A METHOD FOR GENERATING THE TURBULENT INTERMITTENCY FUNCTION

M. Jahanmiri

Department of Mechanical and Aerospace Engineering
University of Defence Science and Technology
Shahinshahr, Isfahan

S. Rudra Kumar

Experimental Aerodynamic Division
N. A. L. Bangalore, India

A. Prabhu

Department of Aerospace Engineering
I. I. Sc., Bangalore, India

Abstract A detection method based on sensitization of a squared double differentiated signal is developed which discriminates the turbulent zones from laminar zones quite accurately. The procedure adopts a variable threshold and a variable hold time of the order of the Kolmogorov time scale. The output file so generated, includes all the information for further analysis of the turbulent signal.

Key Words Turbulence, Intermittency Function, Transitional Flow

چکیده روشی جهت آشکارسازی حوزه توربولانس جریان سیال بوسیله حساس نمودن سیگنال مجذور مشتق دوم تابع سرعت پیشنهاد گردیده که بطور کاملاً دقیق مناطق توربولانس را از مناطق آرام جریان سیال تشخیص می دهد. دراین روش ازیک حد متغیر (Variable Threshold) ویک زمان نگهدارنده (hold time) متغیر به نسبت مقیاس زمانی کول موگوروف استفاده گردیده است. فایل خروجی این نرم افزار شامل کلیه اطلاعاتی است که برای آنالیز بیشتر سیگنال های توربولانس موردنیاز می باشد.

INTRODUCTION

Detection of regions of turbulent flow is important to obtain quantitative information about turbulent spots during laminar-turbulent transition. Various methods of detection of turbulent spots have been reported in the literature (References 1 to 12). These methods make use of some property of turbulence which distinguishes it from the laminar flow. A turbulent flow is, in general randomly fluctuating (wide-band), 3-dimensional, rotational and dissipative. During the passage of a turbulent spot, the mean flow properties are also likely to change appreciably. A detection scheme using the wide-band nature of a turbulent signal or existence of a cascading process requires spectral analysis. This procedure is time-consuming and so difficult for making on-line decisions for or against turbulence. Detection of three-dimensionality and rotation requires complex probes, which are not likely to have adequate spatial resolution. Most often one has only a time trace of streamwise velocity fluctuations. Direct identification of turbulent and non-turbulent zones from the velocity fluctuation data can often lead to non unique turbulent zones depending on the threshold level. Hence it is necessary to sensitize the data to enhance the contrast between turbulent and non-turbulent flows. Earlier investigations (e.g. References 2 and 3) have used differentiation, squaring and dual slope detection in sensitizing the signal.

In this report, a double differentiated and squared signal is used for sensitization. This process is not only simple but also discriminates the turbulent zones from the laminar zones quite accurately. Visual observations show that the intermittency function so defined is accurate within 5%. The procedure adopts a variable threshold and a variable hold time of the order of the Kolmogorov time scale.

EXPERIMENTAL SET-UP

In order to obtain the necessary data for validation of the procedure adopted here for discriminating between turbulent and non-turbulent regions, the experiments were carried but in the 0.5m × 0.5m low turbulence tunnel, at the Department of Aerospace Engineering, Indian Institute of Science. The data for validation were obtained from an ongoing experiment on the investigation of the structure of turbulent spot in a diverging (3-d) flow with zero pressure gradient (Reference 13). To obtain streamline divergence with zero pressure gradient, the test section of the wind tunnel was modified to incorporate distorted duct having one diverging side and a converging top (Figure 1). The walls were adjusted to give zero pressure gradient at every cross-section. A flat plate is mounted horizontally on the centre of the tunnel with an elliptic leading edge smoothly rounded off to give a laminar flow over most of the working section. The wind speed in the tunnel was about 10 m/s.

INSTRUMENTATION AND DATA COLLECTION SYSTEM

Referring to Figure 1 an artificial turbulent spot was generated by driving a puff of air through a 1mm static hole on the flat plate located about 100mm from the leading edge of the plate at a frequency of 3Hz using a loud speaker triggered by a square pulse of amplitude 0 - 5 volts. The frequency was chosen so that the maximum number of spots in one second could be accommodated without mutual interference.

Measurements were carried out with a single wire 12 Micron diameter Pt-Rh etched suitably to give the desired resistance of about 1.8 ohms. The wire was operated with a non-linearized constant temperature anemometer. The output of the hot wire was connected to a signal analyser, A/D converter in a personal computer and oscilloscope. The mean value of the voltage across the hot wire could be directly read on a mean value display unit.

The approximate frequency response of the hot wire system was 25KHz with overheat ratio (R_{hot}/R_{cold}) of 1.5.

The hot wire probe was mounted on a traverse which could be moved along any of three coordinate directions namely streamwise, transverse direction and normal to the flat plate.

A dual channel cathode ray oscilloscope, which was triggered by the pulse driving the speaker, was used to visualize and monitor the turbulent signal.

Ensemble averages were obtained using a dual channel B&K signal analyser which was triggered by a pulse generator. The analyser was connected through an interface card to PC for storing and analysing the data.

The instantaneous turbulence data (for which the intermittency function was generated) was recorded using the PC based data collection system. The system comprises the following units.

1. IBM PC-AT 286 computer
2. External Peripherals including monitor, floppy drive, which, printer and a cartridge drive.
3. IEEE interface
4. A 12 bit, 16 channel speed A/D add on card which can digitise the data as fast as 75 KHz.

A conventional software which digitises and

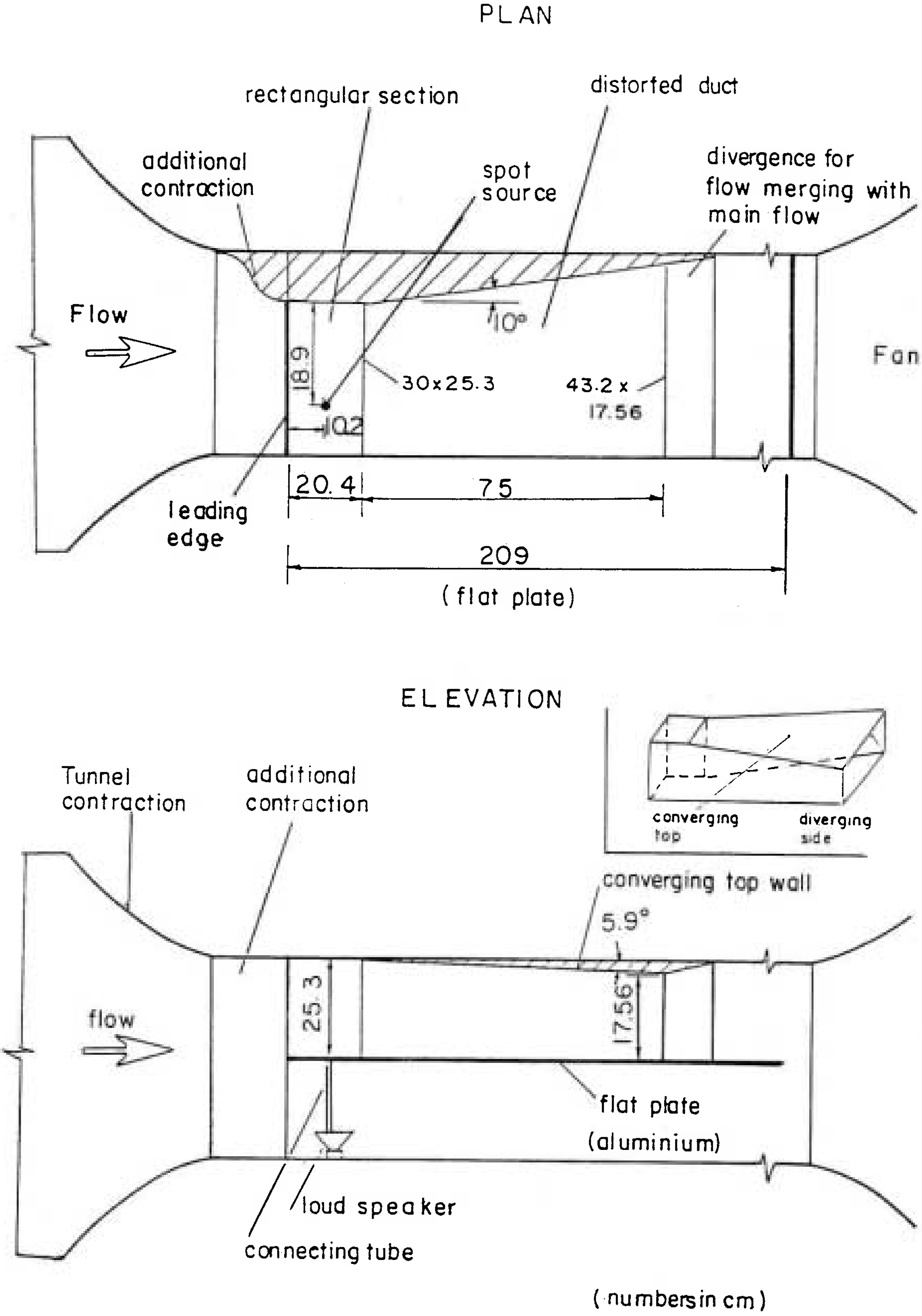

Figure 1. Schematic view of the experimental set-up.

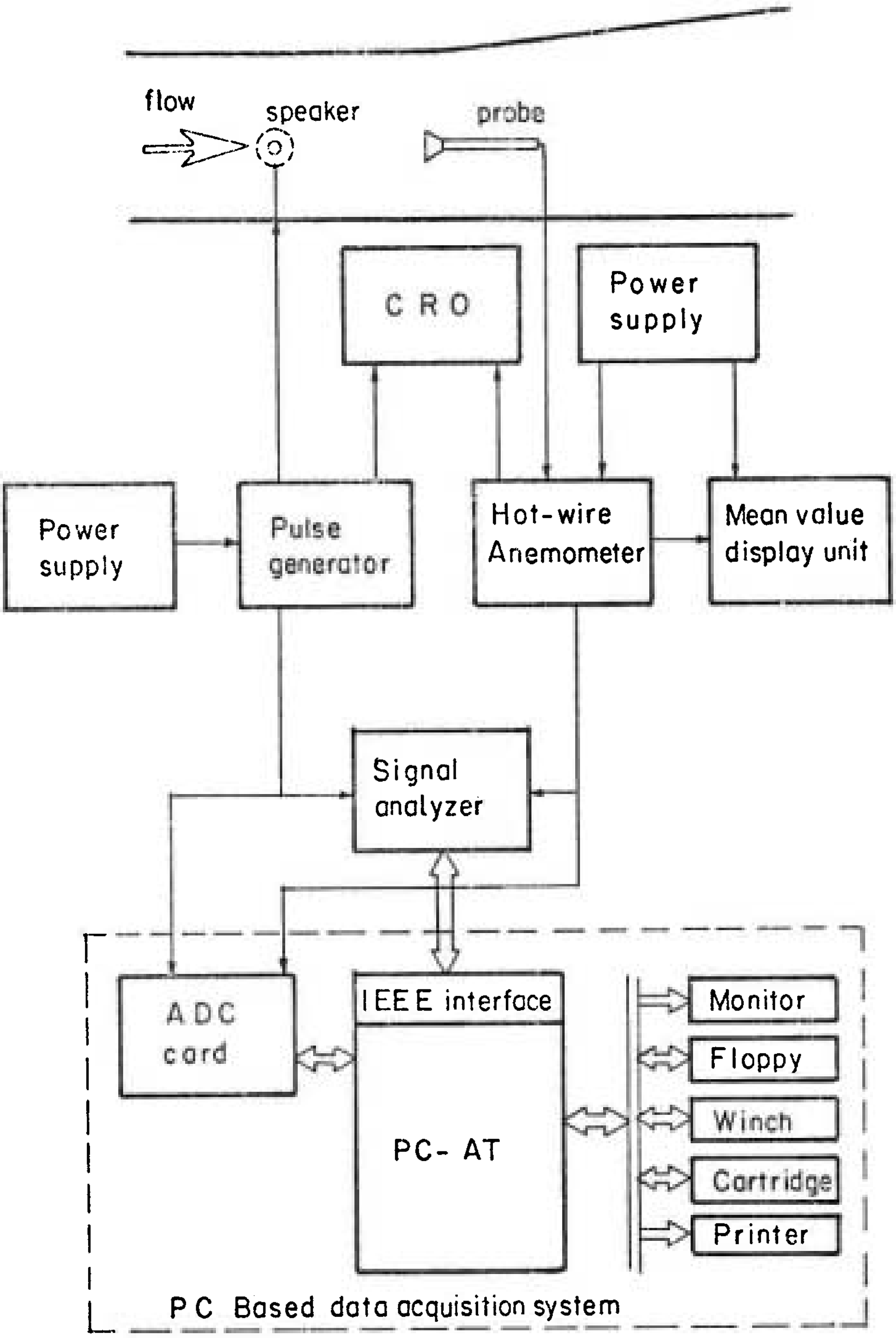

Figure 2. Instrumentation set up.

continuously acquires the data for the kind of studies envisaged on turbulent spots has a basic problem when ensemble average on large number of spots is required. This software leads to a huge data set because the total duration of acquisition is very much larger than the total duration of the spots. The huge data set is largely due to the laminar flow and contains only a small set of data on spots. In view of this, a separate software was developed which stored the data effectively during occurrence of the spot and slightly before and after the spot. This is carried out during the acquisition interactively by the user giving an estimate of the lowest delay time for the leading edge and the highest delay time for the trailing edge, from the console of the acquisition system.

A split buffer memory mode was used to acquire the data continuously. The acquisition device writes the data onto one memory bank when the data on the other memory bank is transferred to the hard disc of the computer.

DERIVATION OF THE INTERMITTENCY FUNCTION

The intermittency function is generated from the recorded time series data by adopting the following procedure. (The input data is called here as f(t) and the trigger pulse data as R(t)).

Step 1: If there are 'N' data samples in the input data f(t), it can be represented in discrete form f(K), K= 0,1,..., N-1 where time of ith sample is given by $t_i = i*\Delta t$, and Δt= sampling interval.

This time series data is double differentiated and squared to obtain F(K) using the central difference formula $F(K) = [f(K-1) - 2f(K) + f(K+1)]^2$, K= 1,2,...,N-2. The maximum value of this resulting series, $F_m(K)$, is obtained and the threshold (Th) is set as $Th = p*F_m(K)$ where p is a fraction selectable in the range 0.0 to 1.0. The actual value of p is selected so that Th is well above the noise level present in the signal, and lies in a range over which the intermittency function does not vary significantly with p.

Step 2: *First pass*: The intermittency function $I_1(K)$ is obtained using the threshold (Th) as follows:

(i) $I_1(K)= 0$ if $F(K) \leq Th$

(ii) $I_1(K)= 1$ if $F(K) > Th$

(iii) A counter is started when $I_1(K)$ changes from 1 to 0, and stopped, when $I_1(K)$ becomes 1. The time internal T_L during which $I_1(K)$ stays at 0 after changing from 1 is obtained.

(iv) T_L is compared with a hold time $T_{hold} = n*\Delta t$ where **n** is a number selectable by the user, so chosen that T_{hold} is in the order of the Kolmogorov time scale. If the time T_L is less than T_{hold}, then $I_1(K)$ for the duration T_L is made '1'; otherwise $I_1(K)$ is made '0' for the duration T_L. This is repeated till the end of F(K) [i.e. $K \leq N-2$].

Second pass: Now the data series $I_1(K)$ is taken and the time internal during which $I_1(K)$ stays at '1' is checked. Whenever it is less than T_{hold} as calculated above, $I_1(K)$ is made 0 during such intervals. This is repeated till the end of the data series $I_1(K)$. This step is conducted to eliminate spurious intermittency zones (if any) present in the series $I_1(K)$, that may arise because of noise. The new series obtained will be the final intermittency function I(K).

ILLUSTRATION

The complete procedure of generating intermittency function is illustrated graphically through Figures 3 to 6. Figure 3 shows a sample of input data with the upper half showing the turbulence data (signal) and the lower half showing the trigger pulse. The number of data samples is plotted on the X-axis and the amplitude for both signal and trigger pulse in volts is plotted on the y-axis. A burst can be seen in the signal after the high-to-low transition in the trigger pulse. Figure 3 is drawn using a graphics utility programme developed for this purpose.

Figure 4 shows the double differentiated and squared signal in the lower half with respect to the signal shown in the upper half. In the example discussed here, the threshold (P) used is 0.75% and the no. of samples 'n' for hold time setting is 5. Figure 5 shows the generated window (intermittency function) (as explained in steps 1 and 2) plotted on the signal. A reflection of the window is also shown on the squared double differentiated signal. Figure 6 shows the intermittency function for the data stretch considered here. In the output file for the intermittency function, the 'low' region is represented by '0's and the high region (corresponding to turbulence) by '1's.

Another output file is also generated which has the following information as columns 1 to 5;

Trigger pulse number, delay of high-to-low (H to L) transition of the corresponding trigger pulse from the beginning of the data, leading edge of the window

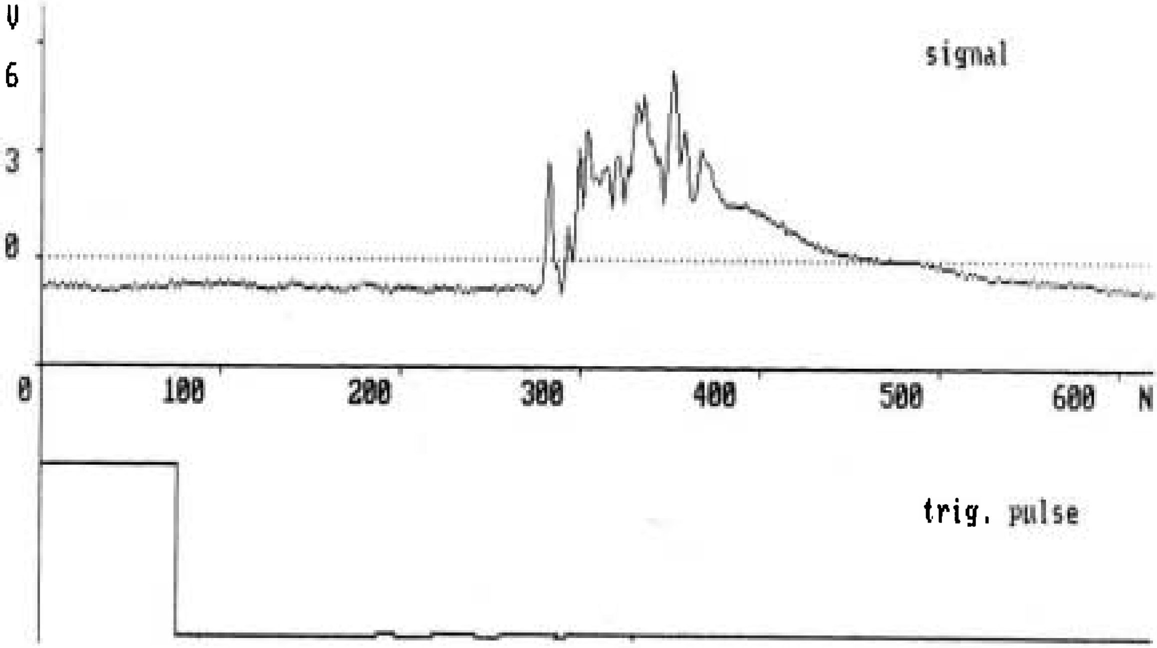

Figure 3. A time trace of turbulent signal in the spot and the corresponding triggering pulse.

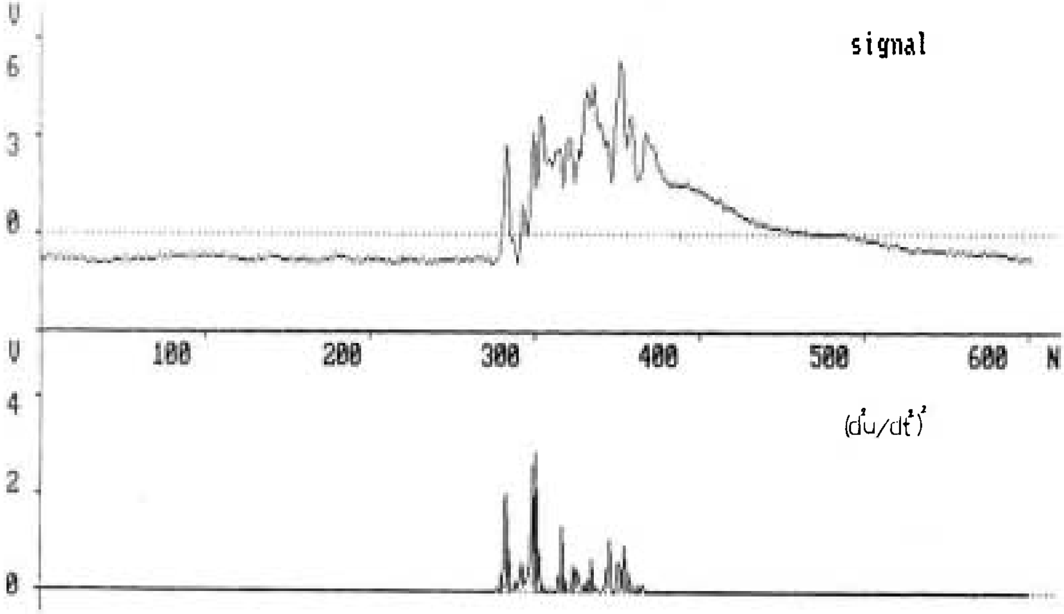

Figure 4. A time trace of turbulent signal in the spot and square of the double differentiation of the turbulent signal

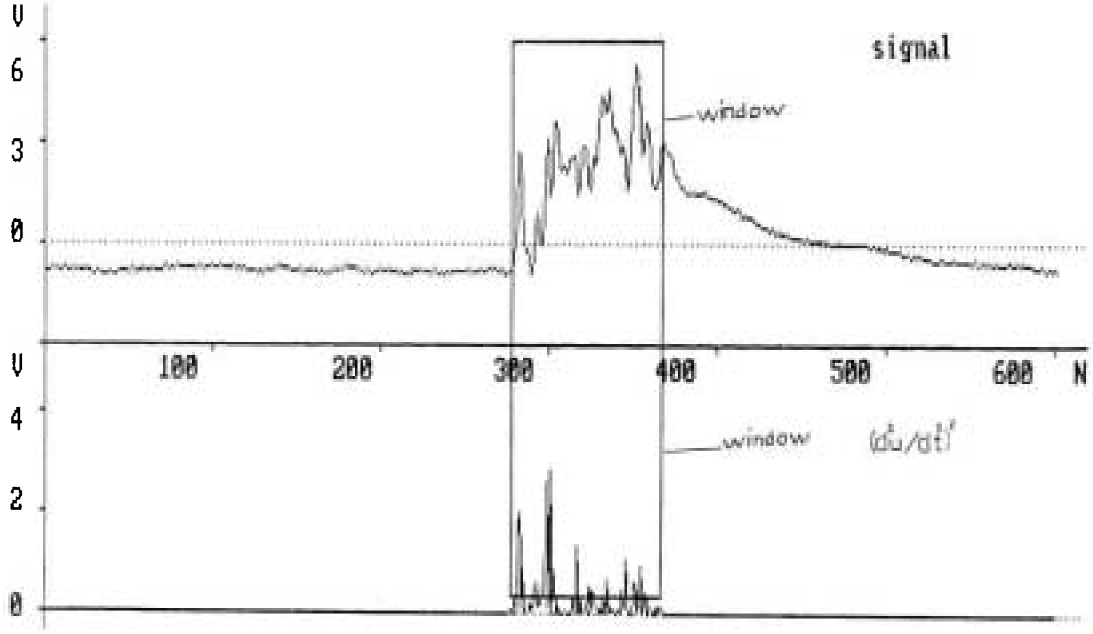

Figure 5. A time trace of turbulent signal in the spot and its squared double differentiation with turbulence region marked by window on both the plots.

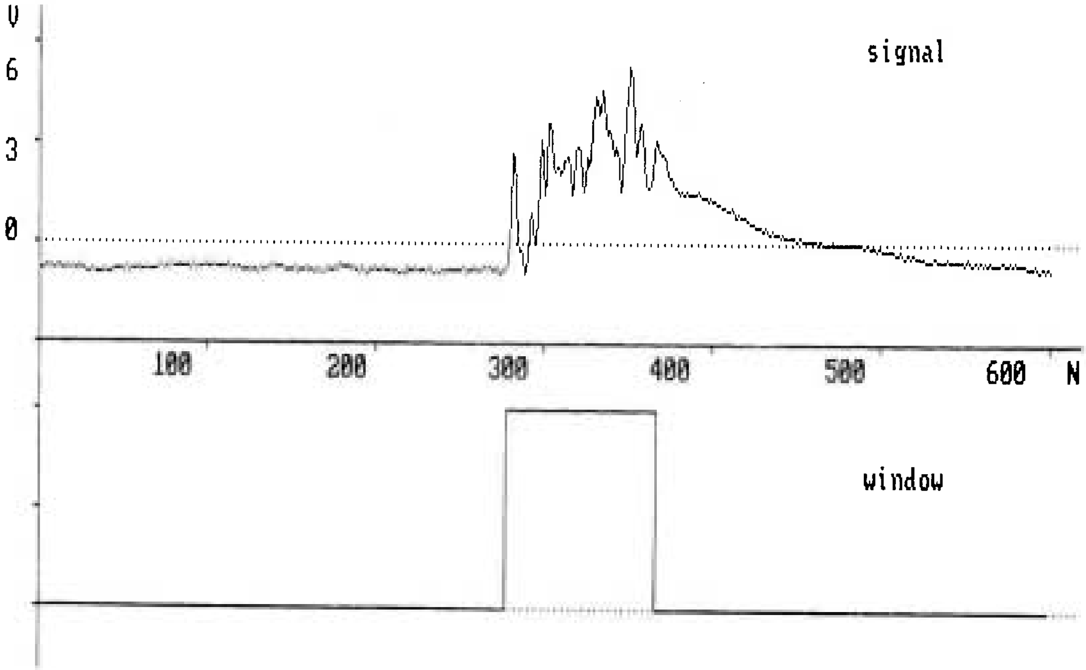

Figure 6. A time trace of turbulent signal in the spot and the corresponding intermittency function (window).

w.r.t trigger pulse (H to L transition), trailing edge of the window and the width of the window respectively.

A sample of this file is shown below, where an example of data stretch with 3 bursts is taken.

1	75	203	293	90
2	1490	203	311	108
3	2904	209	294	85

Leading edge: 205

Trailing edge: 299

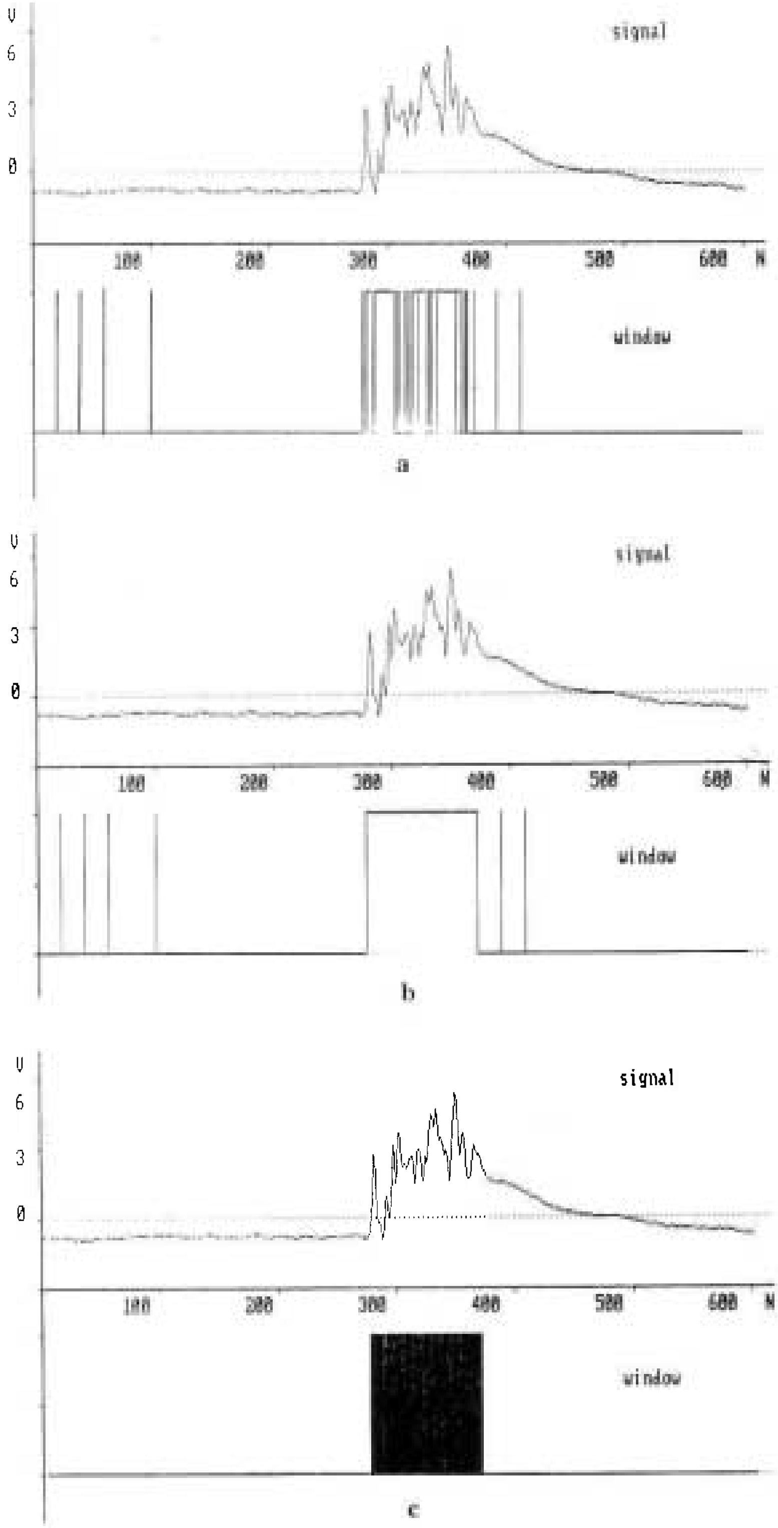

Figure 7. **(a)** Time trace of turbulent signal in the spot and intermittency function with zero hold time. **(b)** Time trace of turbulent signal in the spot and intermittency function with hold time of 10 data samples applied to the regions when I(K)= 0 (first pass). **(c)** Time trace of turbulent signal in the spot and intermittency function with hold time of 10 data samples applied to the output of the first pass and when I(K)= 1 (second pass).

The numbers apart from the first column is given in terms of data points.

At the end of the file, one leading edge and one trailing edge for the complete data stretch are stored which are obtained as follows:

Leading edge is the average of the all leading edges (column 3) and trailing edge is the sum of this leading edge and the average of the width of the windows (column 5).

The effect of threshold and hold time is illustrated in Figures 7(a), 7(b) and 7(c). Figures 7(a) and (b) shows the intermittency function before and after the first pass in the program with an appropriate threshold. It is clearly shown in 7(a) that the intermittency function has split windows even inside the spot. However, after applying the hold time correction in pass 1 (for the duration when the intermittency function is zero) as described earlier, the split windows inside the spot vanishes as shown in Figure 7(b). But the small width spurious windows during the laminar region still remains. This is eliminated as shown in Figure 7(c) by going through pass 2 where hold time correction is applied for the duration of intermittency function being unity.

The spurious windows also get eliminated by increasing the threshold. However, this may require increasing the hold time as well. However, increasing the threshold is also likely to reduce the width of the main window.

The selection of the threshold needs some discussion. In the procedure described above the threshold has been selected in terms of the maximum value of the $(d^2u/dt^2)^2$. However, this may not be universally stable and one might have to visually examine what value of the threshold to be used for each data trace. The purpose of the threshold is to discriminate the laminar region as compared to the turbulent region.

It seems that if the threshold has to be made more objective, it should have to depend on the noise in the laminar region of the hot wire signal. In order to find out whether such an objective threshold can be proposed, the probability density distribution of $(d^2u/dt^2)^2$ signal was calculated. Figure 8 shows the probability density distribution of $(d^2u/dt^2)^2$ normalized with $\overline{(d^2u/dt^2)^2_L}$. Suffix L denotes that the

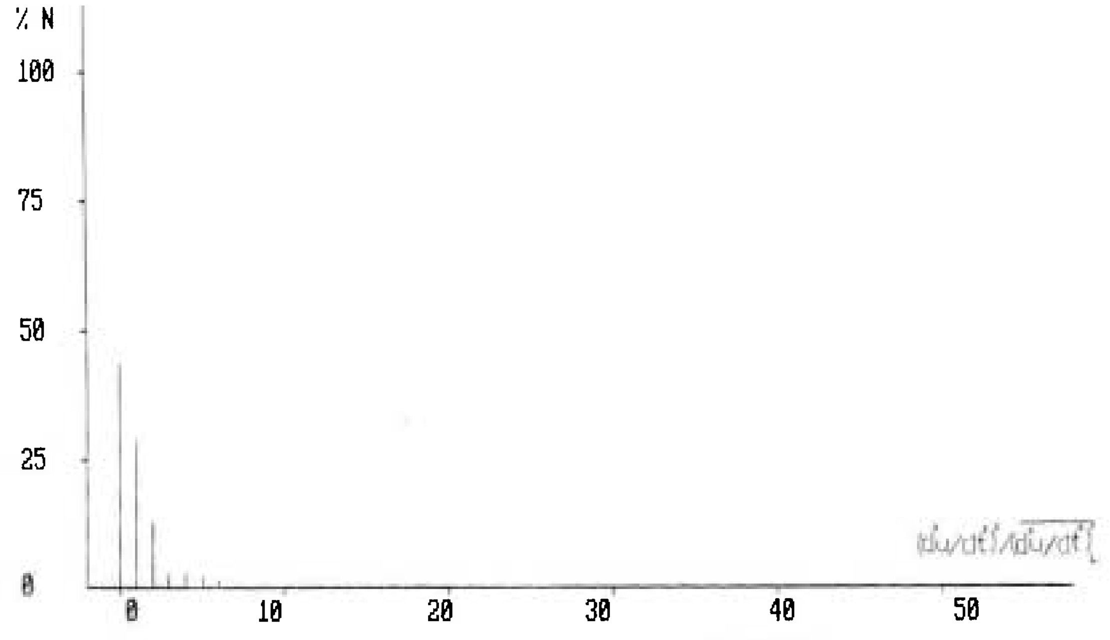

Figure 8. Probability density distribution of $(d^2u/dt^2)^2$ normalized with $\overline{(d^2u/dt^2)^2_L}$ of signal during laminar flow.

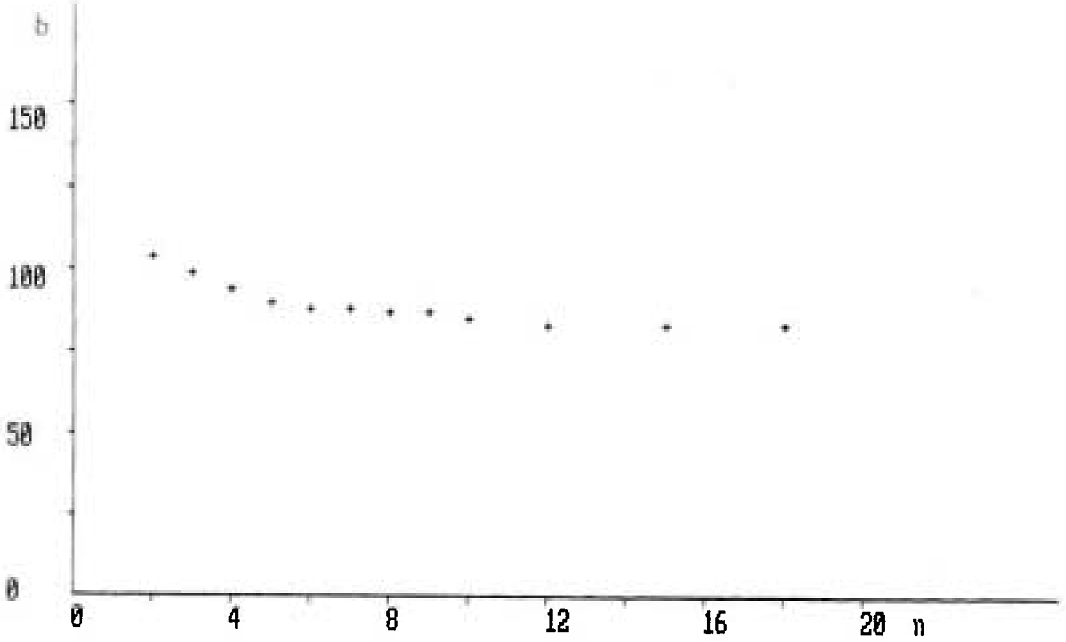

Figure 9. The variation of the window width b (Time duration of the spot) with n, a measure of the threshold level (threshold / $\overline{(d^2u/dt^2)^2_L}$).

value is calculated only during the laminar region and the symbol (—) indicates the average value. The distribution, which has a large peak around zero corresponding to the laminar region, sharply decreases as the absissa increases and is very nearly zero beyond the value of 6. It therefore seems that if the threshold is selected as n time the $\overline{(d^2u/dt^2)^2_L}$ (where n is around 6) then it may be more objective.

The intermittency function was calculated for various values of n and the width b of window thus calculated is shown in Figure 9 as a function of **n**. The Figure shows that for $n < 2$ the split windows appear and for $n > 3$ the variation of the width b is very slow. This suggests that if we choose $n = 3$ or 4, the intermittency function will be defined and the threshold value will be more or less fixed objectively.

CONCLUSION

The method developed for generating intermittency function is unique and helpful for discriminating the turbulent and non-turbulent sequence quite effectively and the output file includes all the data required for calculating turbulent spot shapes. Besides, the output information can be used for further analysis namely conditional averaging of turbulent signal.

Furthermore a typical value of the threshold which could be objectively used based on the probability distribution of $(d^2u/dt^2)^2$ normalized with that in the laminar flow has been suggested.

ACKNOWLEDGEMENT

We are very grateful to Prof. R. Narasimha for his enlightening ideas and constant interactive guidance.

REFERENCES

1. R. A. Antonia "Conditionally Sampled Measurements near the Outer Edge of a Turbulent Boundary Layer", *J. Fluid* Mechanics, Vol. 56, Part 1, (1972) 1-18.
2. T. B. Hedley and J. F. Keffer "Turbulent/non-turbulent Decision in an Intermittent Flow", *J. Fluid Mechanics*,

Vol. 64, Part 4, (1974), 625-644.

3. C. L. Kuan and T. Wang "Investigation of the Intermittent Behaviour of Transitional Boundary Layer Using a Conditional Averaging Technique". Experimental Thermal and Fluid Sciences, vol. 3, (1990), 157-173.
4. R. Narasimha", The Laminar-turbulent Transition Zone in the Boundary Layer", *Prog. Aerospace Sci.*, Vol. 22, (1985), 29-80.
5. R. A. Antonia and P. Bradshaw, *Imp. College, Aero. Rep. No.* 71-04, (1971).
6. D. Arnal and J. C. Juillen, "Study of Intermittency in the Transition Zone of a Boundary Layer", *Recherche Aerospatiale No.* 1977-3, (1977), 147-166.
7. S. Sankaran and R. A. Antonia "Influence of a Favourable Pressure. Gradient on the Growth of a Turbulent Spot", *AIAA Journal*, Vol. 26, No. 7, (1988), 885-887.
8. A. Glezer, Y. Katz, I. Wygnanski on the Breakdown of the Wave Packet Trailing a Turbulent Spot in a Laminar Boundary Layer," *J. Fluid Mech.* Vol. 198, (1989), 1-26.
9. S. Sankaran, R. A. Antonia and D. K. Bisset "Flow Patterns and Organisations within a Turbulent Spot", *Phys. Fluids A.*, Vol. 3, No. 6, (1991), 1560-1571.
10. I. Wygnanski, M. Sokolov and D. Friendman "On a Turbulent Spot in a Laminar Boundary Layer", *J. Fluid Mech.* vol. 78, Part 4, (1976), 785-819.
11. F. K. Owen "Transition Experiments on a Flat Plate at Subsonic and Supersonic Speeds", *AIAA Journal*, Vol. B. No. 3, (1970), 518-523.
12. O. P. Sharma, R. A. Wells, R. H. Schlinker and D. A. Bailey "Boundary Layer Development on Turbine Aerofoil Suction Surfaces", *J. of Engineering for Power, Transaction of the ASME.* Vol. 104, (1982) 698-706.
13. J. Dey, M. Jahanmiri, A. Prabhu and M. Ramazanov Spot Characteristics in a 3-D Flow with Stream Line Divergence under Zero Pressure Gradient", *Fluid Mech, Report 90 FM 3*, Dept. of Aerospace Engg., IISc (1990).