Some Experimental Results on Jet Turbulence

AE 371 (UGP-1)

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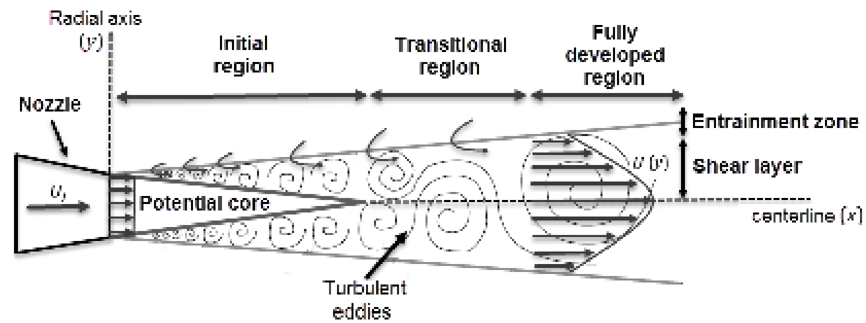
Introduction

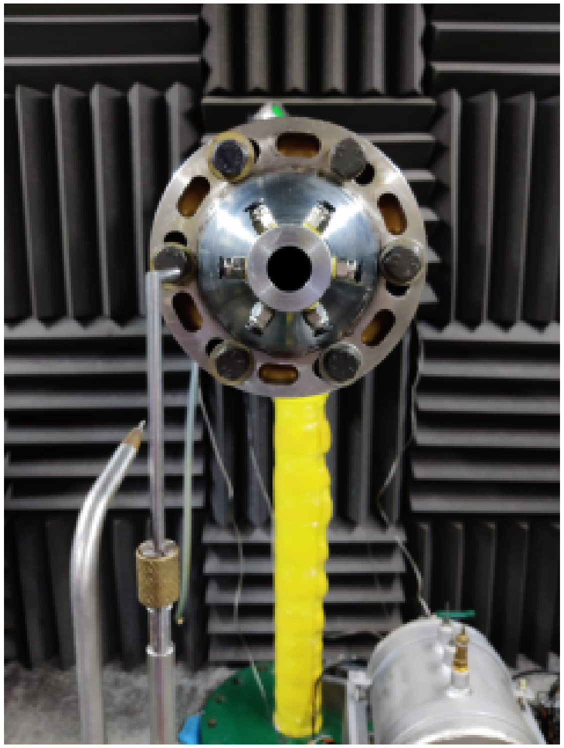
- The turbulence jet study is important for the aircraft's propulsion system and to reduce the jet noise.
- The turbulence measurements were carried out from a jet issuing from a circular nozzle, using a pitot static tube and hot-wire anemometer placed downstream of the jet flow.
- The jet flow evolves as we move along downstream, the flow interacts with the steady outside environment and diffuses in the radial direction, and diffusion of the velocity takes place until the initial momentum decreases enough that viscus forces become dominant and dissipating the energy, making the flow to end.



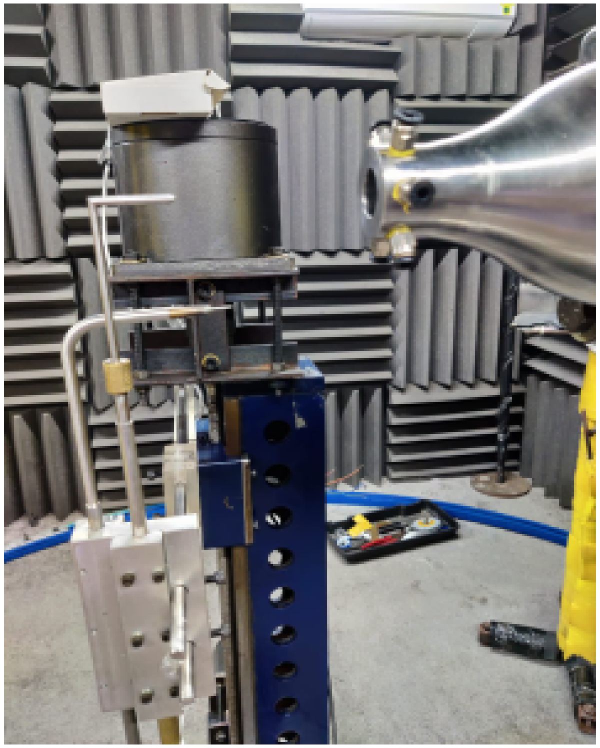
Setup and Procedure

- To setup the flow
- The compressors are turned on to maintain the pressure in the reservoir tanks
- For a clean and dry airflow, the excess condensed water in the tanks is drained out.
- The dryer is turned on and the inlet valve for the dryer is opened after the water gets fully drained. The inlet valve for the chamber is then opened.
- The flow in the chamber or the jet flow velocity can now be regulated by a single valve outside the chamber.

Jet Nozzle

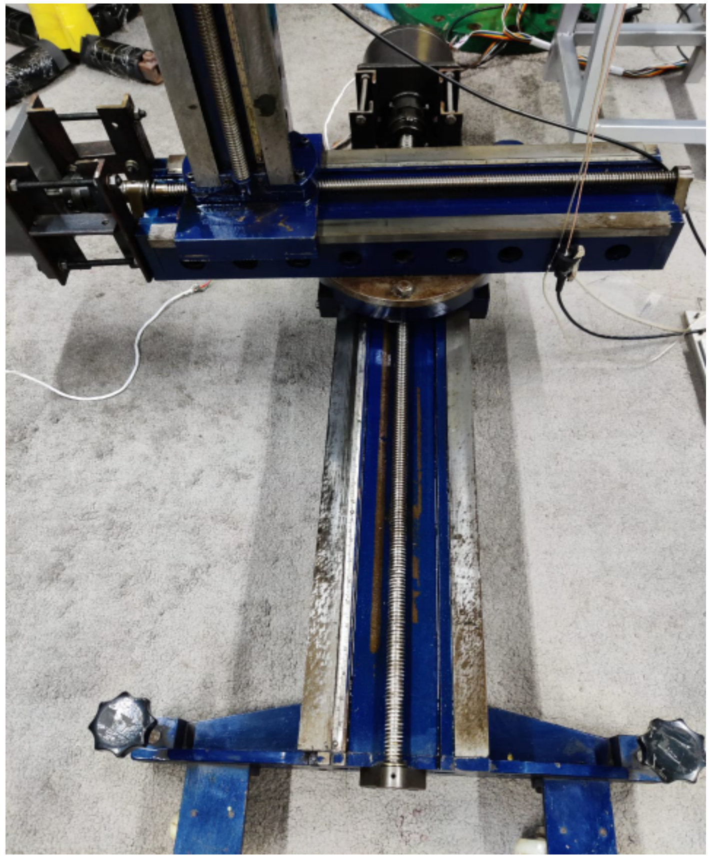


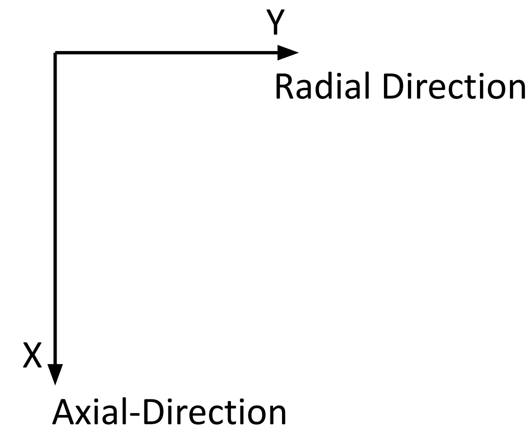
Jet Nozzle and Plenum



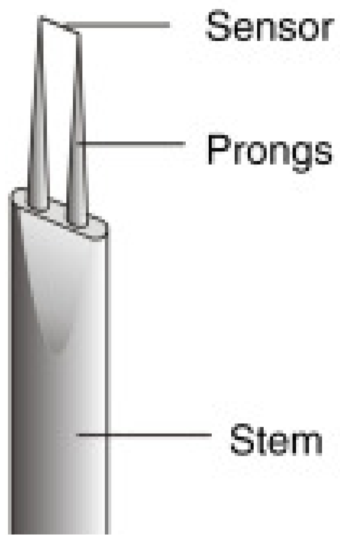
Jet Nozzle and Hot-wire mount

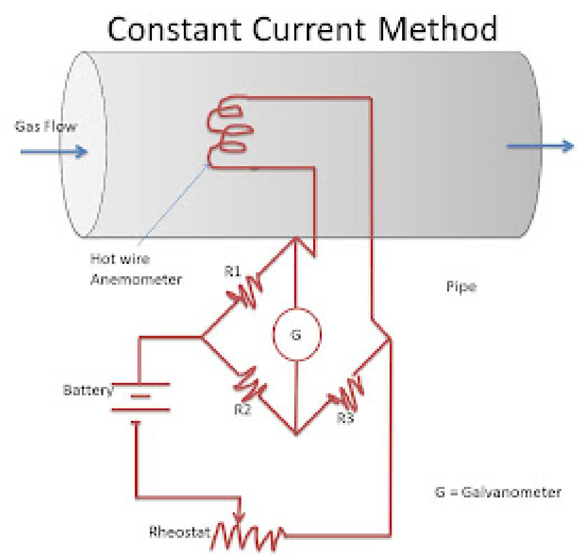
Traverse System





Hot-Wire Probe





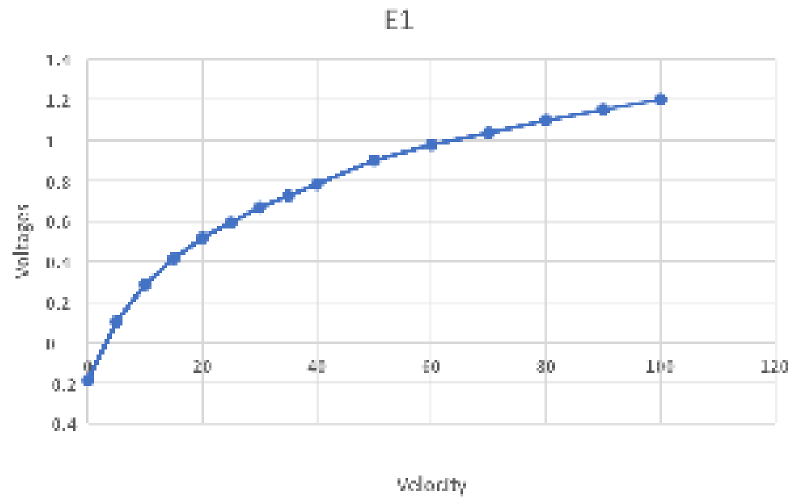
- The Hot-Wire used in the experiment was aligned perpendicular to the x-axis, having a diameter of 5μm and a length of around 1.0mm with an overheat ratio of 0.8.

Pitot Tube Anemometer

Pitot Static Tube

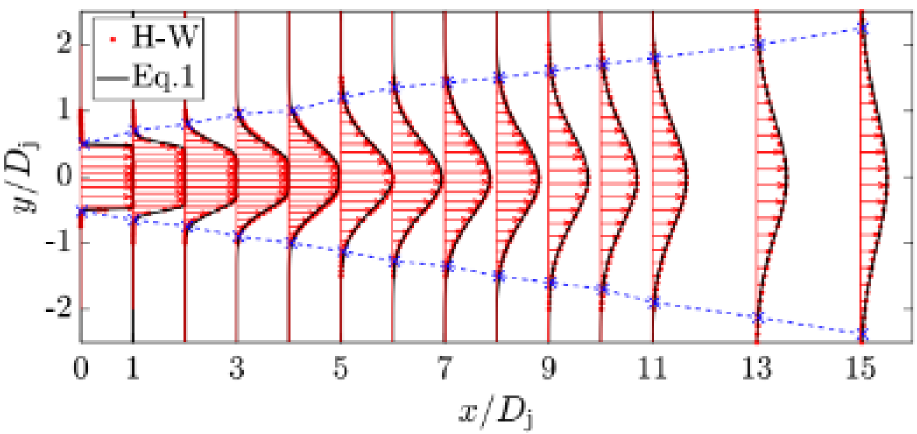
Digital Pitot Tube Anemometer

- Once the flow is set the pitot tube and hot wire are mounted and placed at the nozzle exit for calibration.
- The calibration is done with the help of pitot tube readings, calibration was done for 0 to 100m/s and 0 to 140m/s with steps of 10m/s and with some intermediate points.
- After the calibration was completed the centerline and radial velocity data were taken for different x/D locations along the centerline and y/D for radial direction.
- From the radial velocity data at different spital points, the position of the lipline was found from the turbulence intensity graph. From the centerline data, the location of the potential core was found from the mean centerline velocity decay graph.

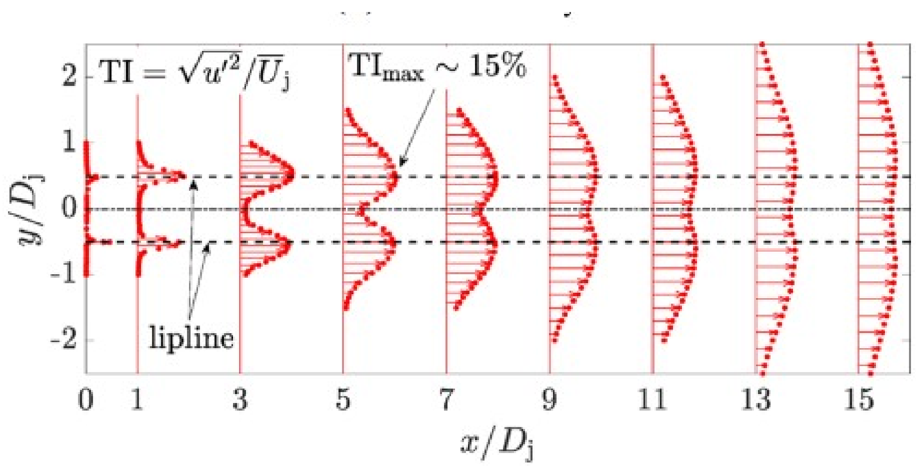


Calibration curve

Downstream Velocity Profile and Turbulence intensity along lipline



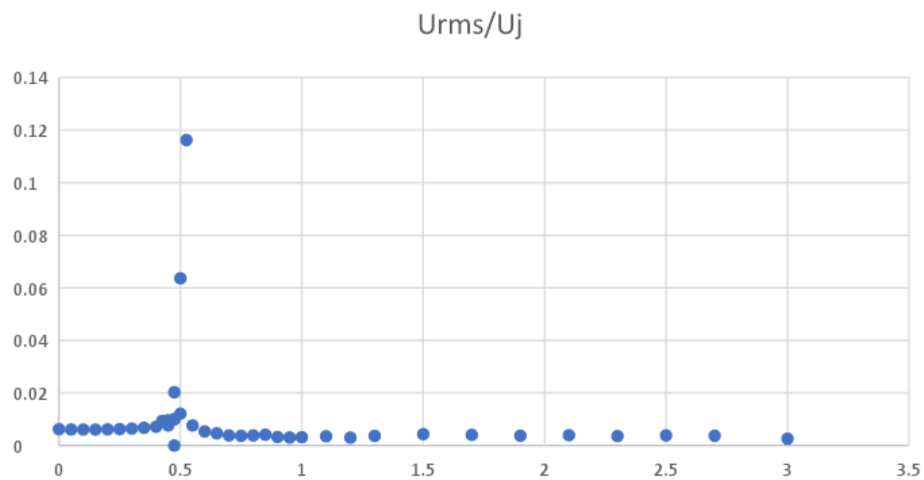
Velocity profile



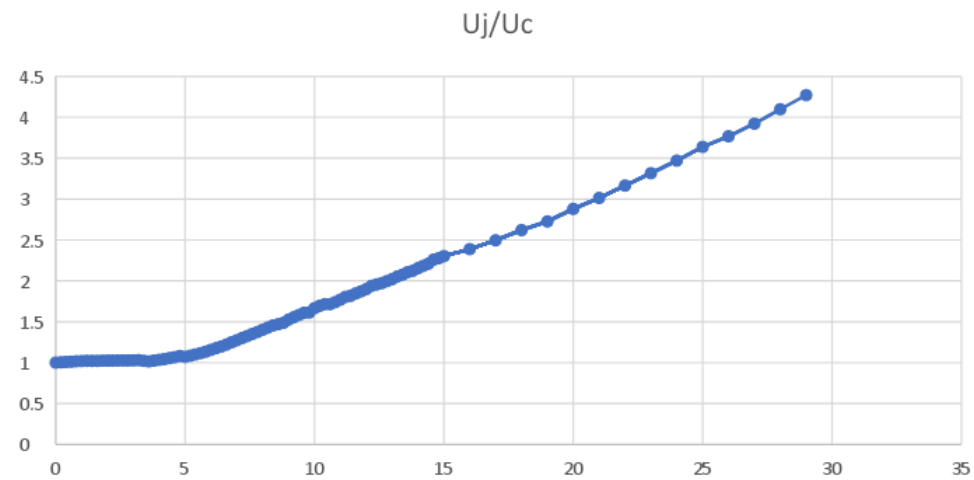
Turbulence intensity profile along lipline

Image Source: Anderson Proença (2019)

Turbulence intensity plot and mean centerline velocity decay plot



Turbulence intensity VS y/D, for 48m/s (lipline at 0.5y/D location)



Axial decay of centerline mean velocity for 48m/s
(Potential core location at X/D = 5)

Turbulence Velocity Spectra and Auto-correlation

Autocorrelation function for time scale

$$r(\tau) = \overline{\acute{u}(t)\acute{u}(t+\tau)}$$

Where, $\acute{u}(t)$ is the velocity fluctuations in time scale defined as: $\acute{u}(t)$ = U(t) - U_{mean}

U(t) is the instantons velocity and U_{mean} is the average velocity.

Normalized autocorrelation function:

$$R(\tau) = \frac{\overline{\acute{u}(t)\acute{u}(t+\tau)}}{\overline{\acute{u}^2}}$$

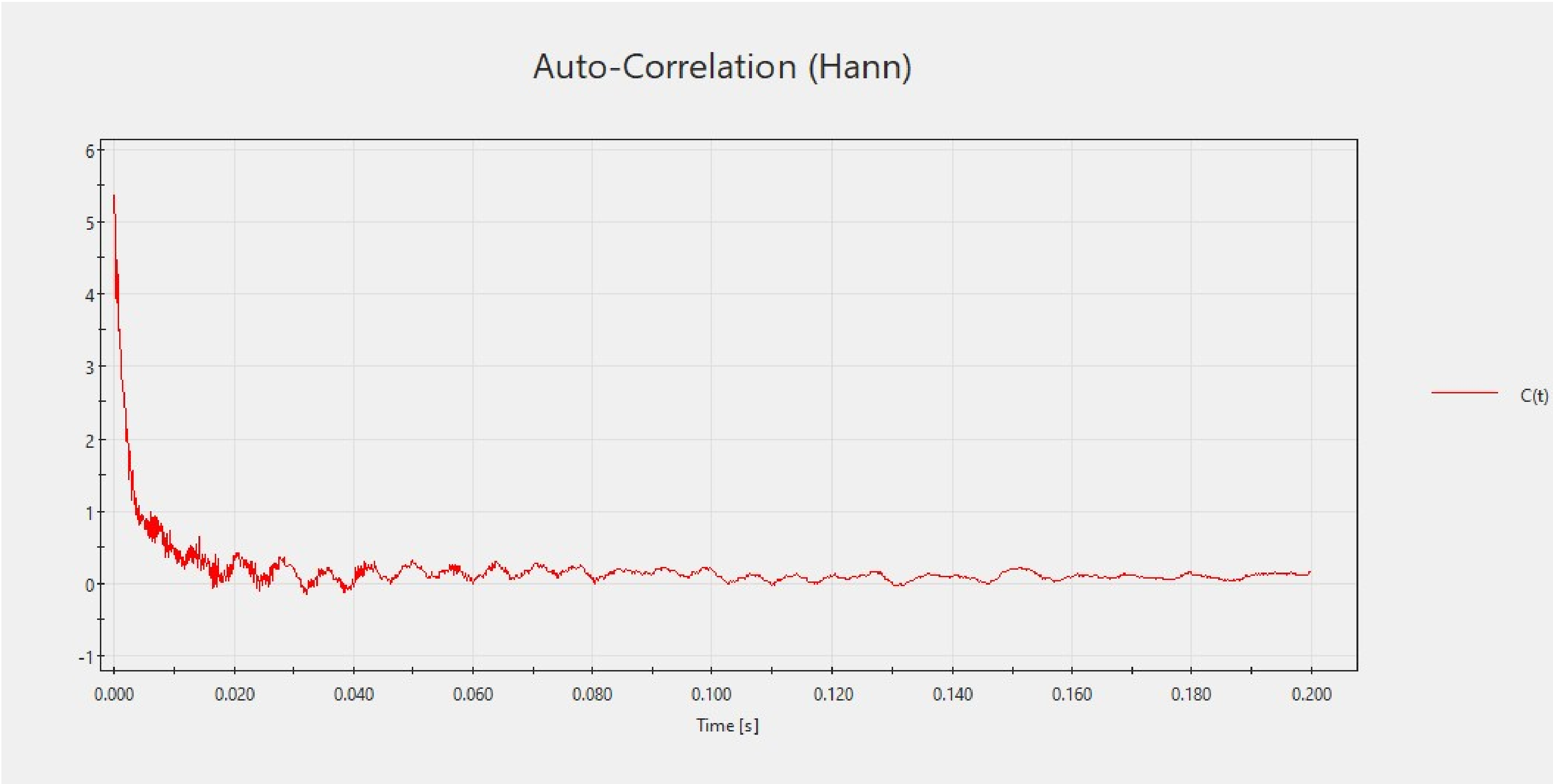
where, $\overline{\acute{u}^2}$ is square of rms(root mean square) value of $\acute{u}(t)$

Power Spectral Density (PSD) function:

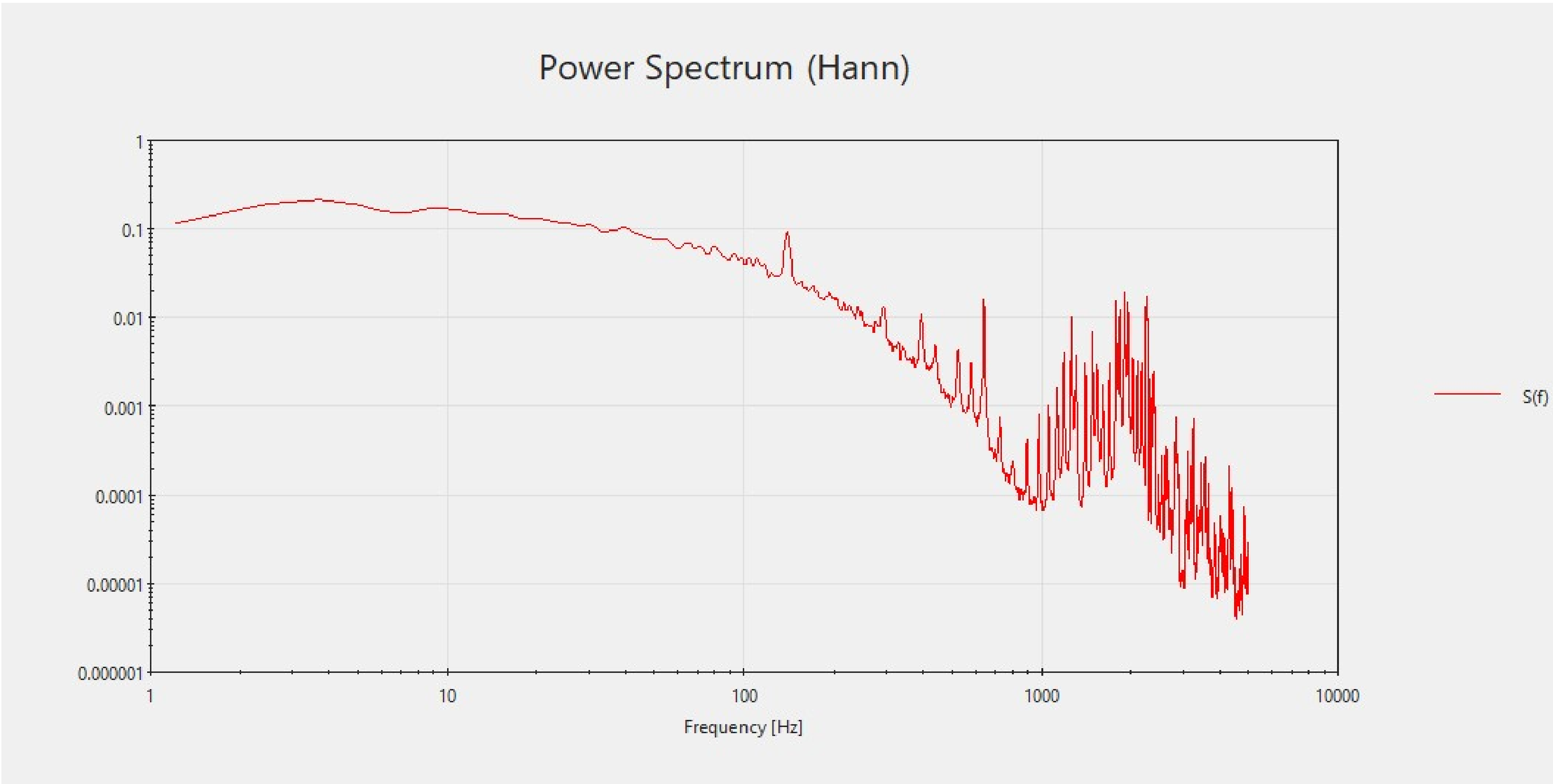
$$S(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} r(\tau)e^{-i\omega\tau}d\tau$$

Power spectra and autocorrelation, both are Fourier pairs. The PSD is obtained from Fourier transformation of autocorrelation function.

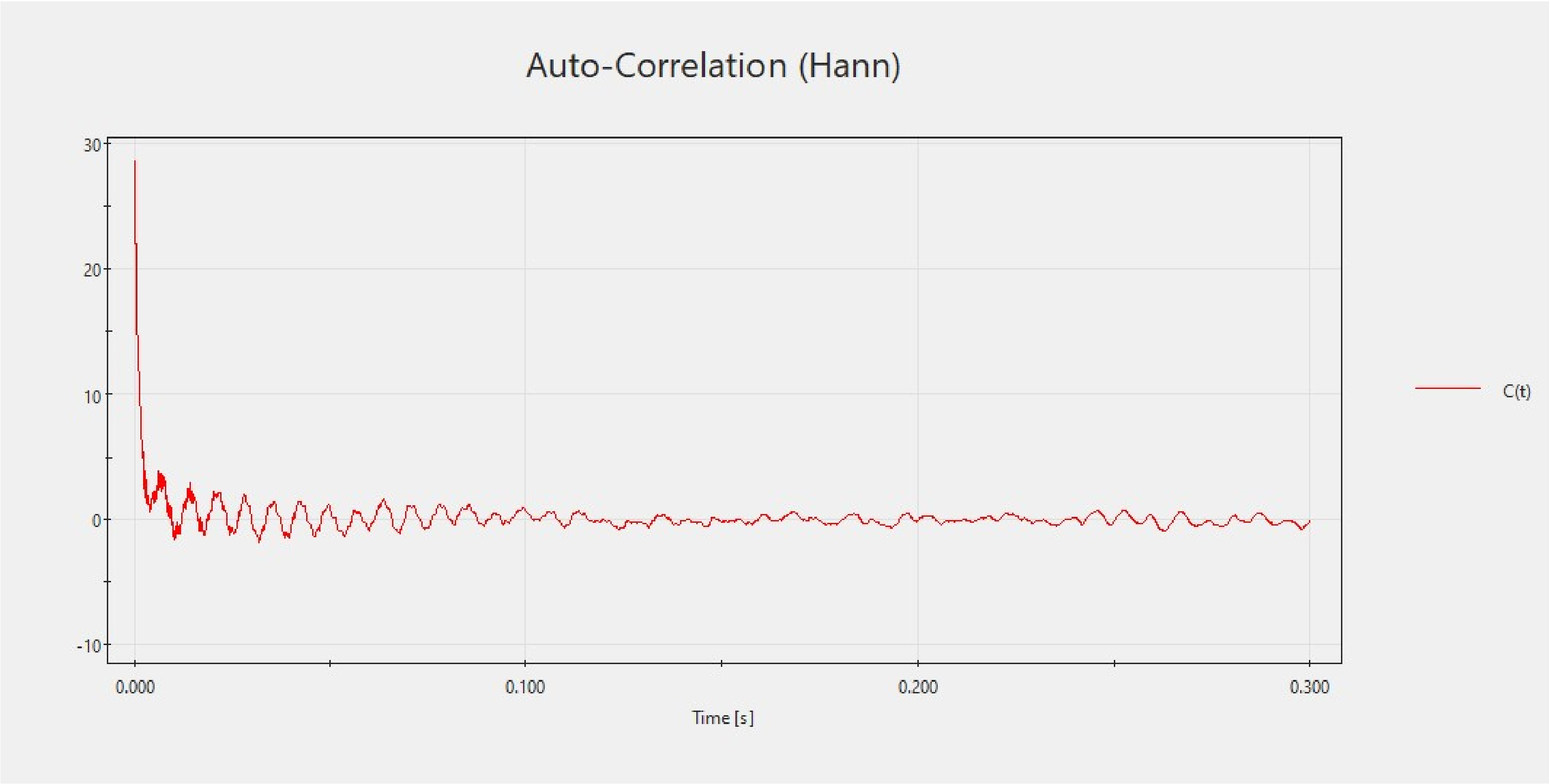
Auto-correlation for 48m/s velocity along the lipline at the nozzle exit (Y/D = 0.47)



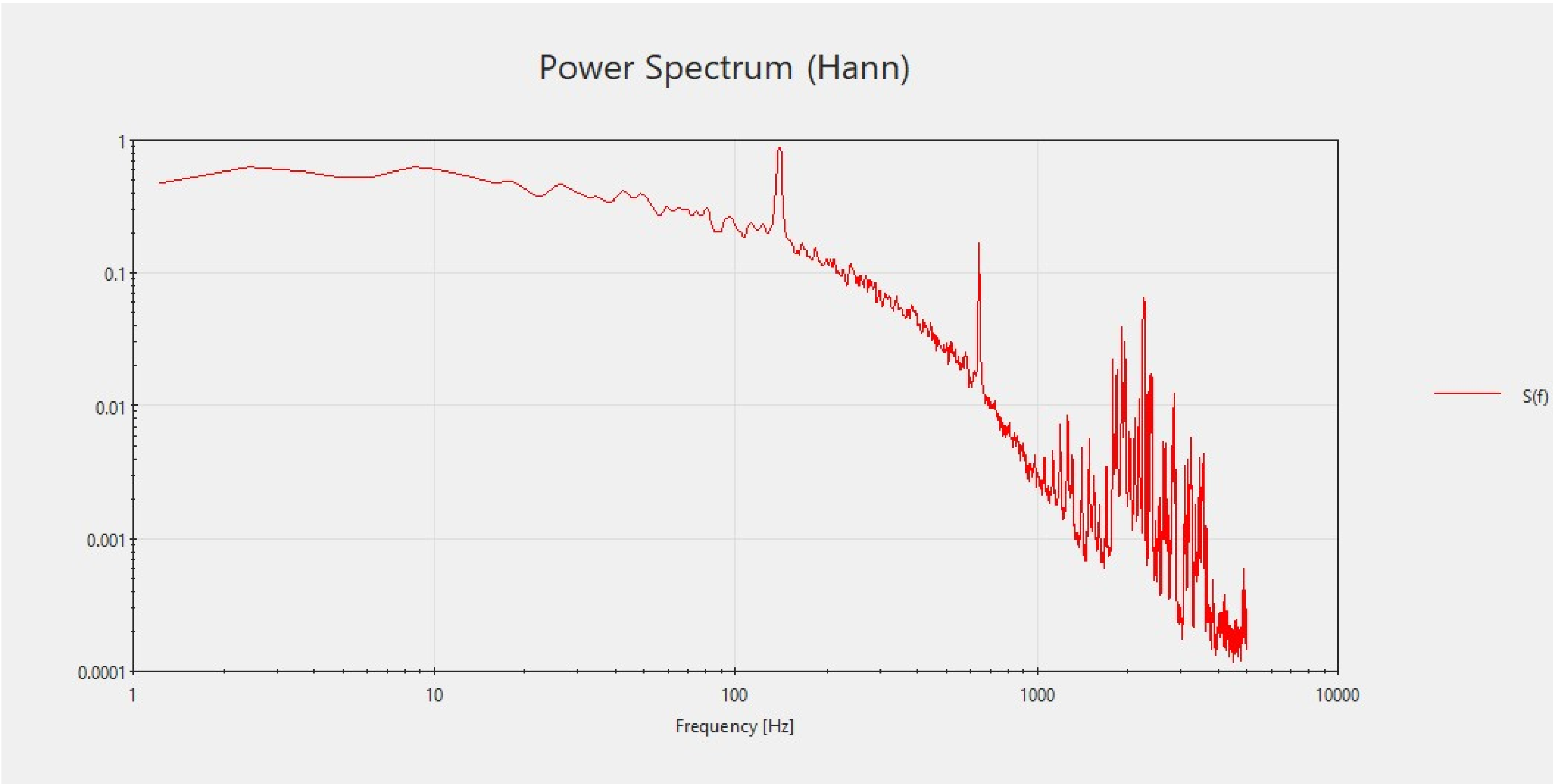
Power Spectrum for 48m/s velocity along the lipline at the nozzle exit (Y/D = 0.47)



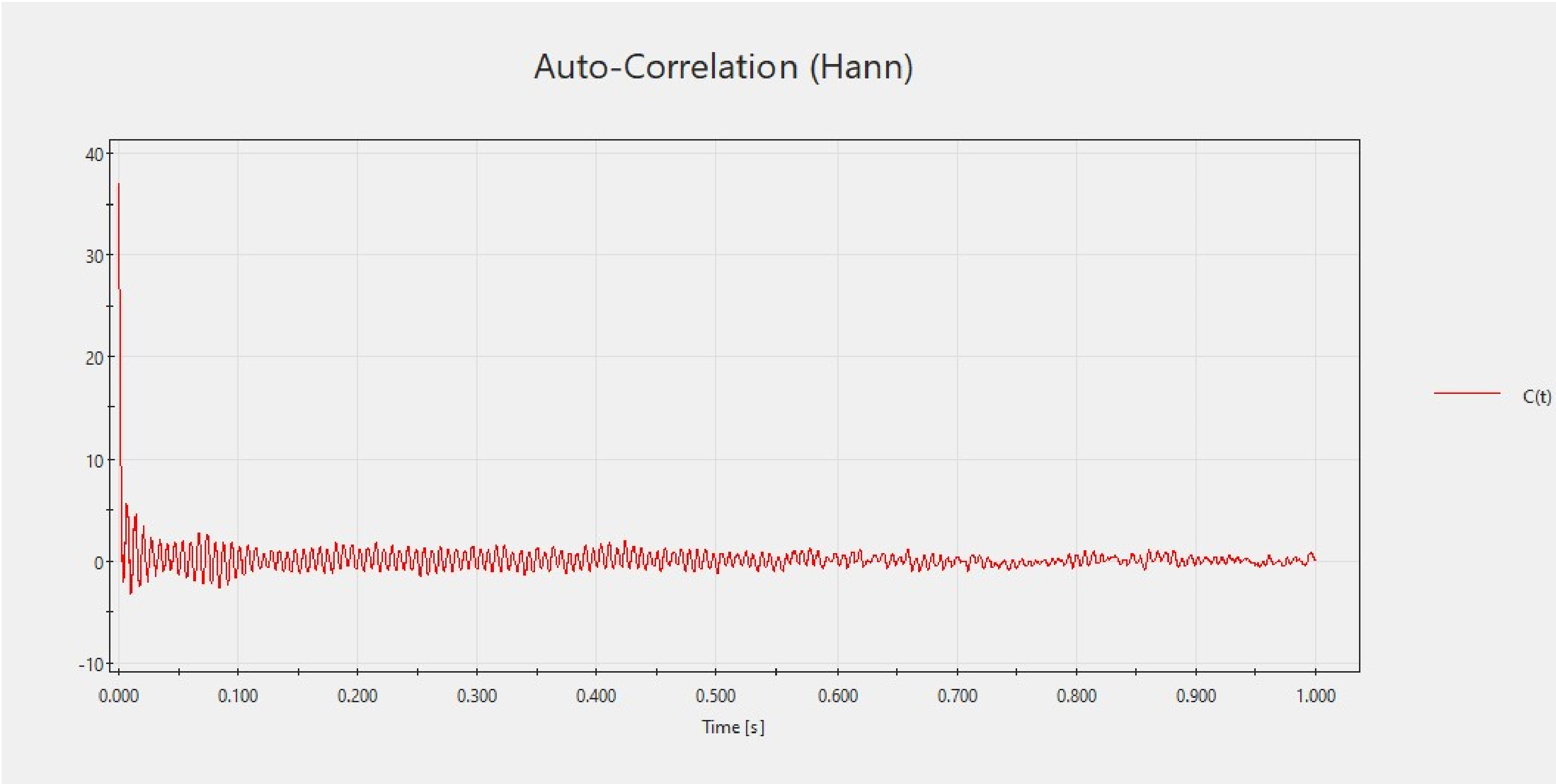
Auto-correlation for 80m/s velocity along the lipline at the nozzle exit (Y/D = 0.45)



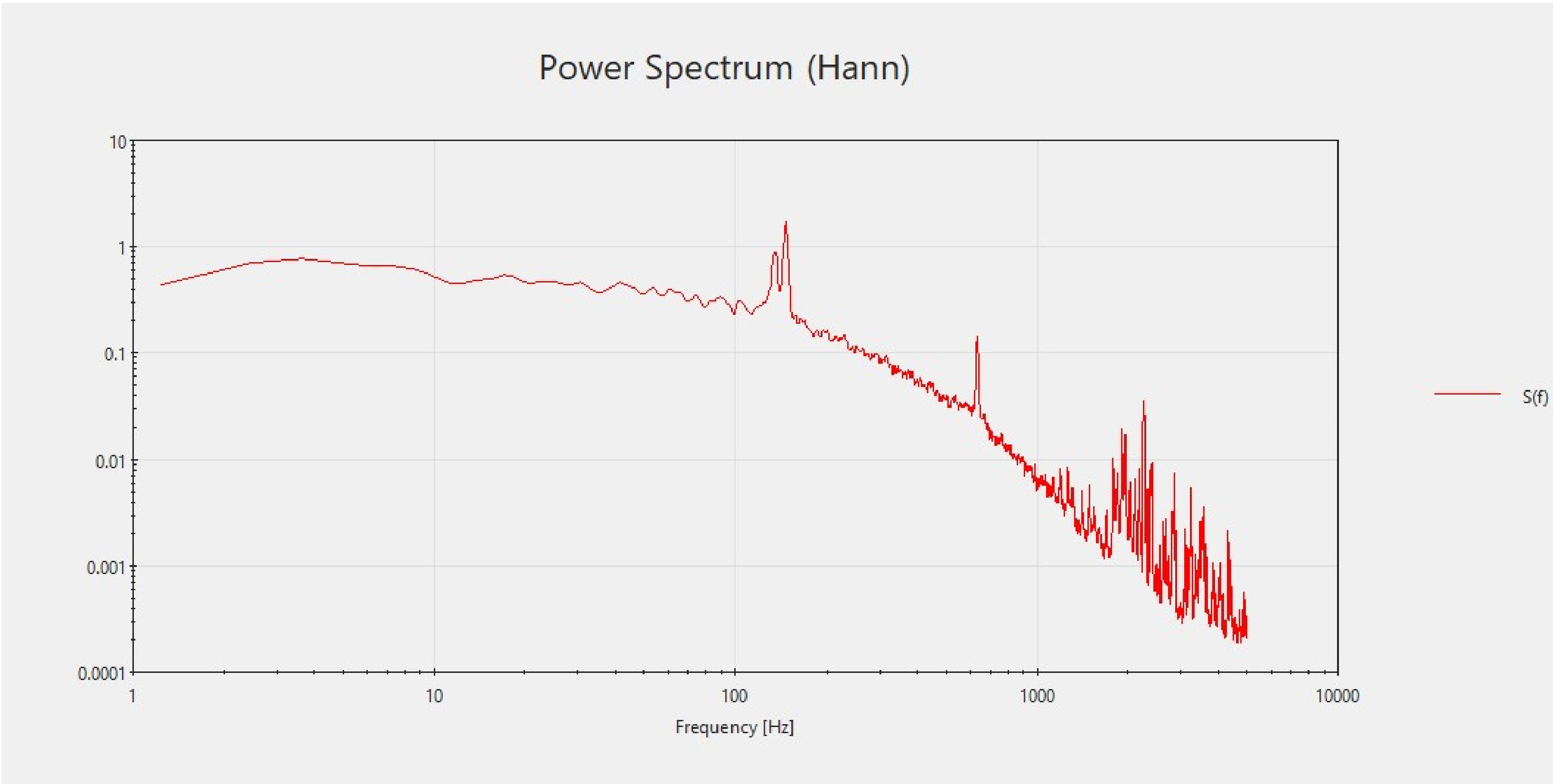
Power Spectrum for 80m/s velocity along the lipline at the nozzle exit (Y/D = 0.45)



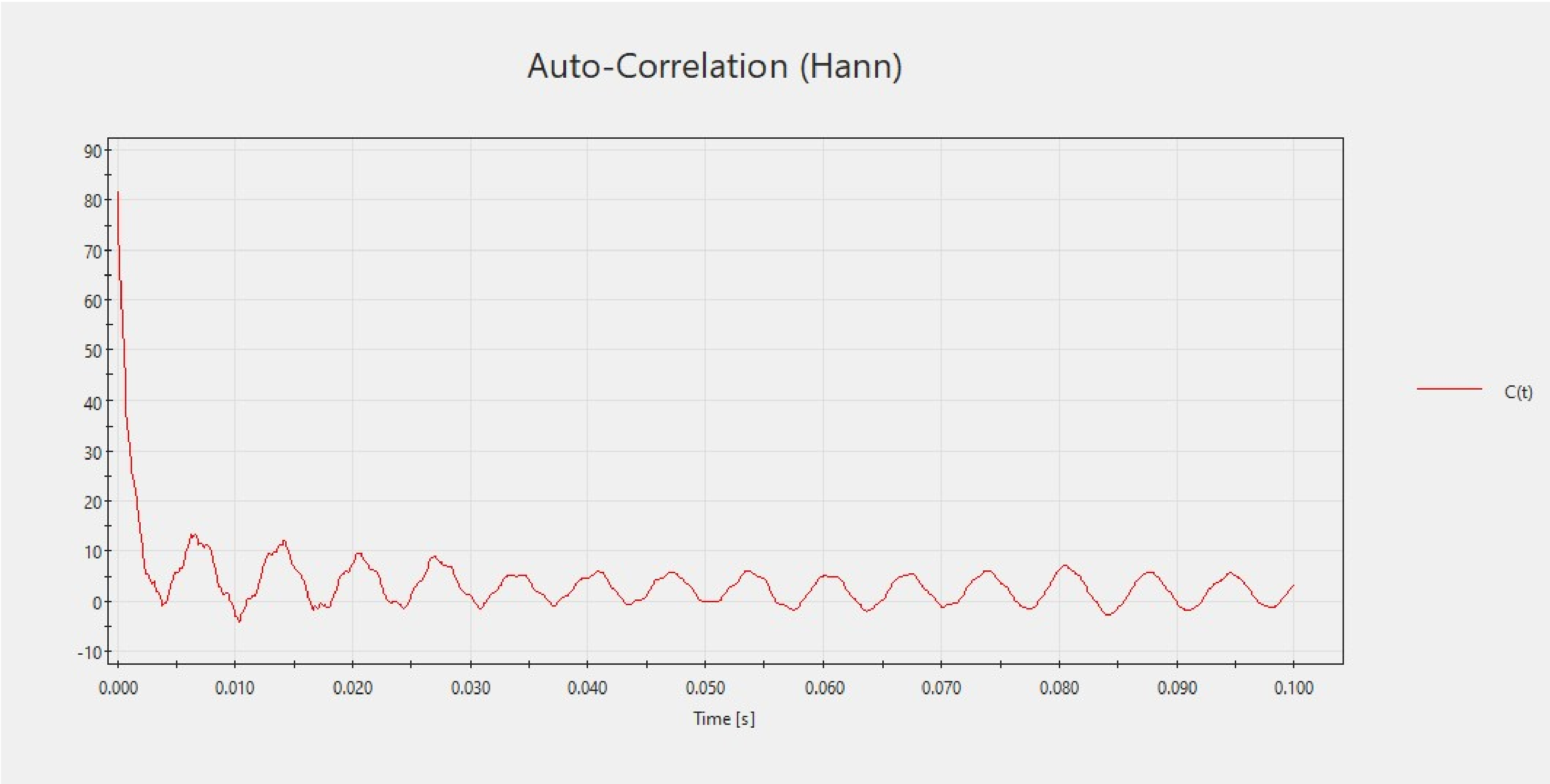
Auto-correlation for 100m/s velocity along the lipline at the nozzle exit (Y/D = 0.46)



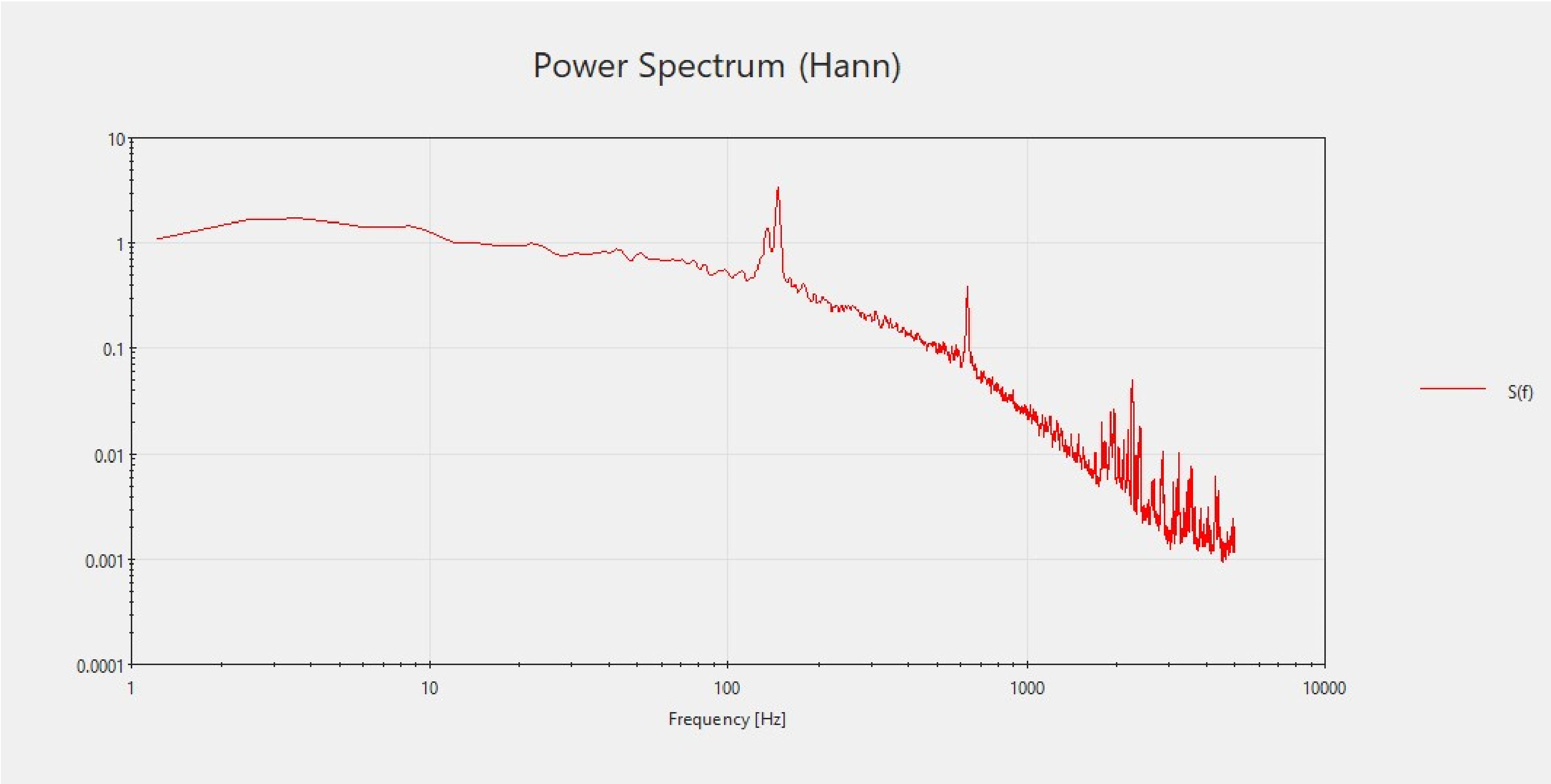
Power Spectrum for 100m/s velocity along the lipline at the nozzle exit (Y/D = 0.46)



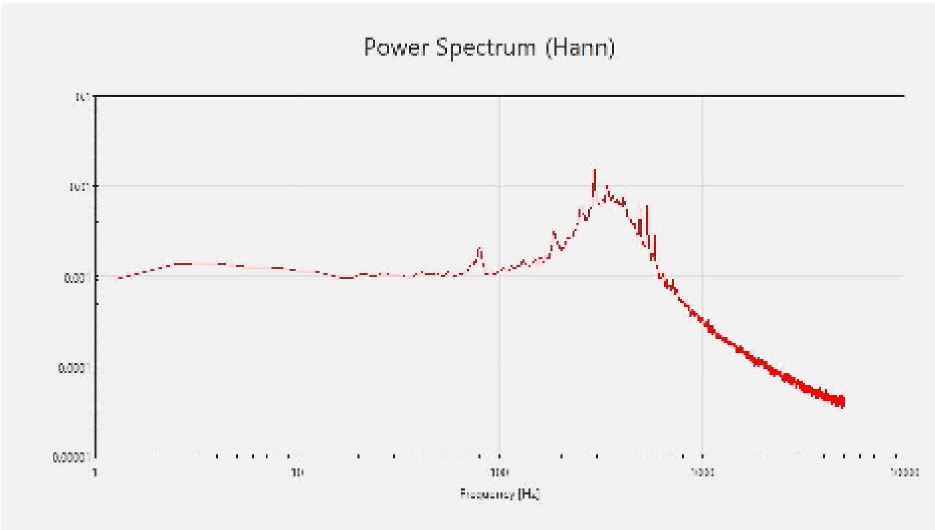
Auto-correlation for 120m/s velocity along the lipline at the nozzle exit (Y/D = 0.46)



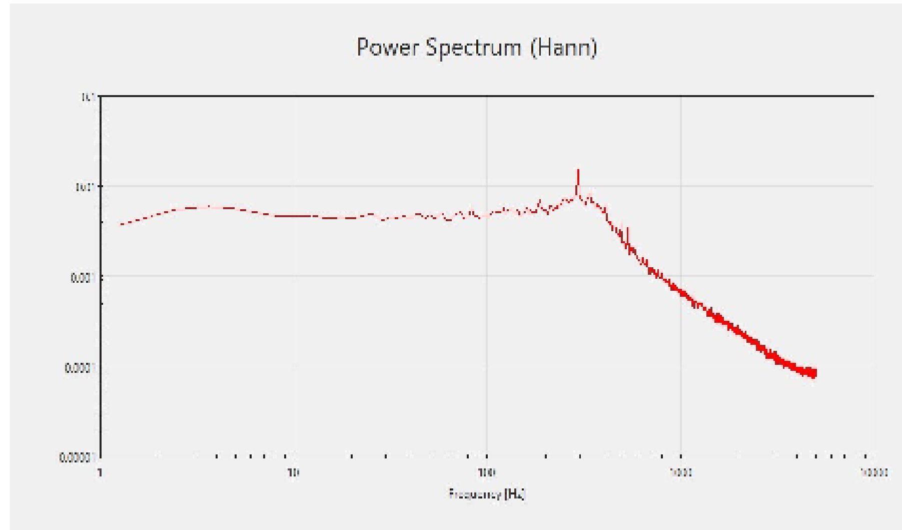
Power Spectrum for 120m/s velocity along the lipline at the nozzle exit (Y/D = 0.46)



The power spectrum for the point upstream of the potential core and at the potential core along the centerline for 15 m/s velocity

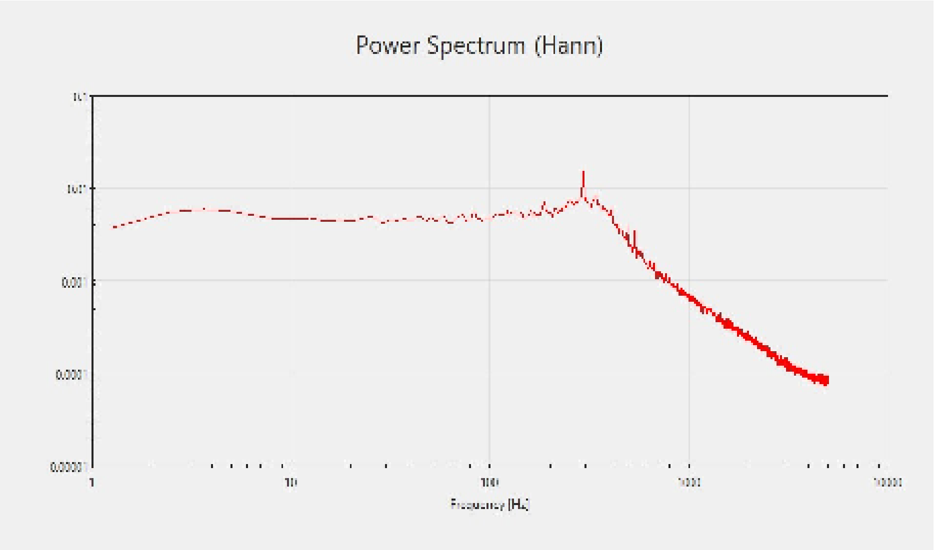


At, X/D = 3.4

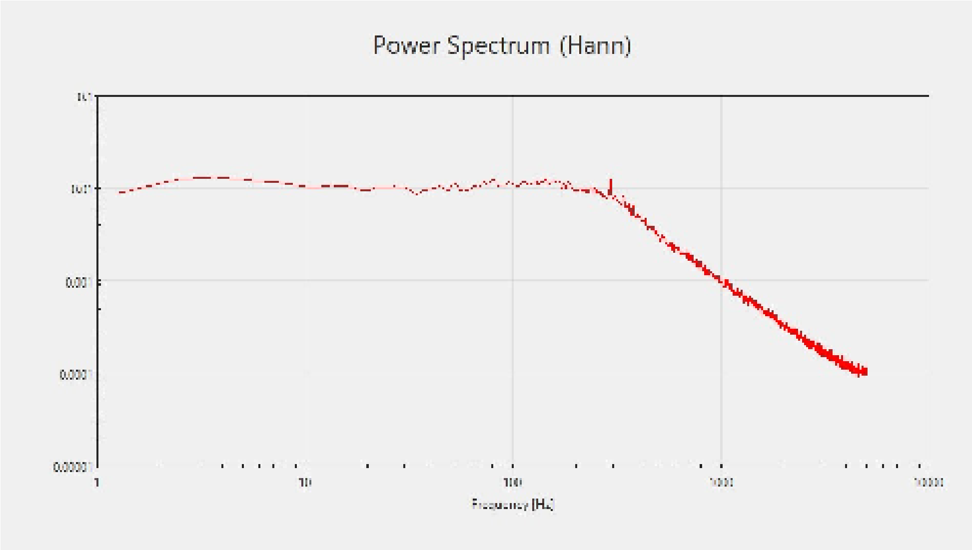


At, X/D = 4.4

The power spectrum for the point downstream of the potential core and at the potential core along the centerline for 15 m/s velocity

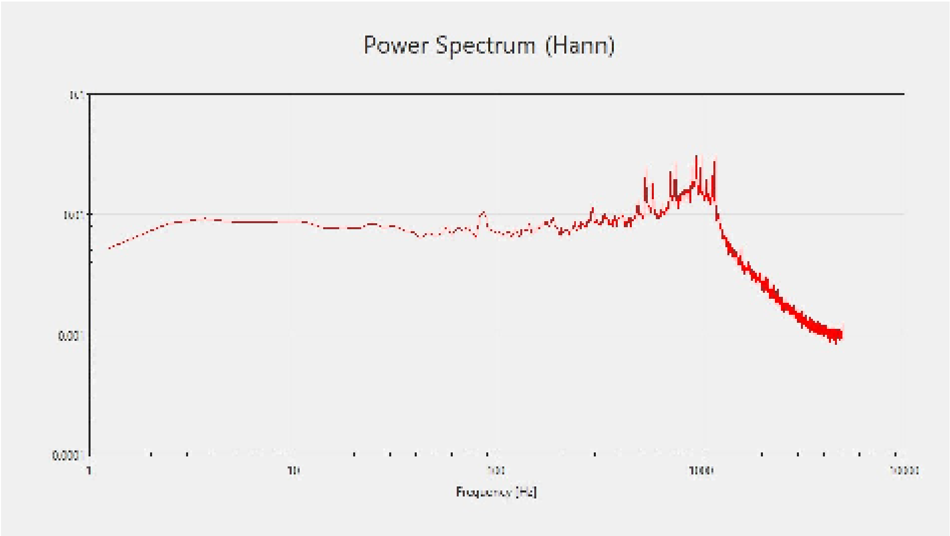


At, X/D = 4.4

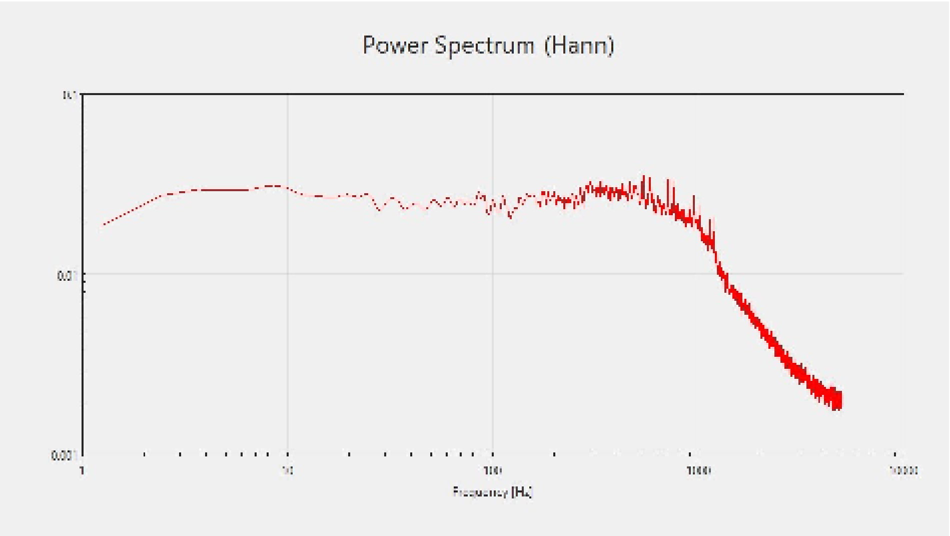


At, X/D = 5.4

The power spectrum for the point upstream of the potential core and at the potential core along the centerline for 48 m/s velocity

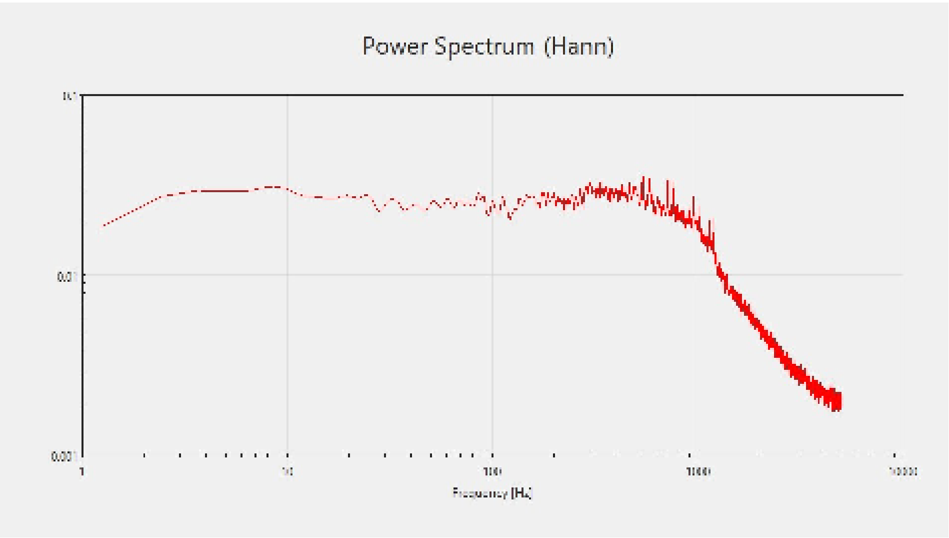


At, X/D = 4.2

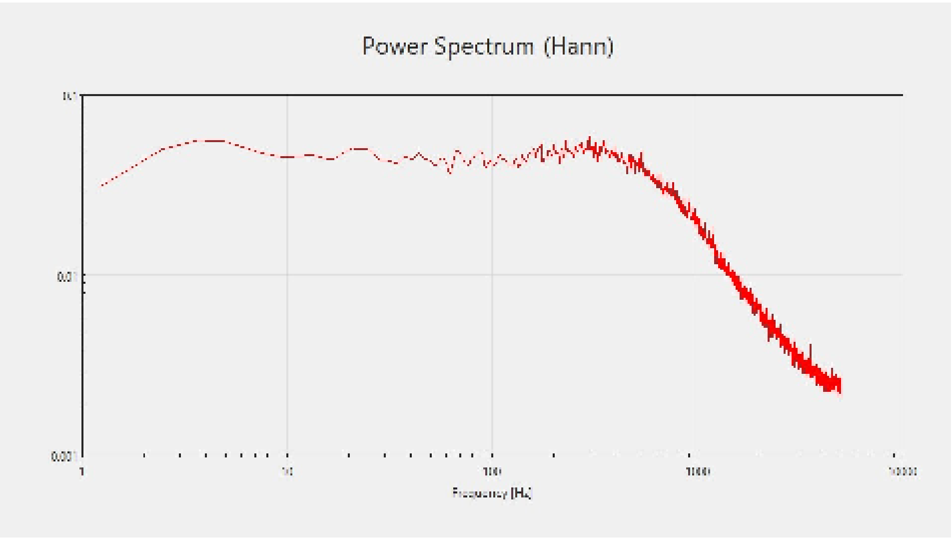


At, X/D = 5.2

The power spectrum for the point downstream of the potential core and at the potential core along the centerline for 48 m/s velocity

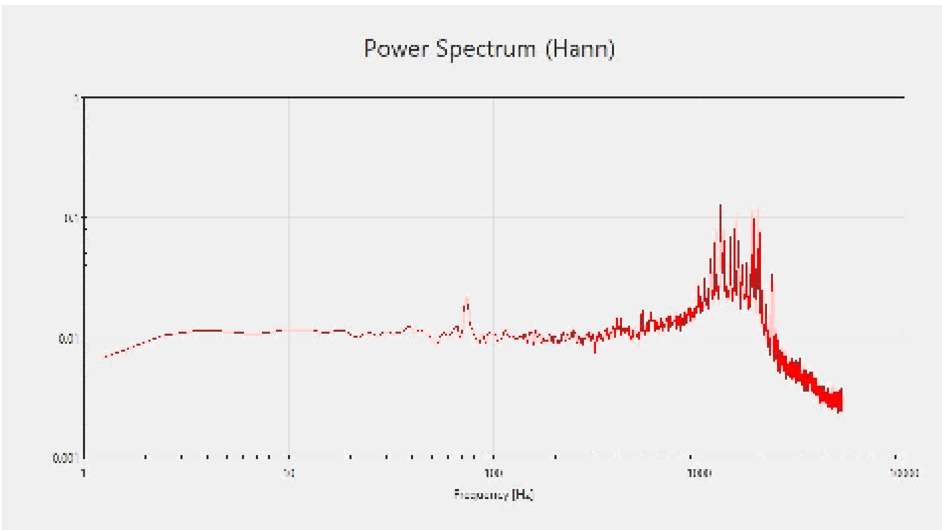


At, X/D = 5.2

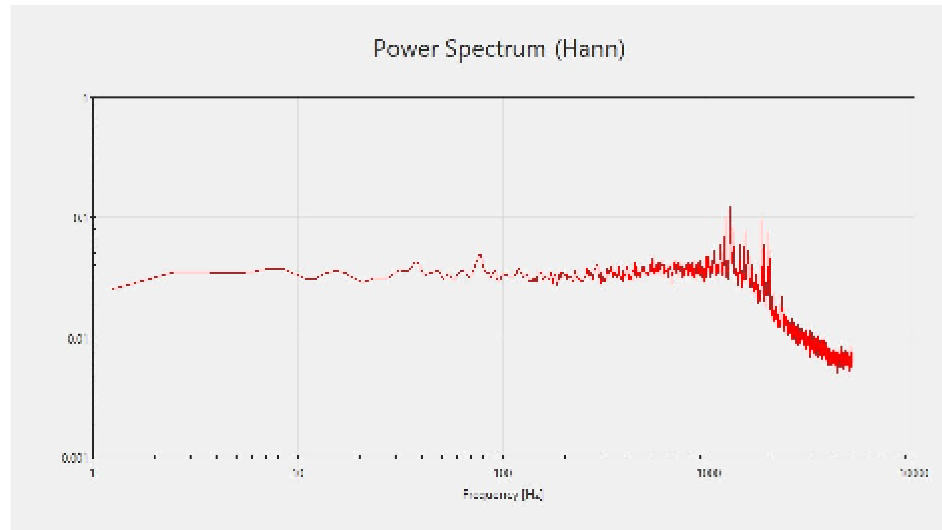


At, X/D = 6.2

The power spectrum for the point upstream of the potential core and at the potential core along the centerline for 80 m/s velocity

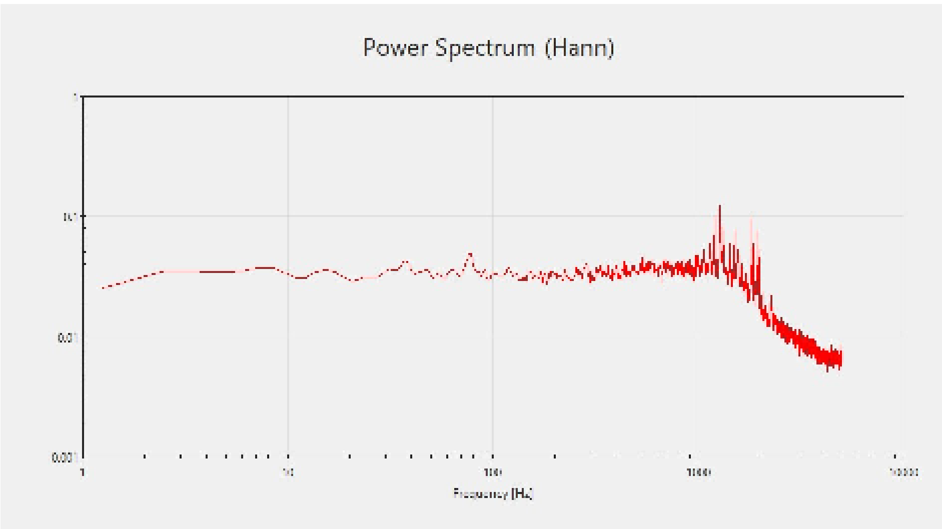


At, X/D = 4.0

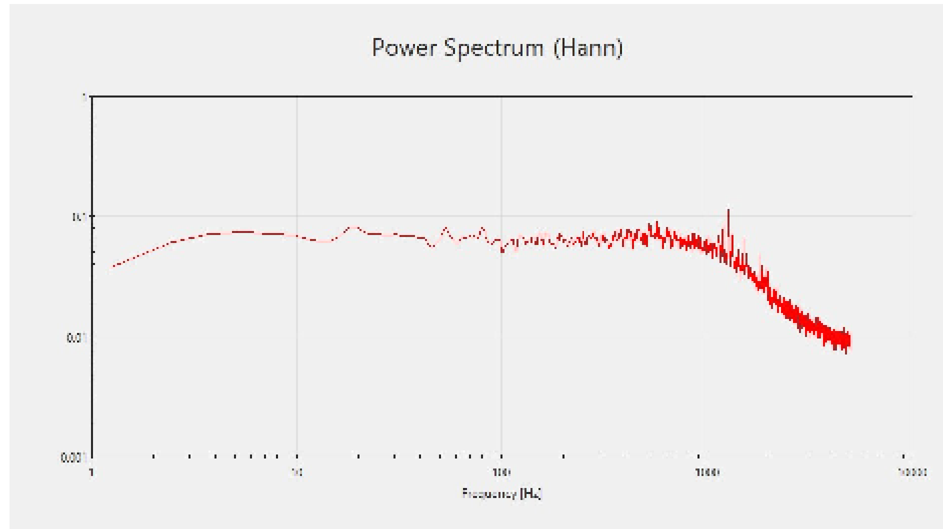


At, X/D = 5.0

The power spectrum for the point downstream of the potential core and at the potential core along the centerline for 80 m/s velocity

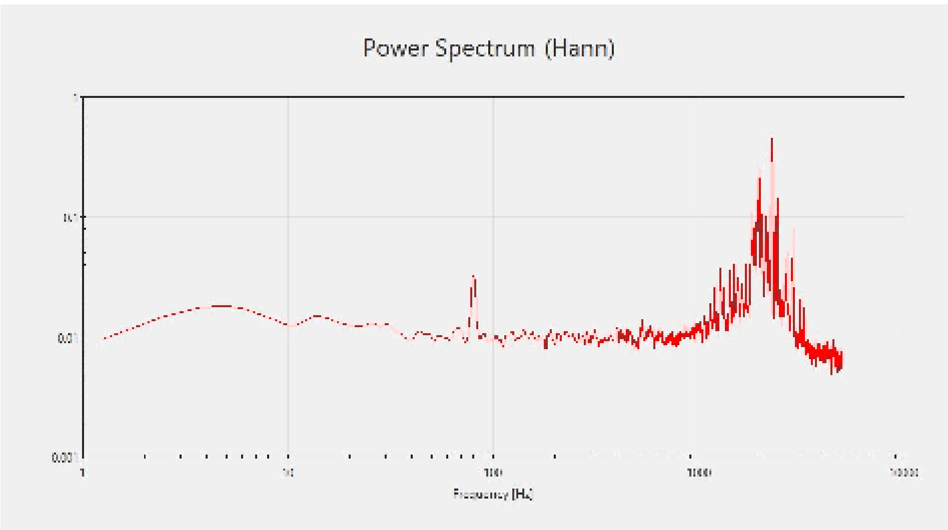


At, X/D = 5.0

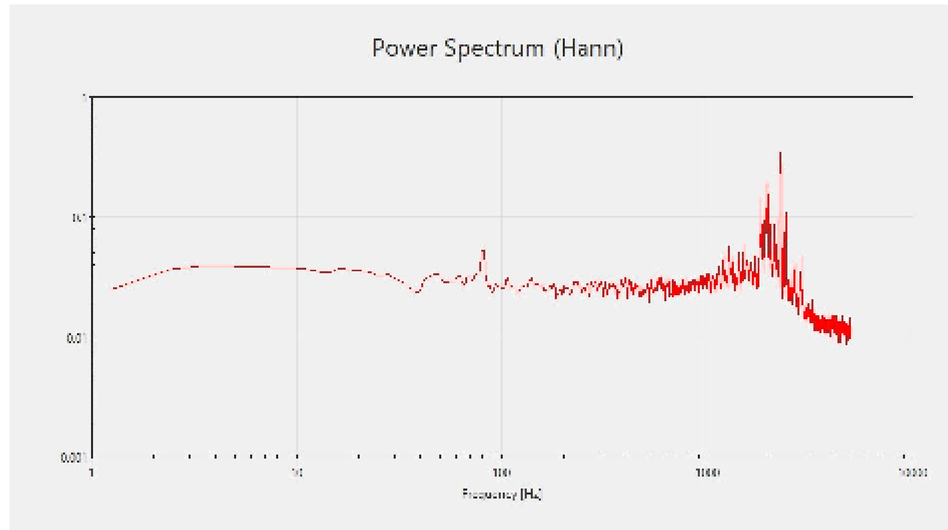


At, X/D = 6.0

The power spectrum for the point upstream of the potential core and at the potential core along the centerline for 120 m/s velocity

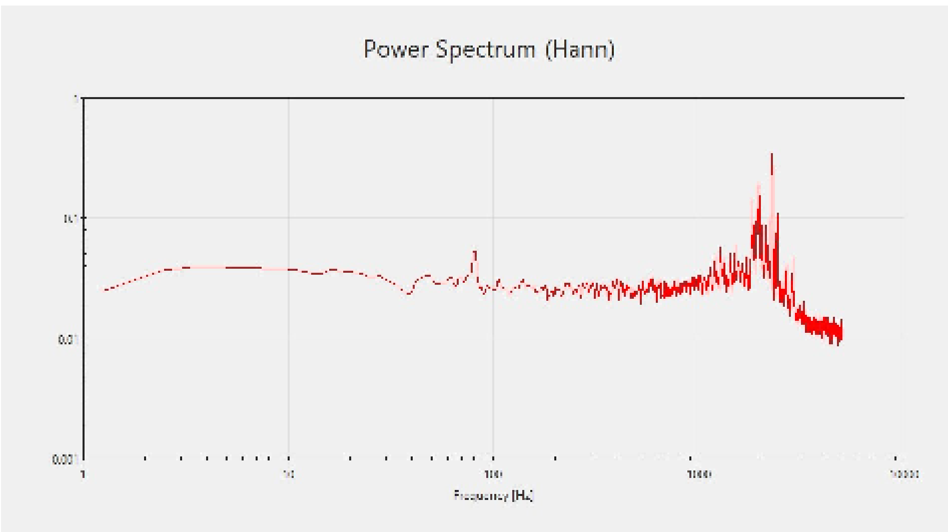


At, X/D = 4.0

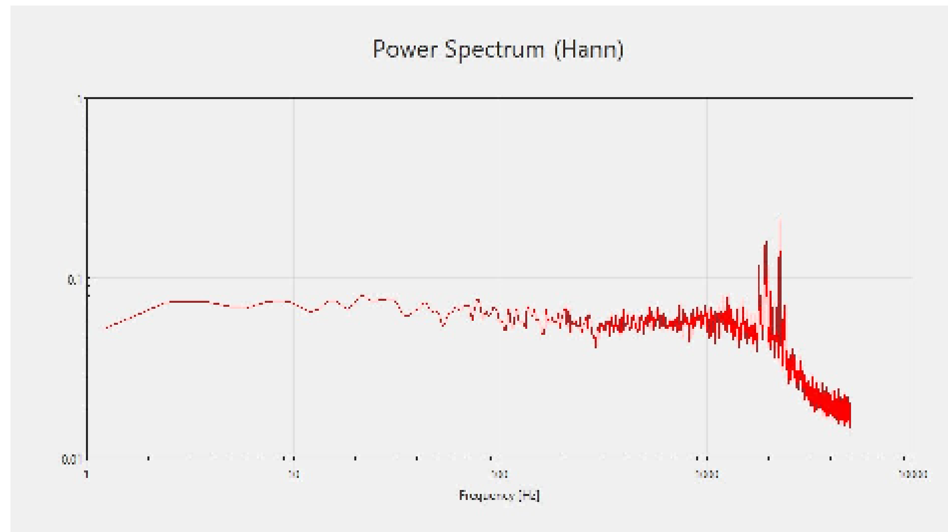


At, X/D = 4.8

The power spectrum for the point downstream of the potential core and at the potential core along the centerline for 120 m/s velocity



At, X/D = 4.8



At, X/D = 5.8

Strouhal number

- A non-dimensional parameter called Strouhal number for scaling the frequency and power spectral density amplitude, it is expressed as St

$$St = \frac{(F)(D)}{U_j}$$

Where F is the peak dominating frequency from PSD plot

D is the nozzle diameter

U_j is nozzle exit velocity.

Strouhal Number Calculation for different velocities at the potential core

Velocity in m/s	X/D location of potential core	Strouhal number
15	4.4	0.40
48	5.2	0.341
60	4.4	0.466
80	5	0.45
100	4.6	0.40
120	4.8	0.416

Conclusion

- The present Reynolds number range (20,000 – 160,000) falls after the critical Reynolds number $Re_d \approx 10,000$ from *J. Mi* (2013), that have a close agreement with the independence of the Reynolds number with mean centerline velocity decay and spread.
- The Strouhal number was found to have very small variations with the Reynolds number, giving no effect of the Reynolds number on the number of vortices formed in the jet flow. This agrees well with what is mentioned in (2009) *Andrew pollard*.