

STUDIES ON SPECTRAL ANALYSIS OF RANDOMLY SAMPLED SIGNALS:
APPLICATION TO LASER VELOCIMETRY DATA

by

Dr. Dave Sree
Department of Aerospace & Mechanical Engineering
Tuskegee University
Tuskegee, AL 36088

Abstract

Spectral analysis is very useful in determining the frequency characteristics of many turbulent flows, for example, vortex flows, tail buffeting, and other pulsating flows. It is also used for obtaining turbulence spectra from which the time and length scales associated with the turbulence structure can be estimated. These estimates, in turn, can be helpful for validation of theoretical/numerical flow turbulence models. Laser velocimetry (LV) is being extensively used in the experimental investigation of different types of flows, because of its inherent advantages: nonintrusive probing, high frequency response, no calibration requirements, etc. Typically, the output of an individual realization laser velocimeter is a set of randomly sampled velocity data. Spectral analysis of such data requires special techniques to obtain reliable estimates of correlation and power spectral density functions that describe the flow characteristics.

Standard techniques of spectral analysis used for uniformly sampled (equispaced) signals are not directly applicable to randomly sampled data. Shapiro and Silverman [1] showed, theoretically, that alias-free spectral estimates can be obtained from randomly sampled data if the sampling is Poisson distributed. Based on this theory, Mayo et al [2] developed a correlation-based 'slotting' technique to compute the autocorrelation and power spectrum estimates through use of Fourier transform. Also, Gaster and Roberts [3] developed a direct transform method to compute the power spectrum estimates directly from the randomly sampled data, and, if needed, the autocorrelation estimates can be obtained using inverse Fourier transform. The slotting technique is faster than the direct transform method and has been looked into in detail by Srikantaiah and Coleman [4] to make reliable spectral estimates from randomly sampled laser velocimetry data.

The Experimental Methods Branch of NASA Langley Research Center had expressed a need for research, and development of computer codes, for reliable and improved estimation of turbulence spectra and the associated time and length scales from LV data. During his 1992 NASA/ASEE Summer Fellowship tenure, the author has developed FORTRON codes for obtaining the autocorrelation and power spectral density estimates using the correlation-based

slotting technique. Extensive studies have been conducted on simulated first-order spectrum and sine signals to improve the spectral estimates. A first-order spectrum was chosen because it represents the characteristics of a typical one-dimensional turbulence spectrum. Digital prefiltering techniques, first introduced by Roberts and Ajmani [5], to improve the spectral estimates from randomly sampled data have been applied. Studies show that the spectral estimates can be increased up to about five times the mean sampling rate. Figure 1 illustrates the results of this study on simulated first-order spectrum. The codes are currently being used on LV experimental data from different flow facilities at NASA Langley. Figure 2 shows the turbulence spectra measured at two different locations in the backward-facing step flow facility. These results will be compared with hot-wire measurements. Further improvements and validation of the spectral analysis codes will continue.

Large data sets (of the order of 100,000 points or more), high data rates, and, of course, Poisson sampling are very important requirements for reliable estimation of turbulence spectra. The Poisson sampling requirement is usually met in carefully conducted LV experiments. But, often, certain flow conditions, depending upon measurement location, flow phenomenon, and particle dynamics, force the sampling process to be non-Poisson. The high data rate requirement may not be achieved. The effect of non-Poisson sampling has also been studied on simulated, as well as, real data. Results show that the estimated spectrum deviates considerably from the true spectrum and that non-Poisson sampling is not amenable to spectral improvements from prefiltering techniques. Further research is required to determine the effects of other influences like particle dynamics, velocity bias, etc. on the accuracy of spectral estimates. Research is also needed to extend the spectral analysis techniques to obtain cross-correlation and cross-power spectral estimates from randomly sampled 2-D/3-D LV experimental data.

REFERENCES:

1. Shapiro, H.S.; and Silverman, R.A.: "Alias-free sampling of random noise." J. Soc. Ind. App. Math., 8, pp 225, 1960.
2. Mayo, Jr. W.T.; Shay, M.T.; and Riter, S.: "The development of new digital data processing techniques for turbulence measurements with a laser velocimeter." Report # AD-784-891, AEDC-TR-53, Texas A&M University, 1974.
3. Gaster, M.; and Roberts, J.B.: "Spectral analysis of randomly sampled records by a direct transform method." Proc. R. Soc. Lond. A., 354, pp 27, 1977.
4. Srikantaiah, D.V.; and Coleman H.W.: "Turbulence spectra from individual realization laser velocimetry." Expt. in Fluids, 3, pp 35, 1985.
5. Roberts, J.B.; and Ajmani, D.B.S.: "Variance reducing techniques for the spectral analysis of randomly sampled signals." Proc. Intl. specialists meeting on the use of computers in laser velocimetry, ISL, St. Louis, France, 1987.

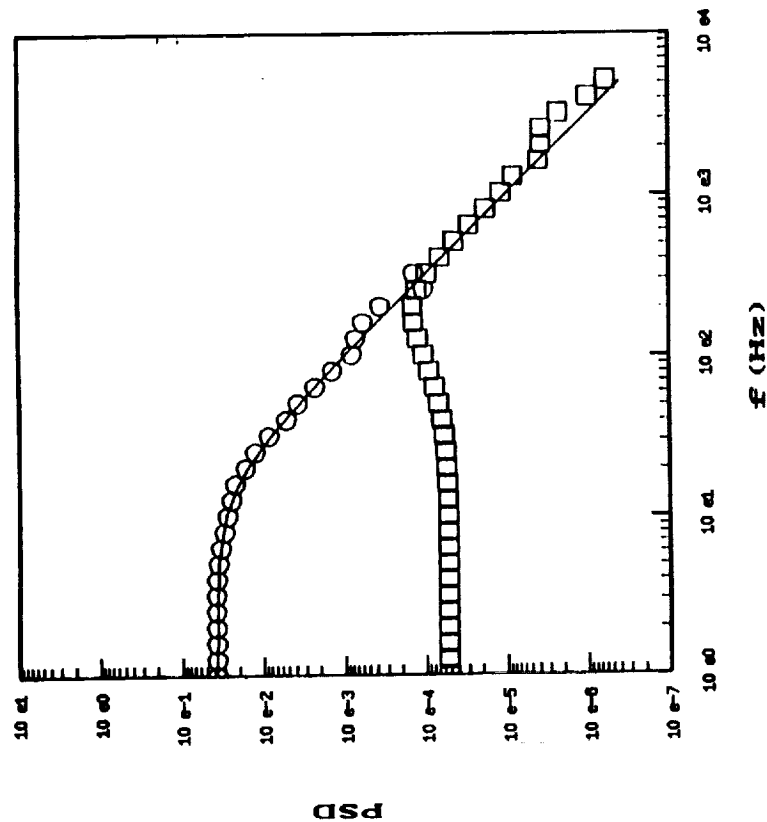


Figure 1: Study on simulated first-order spectrum. Solid line is theoretical spectrum. Circles are estimated values of unfiltered data. Squares are improved values by prefiltering techniques (kind of high-pass filtering) which extend spectral estimates up to about five times data rate (1000/s here). PSD: Power Spectral Density.

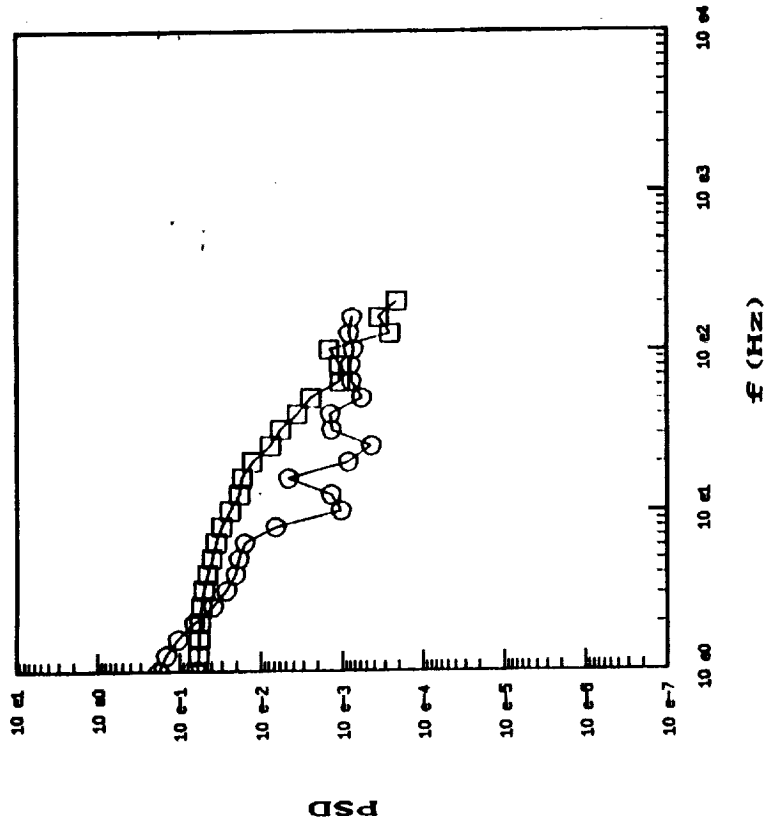


Figure 2: Turbulence spectra from LV measurements at 3" upstream (circles, data rate: 188/s) and 27" downstream (squares, data rate: 96/s) axial locations in backward-facing step flow facility at NASA Langley. Note facility fan frequency of 18.5 Hz (1110 RPM) is detected.