# Effect of control discretization on streamwise traveling waves of spanwise wall velocity

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Since their introduction, streamwise traveling waves (StTW) [1] represented a promising open-loop turbulence control strategy. In the years, the effect of StTW in a turbulent pipe flow was studied experimentally [2], dividing the wall into thin slabs rotating with different velocities. Despite substantial overall agreement in the control behavior, differences exist between numerical and experimental results in specific regions of the frequency-wavenumber space. The authors linked these differences to the discrete spatial waveform approximating the continuous wave. Recently, Marusic and coworkers [3] performed experiments of a controlled boundary layer up to $Re_\tau = 12800$ using a discrete setup similar to the one described by Auteri et al.

Few studies highlight the effect of discretization on control performance. In the following, we present a selection of the results obtained by different Direct Numerical Simulations of a turbulent pipe flow subjected to three types of control: the continuous sine (sin) and sinusoidal waves discretized with three (s3) and six segments (s6). Fig. 1-a shows the effect of discretization in the drag reduction, measured in case of constant flow rate as $R = 1 - C_f/C_{f,0}$. As expected, by increasing the number of elements approximating the continuous function, the discretization effects reduce, as s3 substantially differs from sin. The main differences are two: first, for negative frequencies, s3 and s6 show clear wiggles missing in the continuous control. Second, at the positive frequencies where typically drag increase occurs, s3 exhibits a reduction of R but never a negative value. Incidentally, the discretization prevents also the relaminarization occurring at frequency $\omega^+ = 0.02$. Clearly, as shown by Fig. 1-b, the loss of the control continuity affects also $\overline{uu}^+$, $\overline{vv}^+$, and $\overline{uv}^+$.

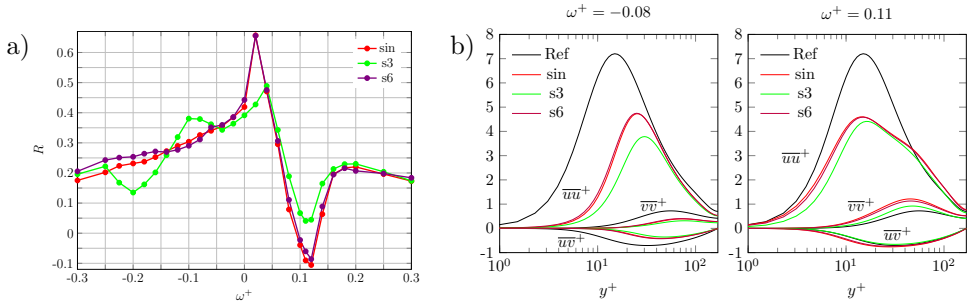


Figure 1: (a) $R$ for three types of control: continuous sine (sin) and sinusoidal waves discretized with three (s3) and six segments (s6). $\omega^+$ varies while $\kappa_x^+ = 8.4 \cdot 10^{-3}$ (b) Wall-normal profile of Reynolds normal and shear stresses.

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[1] Quadrio et al., *J. Fluid Mech* **627**, 161 (2009).
[2] Auteri et al., *Phys. Fluids* **22**, 115103 (2010)
[3] Maurusic et al., *Nat. Commun.* **12**, 5805 (2021)