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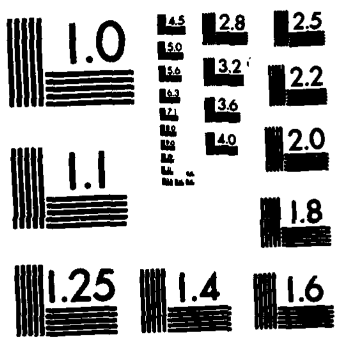
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Within the last decade, many of the attributes of turbulent shear flows have been ascribed to large coherent eddy structures. In bounded shear flows, there appeared to be two distinct coherent eddies; one which governs the outer flow field and is responsible for entrainment in the case of turbulent boundary layers, and the second which dominates the wall region near the boundary. The research reported here concentrated on the wall region which is dominated by the bursting phenomenon consisting of several distinct characteristics. In this

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region, the flow has a propensity to form ubiquitous streamwise vortices appearing in counterrotating pairs. Although their streamwise extent is presently unknown, it is probably at least an order of magnitude greater than their diameter. One of the more easily visualized aspects of the bursting phenomenon are streaks of low speed fluid. They seem to form between two of the vortices as they remove low speed fluid from the wall and lift it upward. The streaks usually end by being lifted away from the wall. At about the same time and/or slightly thereafter, they appear to oscillate. This oscillatory motion increases in amplitude and scale until a breakdown occurs at which time completely chaotic motion ensues. This phase of the wall structure occurs on a very short time scale and consequently has been called the "burst". Soon thereafter, a larger scale motion emanating from the outer flow field approaches the wall and cleans the entire area of the chaotic motion; consequently, this phase of the structure has been called a "sweep". The sweep seems to scale with the outer flow variables, and it appears to form a highly irregular interface with the wall region. The irregularities on this interface appear to scale with the wall variables.

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RESEARCH ON WALL TURBULENCE

Final Report

ARO-DA-ARO-D-31-124-73-G118
DAAG29-76-G-0297
DAAG29-79-C-0137

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Principal Investigator

I Problem studied

Within the last decade, many of the attributes of turbulent shear flows have been ascribed to large coherent eddy structures. In bounded shear flows, there appeared to be two distinct coherent eddies; one which governs the outer flow field and is responsible for entrainment in the case of turbulent boundary layers, and the second which dominates the wall region near the boundary. The research supported by ARO concentrated on the wall region which is dominated by the bursting phenomenon consisting of several distinct characteristics. In this region, the flow has a propensity to form ubiquitous streamwise vortices having radii of typically $20\text{-}50\nu/u_\tau$. They appear in counterrotating pairs as has been deduced from streamwise velocity correlations. Although their streamwise extent is presently unknown, it is probably at least an order of magnitude greater than their diameter. One of the more easily visualized aspects of the bursting phenomenon are streaks of low speed fluid. They seem to form between two of the vortices as they remove low speed fluid from the wall and lift it upward. These streams typically are $10\text{-}20\nu/u_\tau$ wide and $100\text{-}1000\nu/u_\tau$ long and appear randomly in space and time. The streaks usually end by being lifted away from the wall. At about the same time and/or slightly thereafter, they appear to oscillate. This oscillatory motion increases in amplitude and scale until a breakdown occurs at which time completely chaotic motion ensues. This phase of the wall structure occurs on a very short time scale and consequently has been called the "burst". Soon thereafter, a larger scale motion emanating from the outer flow field approaches the wall and cleans the entire area of the chaotic motion; consequently, this phase of the structure has been called a "sweep". The sweep seems to scale with the outer flow variables, i.e. δ and U_∞, and it appears to form a highly irregular interface with the wall region. The irregularities on this interface appear to scale with the wall variables ν and u_τ.

II Summary of Important Results

Many aspects of this problem were unexplored and unknown when this research was initated in 1972. The approach adopted was to first develop an experiment technique to detect certain aspects of the problem and then to study different elements of the bursting process. Some of the more interesting results follow:

1. VITA Detection Technique

A variable internal averaging technique (VITA) was developed to detect the important phase relationship associated with the bursting process. This method is described by Blackwelder and Kaplan (1976). It was so successful that it is now the most often used and quoted method for studying the wall layer structure.

2. Inflectional Velocity Profiles

The detection technique was first used on simultaneous streamwise velocity signals taken from the wall region. Conditional samples were obtained by ensemble averaging many separate bursting events. The resulting velocity profiles clearly showed that an inflectional profile existed on the average. Although this had often been suspected, this data offered the first quantitative proof and has been used as a standard in more recent modelling schemes of this phenomenon.

3. Turbulent Production

Using the detection criteria, it was shown that most of the turbulent energy production is indeed associated with the above process. This has been verified by other investigators and is one of the fundamental reasons this research is important towards understanding the wall region and in modelling bounded shear flows.

4. Importance of Phase Information

During the earlier work on this project, many of the conditional averages seemed to decay too rapidly in space and time. This was traced to a random phase which existed in the individual members of the ensemble. Blackwelder (1977) showed that even if the individual members of an ensemble were identical, a random arrival time as a measuring location would severely reduce the magnitude of the ensemble average.

5. Relationship to the Outer Structure

To study the role of the large scale eddies above the wall, the entire wall was slightly heated and temperature was used as a passive contaminant. Simultaneous temperature traces of Chen and Blackwelder (1978) showed that the back sides of the outer large eddies were extremely dynamic and suggested that they are related to the bursting period at the wall.

6. Bursting Frequency

Before this phase of the research was undertaken, it had been conjectured that the frequency of occurrence of the bursts scaled with the boundary layer thickness and the free stream velocity, Blackwelder and Haritonidis (1983) have shown that the frequency non-diminsionalized with viscous wall parameters is constant independent of the outer flow field over the Reynolds number range $10^3 < U_\infty \theta / \nu < 10^4$.

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