar{u}'(t)dt\right]^2$ |
| m*u*-level | Detecting deficits in the mean streamwise velocity | $D(t)=\begin{cases}1, \quad \bar{u}'<-L\bar{u}'_{rms} \\ 0, \quad \bar{u}'>-0.25L\bar{u}'_{rms}\end{cases}$ |

### 3.2 Bursts detection results

Luchik & Tiederman[6] applied the techniques above to their experimental data and obtained the average burst period normalized by inner scales as follows

$$T_B^+ = T_B \cdot u_\tau^2 / \nu \approx 90 \tag{1}$$

where $T_B^+, u_\tau, \nu, T_B$ are the normalized burst period, friction velocity, kinetic viscosity and dimensional burst period. We apply the same techniques to our LES results.

The way to determine the grouping parameter is quite similar to Luchik & Tiederman's for *uv* quadrant 2 technique, but different from theirs for other two techniques. Firstly, the probability distribution of time between ejections is obtained by using these techniques with threshold value: $H=1.0, L=0.5, k=0.4$ for *uv* quadrant 2, VITA and m*u*-level respectively. Then, the $\tau_E$ is chosen as the value of $T_E$ where $P(T \le T_E)=P_E$, and $P_E$ called probability threshold, is set to be 0.5 for *uv* quadrant 2, and 0.3 for m*u*-level and 0.2 for VITA.

In present LES, all variables are non-dimensionalized by $u_\tau, \nu, \delta$. So we have $T_B^+ = Re_\tau \cdot T_{BN}$, where $T_{BN}$ is the numerical burst period. According to Eq. (1), $T_{BN} \approx 0.5$ for $Re_\tau = 180$, and $T_{BN} \approx 0.3$ for $Re_\tau = 300$. For the case of $Re_\tau = 180$, the detection results by three techniques at three positions ($y^+ = 26, 33, 41$) are presented in Fig.4~Fig. 6. The existence of threshold-independent range can be found in *uv* quadrant 2 and m*u*-level results. The detection results of average burst period are quite acceptable in the threshold range of $0.5 \le H \le 1.5$ for *uv* quadrant 2, $0 \le L \le 1.25$ for m*u*-level and $0.1 \le k \le 0.5$ for VITA. In the sense of threshold-independent range, m*u*-level and *uv* quadrant 2 technique yield the same good result. The narrowest threshold-independent range in VITA technique makes it inferior to the other two techniques. Furthermore, the same algorithm is applied to the case of $Re_\tau = 300$, as shown in Fig.7~Fig.9. The same conclusion as above can be drawn. Note that $T_{BN} \approx 0.3$ in this case.

## 4. CONCLUSIONS

The conventional burst-detection techniques are applied to LES database. They all perform in the similar way to experimental results. In particular, with a grouping parameter, *uv* quadrant 2 and m*u*-level are able to give proper burst period with a quite wide range of threshold, slightly different from but as a whole in consistent with experimental results of Luchik & Tiederman's[6]. While VITA gives right burst period

with narrow range of threshold. The choice of grouping parameter is relatively subjective in our detections at present. A guide line for determination of it is urgently needed.

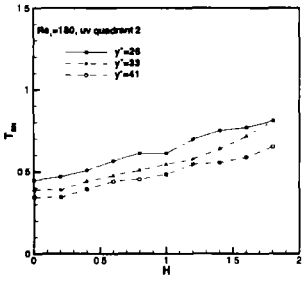


Fig.4 Bursts detecting results by $uv$ quadrant 2, $Re_\tau = 180$

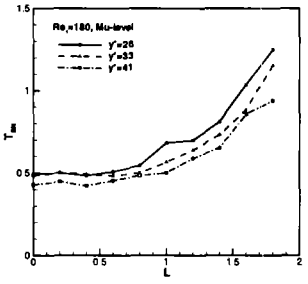


Fig.5 Bursts detecting results by m$u$-level, $Re_\tau = 180$

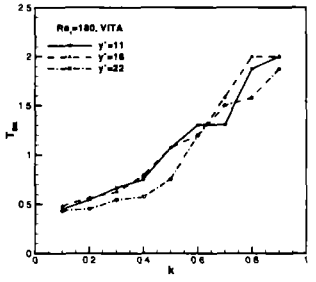


Fig.6 Bursts detecting results by VITA, $Re_\tau = 180$

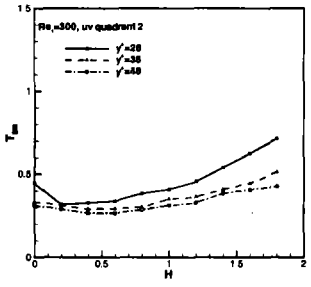


Fig. 7 Bursts detecting results by $uv$ quadrant 2, $Re_\tau = 300$

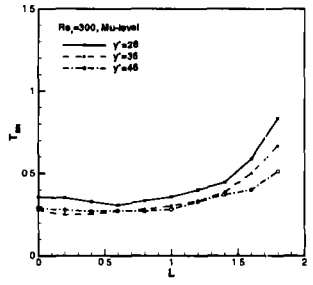


Fig.8 Bursts detecting results by m$u$-level, $Re_\tau = 300$

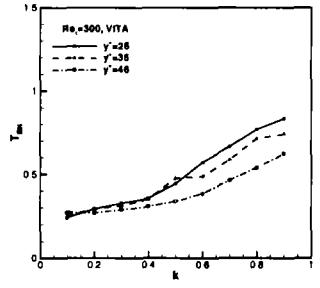


Fig.9 Bursts detecting results by VITA, $Re_\tau = 300$

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