Contribution to the Measurement of Turbulent Structures

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Outline

- Introduction
- Integral Length Scales
- Experimental set up
- Signal processing
- Result
- Conclusion

Introduction

- Objective : Size estimation of turbulent structures.
- Classical way : Integral Length Scales (ILS) measurement with:
  - Hot Wire Anemometry method
  - Laser Doppler Velocimetry method.
- Measurement inside a transparent combustion engine:
  - Schlieren Optical Method & High Speed Film Camera
  - Signal processing: Time-Frequency distributions.

Integral Length Scales

Integral Length Scale represents a temporal average of all the length scales present in a flow.

$$T = \int_0^\infty R_E(0,0,0;\tau).d\tau$$

$$L_x = \int_0^\infty R_E(\Delta x,0,0;0).d(\Delta x)$$

$$L_y = \int_0^\infty R_E(0,\Delta y,0;0).d(\Delta y)$$

Eulerian space-time correlation coefficients R_E (Δx, Δy, Δz ; t) of the velocity fluctuation u (x, y, z ; t) considering a point p (x, y , z) at time t.

ILS Measurement

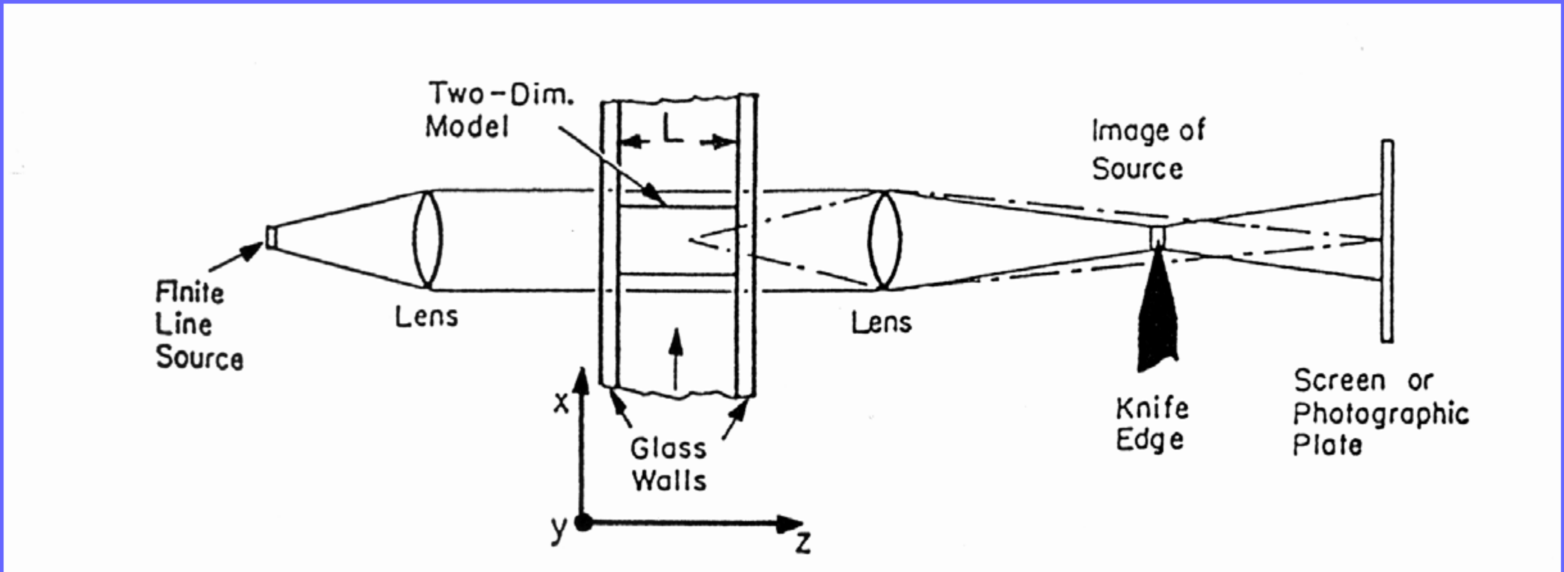
- From the velocity fluctuation (L.D.V.):
  - Covariance function.
  - Integral Length Scale (Empirical cut off frequency).
- From Schlieren optical method:
  - Schlieren images.
  - Time-Frequency distributions.

Experimental Set-up

- Air – propane IC Engine.
- Optical access in combustion chamber : Quartz windows.
- RPM = 1000
- CR=7.5
- Re_T = 100
- Crankangle: -40° before TDC to +20° after TDC.

Experimental Set-up

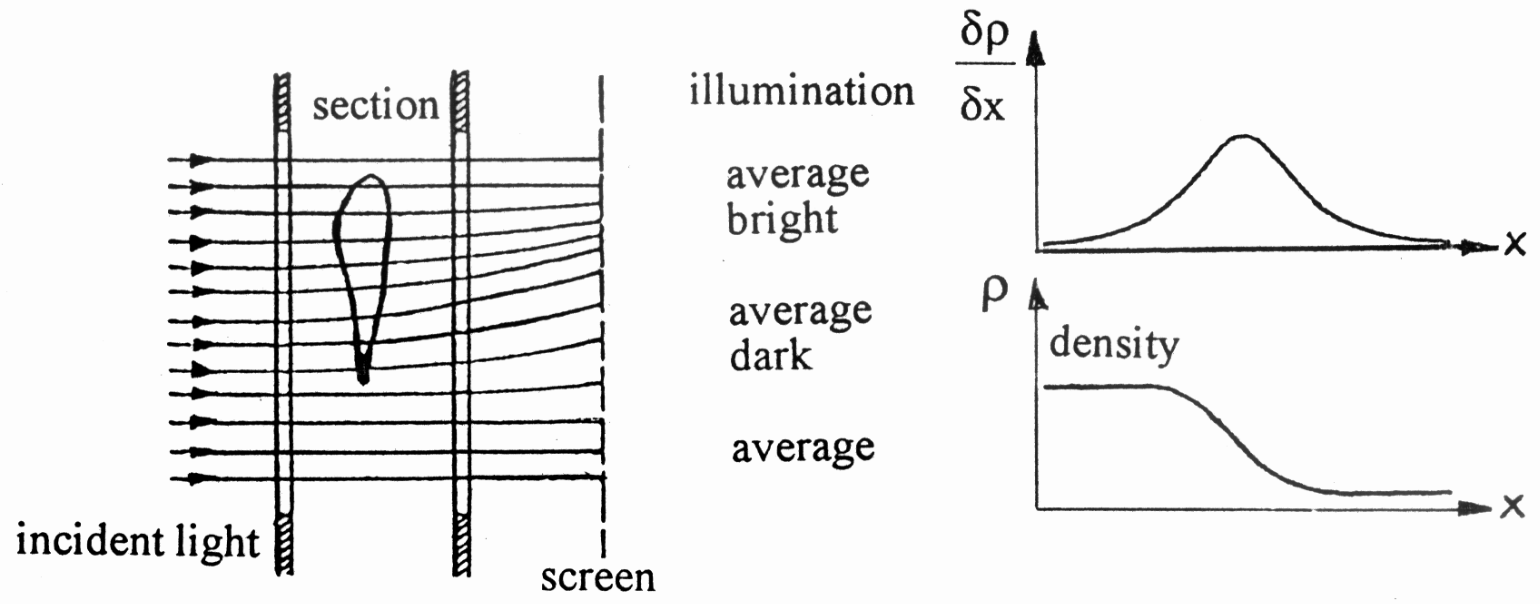
Schlieren system



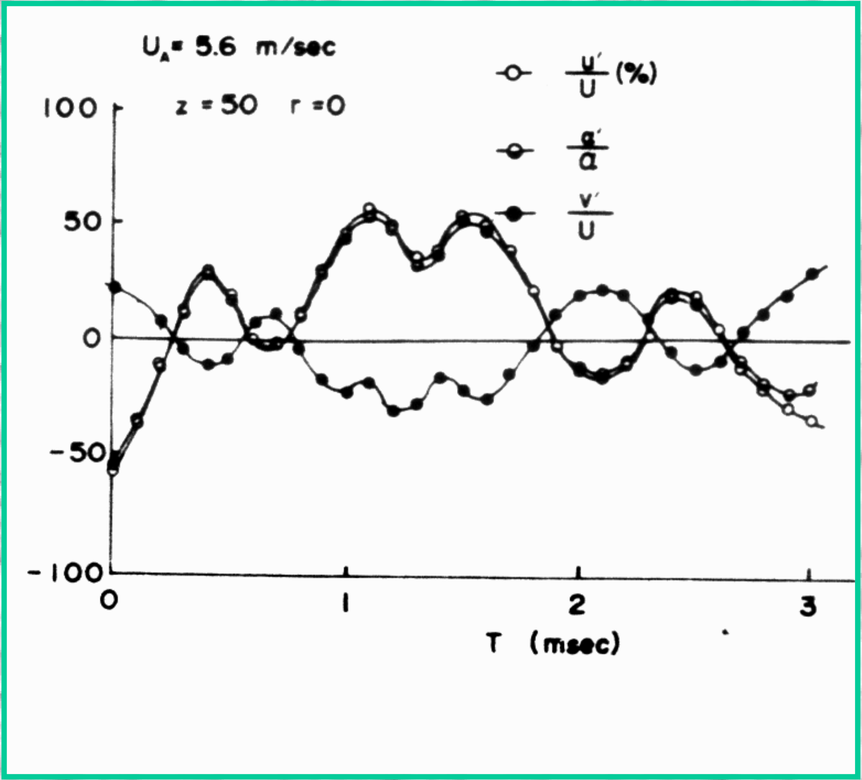
Deflection along x axis:

$$\vec{\varepsilon} = \frac{\vec{L}}{R} = L.\overrightarrow{grad}\; n = L.K_{G-D}\, \overrightarrow{\frac{\partial \rho}{\partial x}}$$

Experimental Set-up



Velocity & Density



*High correlation between:

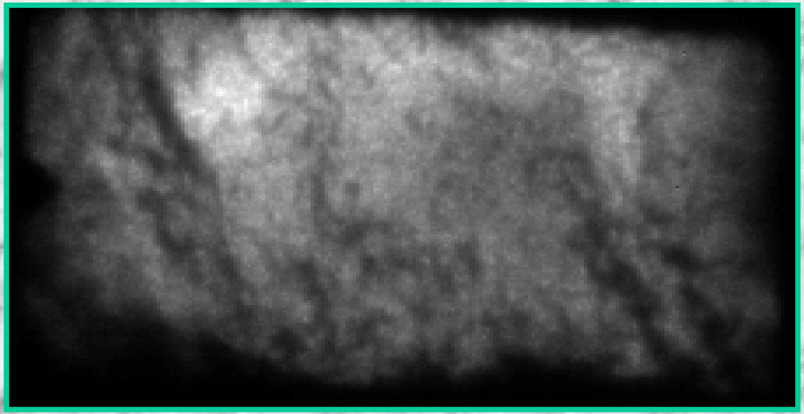
- Density Fluctuations
- Velocity Fluctuations

(Y. Aihara et al 1974).

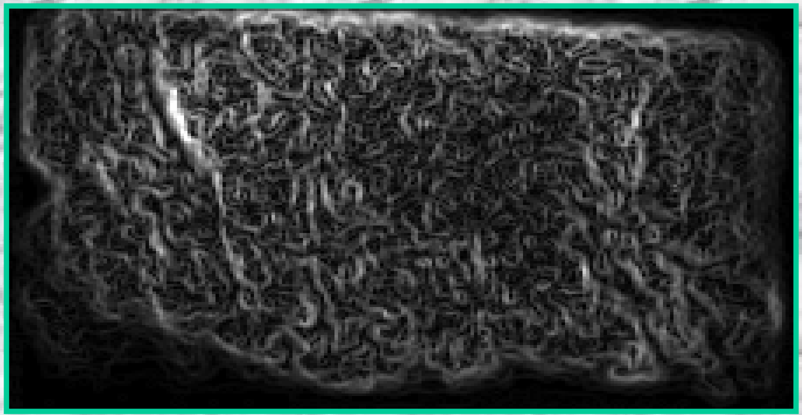
*From Schlieren Images:

- Density fluctuations
- Covariance function
- Integral Scales.

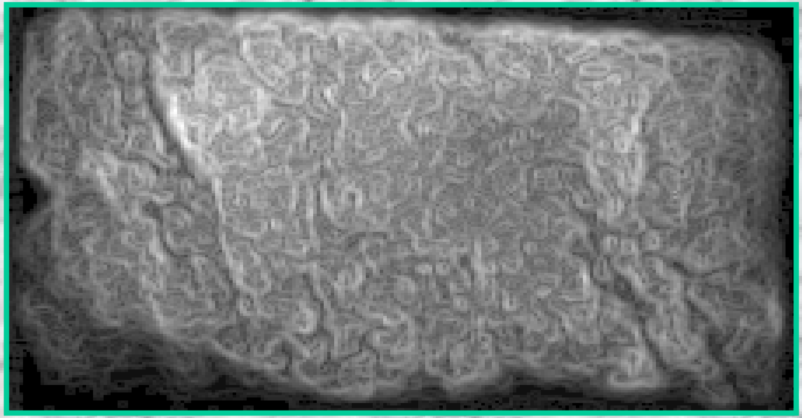
Turbulence image



Schlieren view



Sobel gradient image



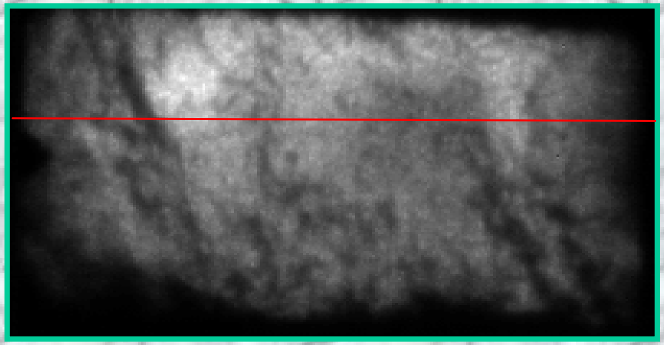
“Turbulence” view

Signal processing

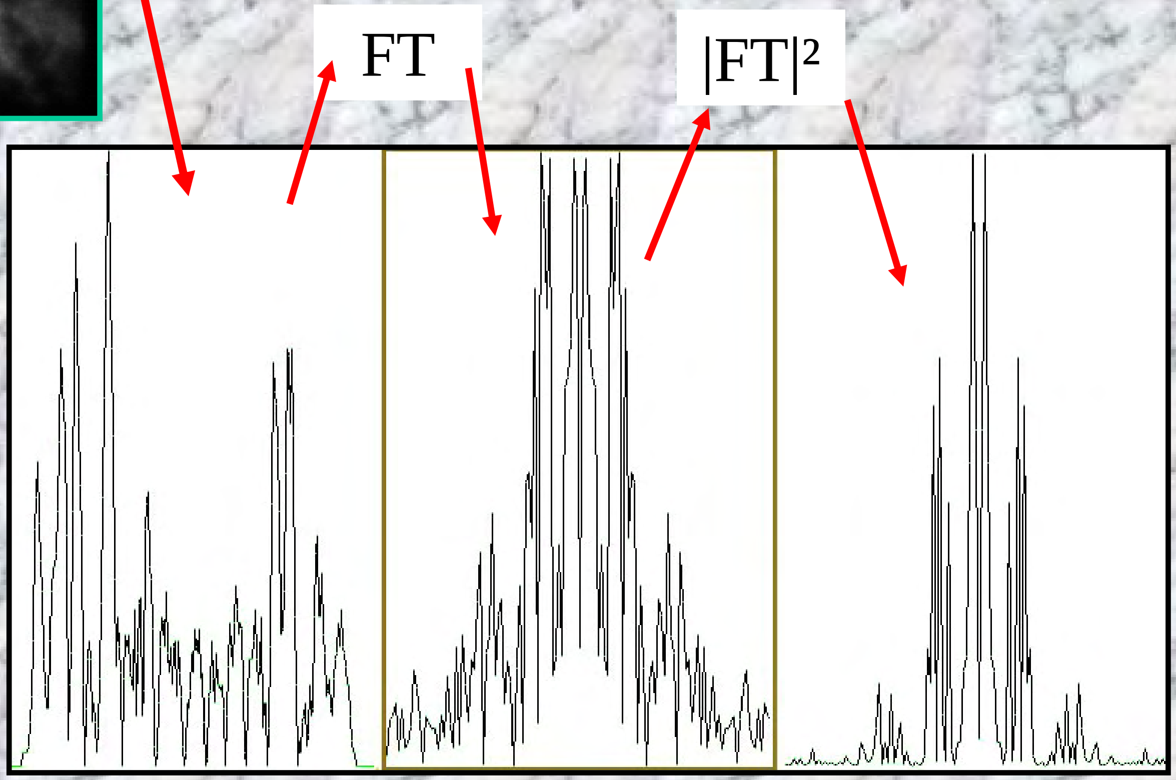
Measurement with Time-Frequency distributions of non stationary density fluctuations.

- Spectrogram : squared short time Fourier transform
- Wigner-Ville distribution.

Signal processing – Fourier Transform



Schlieren view



Spectrogram

$$S_Z(t,\nu) = \left| \int_{\mathbf{R}} Z(\tau).H^*(\tau - t) e^{-i2\pi\nu\tau} d\tau \right|^2$$

$$S_{\Gamma_z}(\xi,\nu) = \left| \int_{\square} \Gamma_Z(\tau).\Gamma^*_H(\xi,\tau).e^{-i2\pi\nu\tau}.d\tau \right|^2$$

Z consists in a row of a considered “Turbulence” image

Γ is the covariance of the non-stationary signal Z

Wigner-Ville distribution

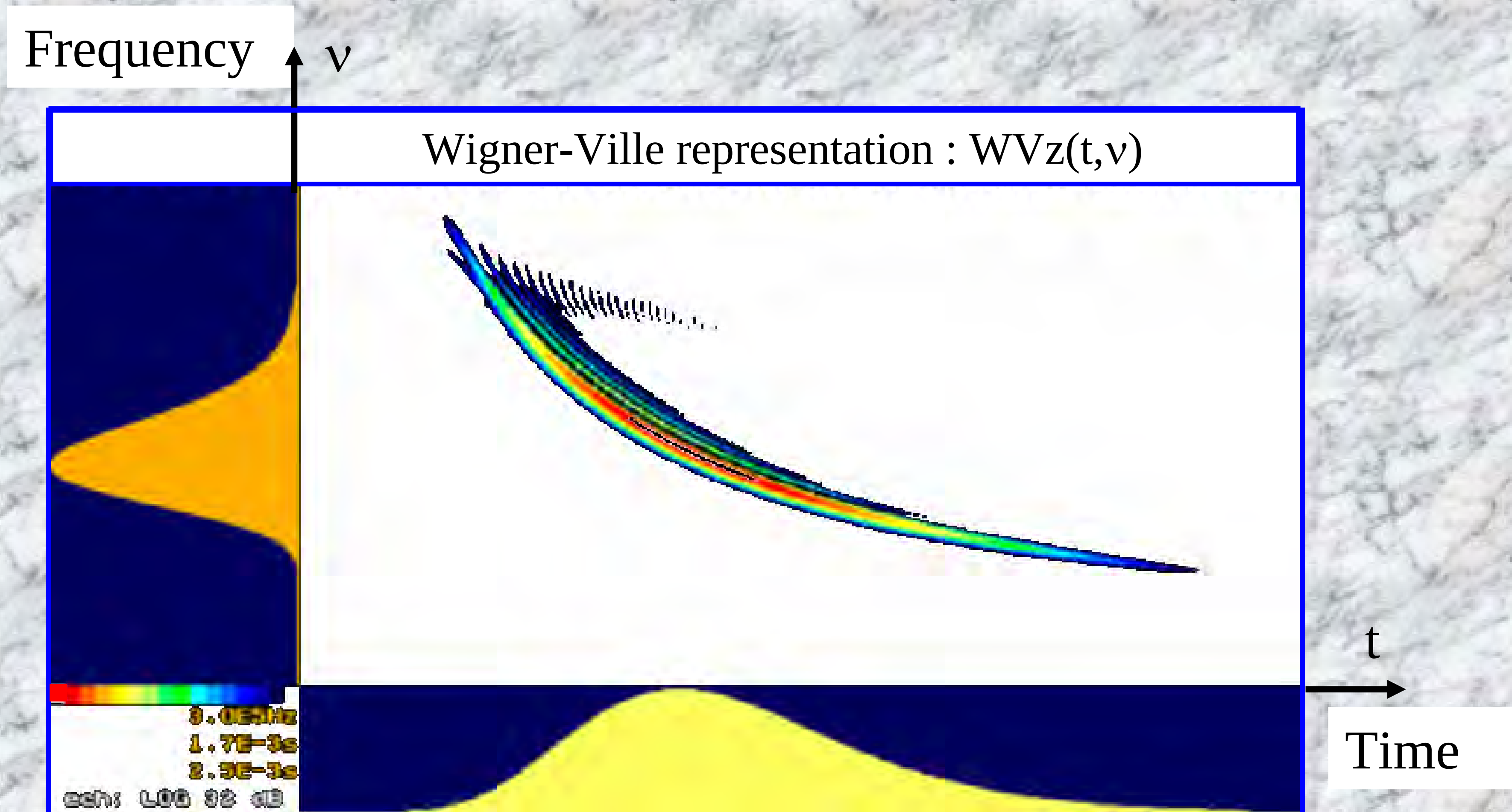
$$W_Z(t,\nu) = \int_{\mathbf{R}} z\left(t+\frac{\tau}{2}\right).z^*\left(t-\frac{\tau}{2}\right).e^{-2i\pi\nu\tau}d\tau$$

$$W(\xi,\nu) = \int_{\mathbf{R}} \Gamma_Z(\tau,\xi).\Gamma^*{}_Z(\tau,\xi).e^{-2i\pi\nu\tau}d\tau$$

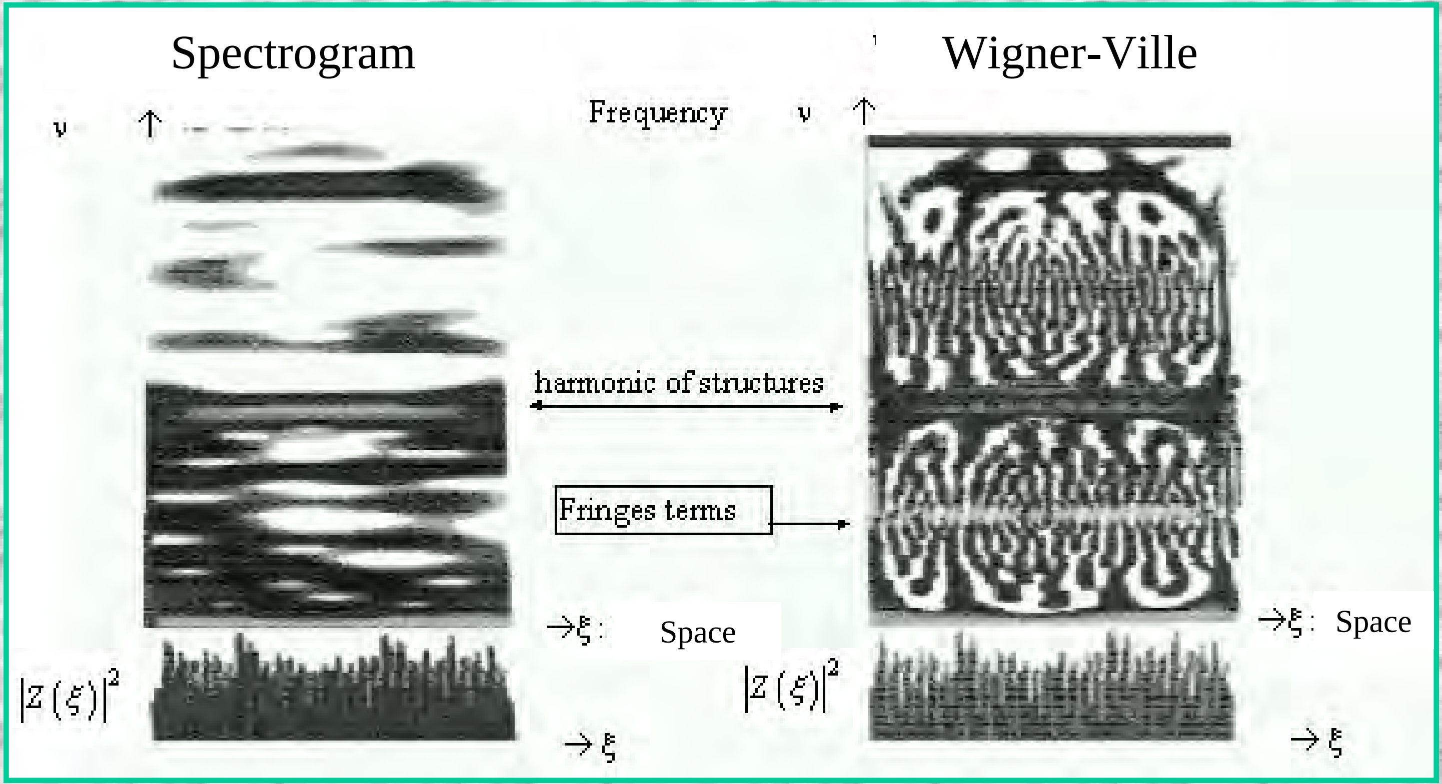
Z consists in a row of a considered “Turbulence” image

Γ is the covariance of the non-stationary signal Z

Hyperbolic frequency modulation

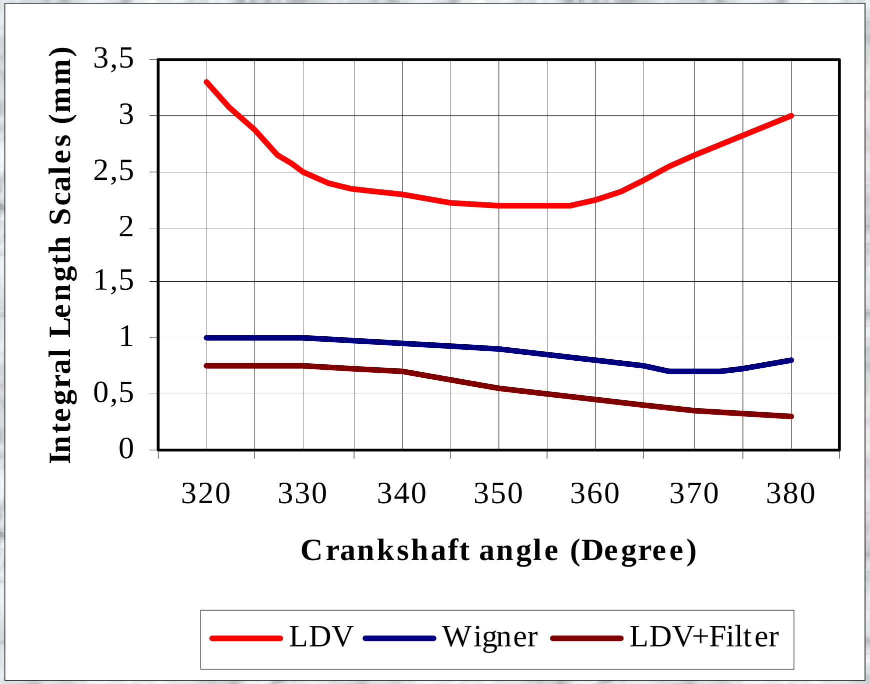


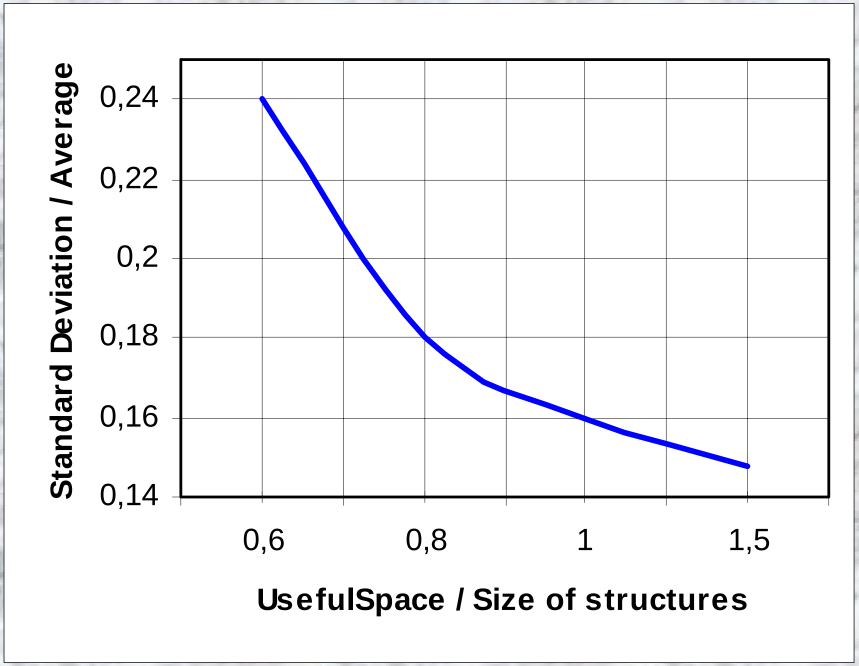
Time-Frequency analysis of the density fluctuation



Results

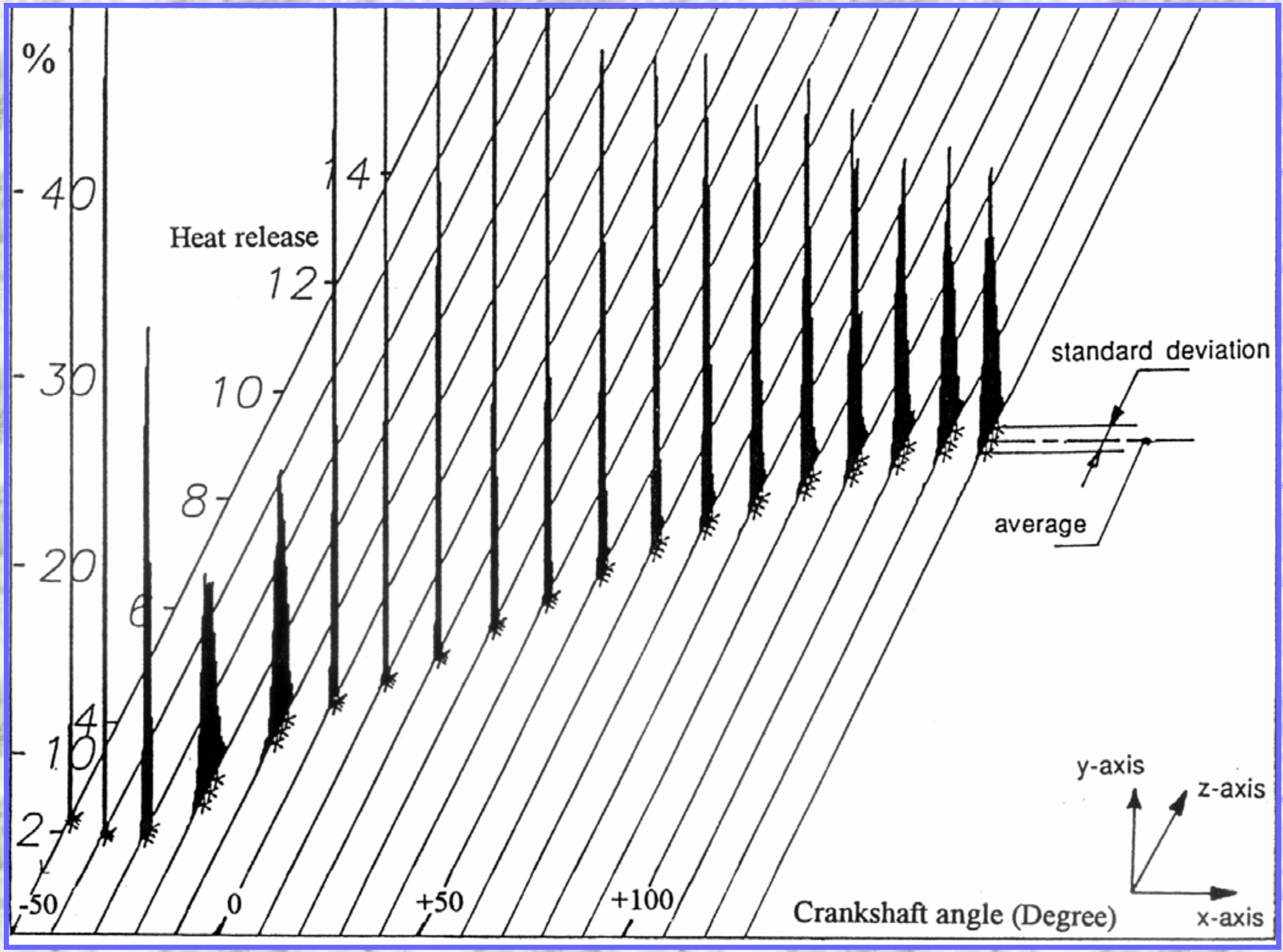
I.L.S. sizes compared with LDV sizes





Dispersion of heat release

Heat release over 800 cycles



Results

- Resulting Turbulent structure sizes have been compared with L.D.V. sizes.
- Correlation between dispersion of heat release and sizes of structures is established.

Conclusions

- Non classical method to measure turbulent structures.
- Direct comparison with L.D.V.
- An other way : 2D wavelet transform to estimate Lipchitz exponent in order to measure turbulent structures in term of singularities.
- Over crossing of domains.

Introduction : Concept description