A study on the energy transfer of a square prism under fluid-elastic galloping

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Abstract

Extracting useful energy from flow induced vibrations has become a developing area of research in recent years. In this paper, we analyse power transfer of an elastically mounted body under the influence of fluid-elastic galloping. The system and the power transfer is analysed by numerically integrating the quasi-steady state model equations and direct numerical simulations. The power transfer is analysed for both high ($Re = 22300$) and low ($Re = 200$) Reynolds numbers cases.

The linear analysis of the model equation shows that the system is governed by two parameters, namely the combined mass-stiffness parameter Π_1 and the combined mass damping parameter Π_2. A combined mass-damping coefficient, Π_2, that can be derived from the equation of motion, is shown to be the parameter that governs power output. The system is a balance between the power delivered to the system due to fluid-dynamic forcing and power removed through mechanical damping which are governed by the fluid-dynamic forcing characteristics (i.e. the lift force as a function of incident angle) and mechanical damping coefficient as represented by Π_2 respectively. Comparing the DNS results with the QSS data uncovered that a good agreement of the data could be obtained even at low Reynolds numbers when the mass-stiffness,Π_1, is high representing a high mass to stiffness ratio. At low Π_1, the system shows a significant response to forces associated with shedding and this is shown to suppress the galloping response.

Keywords:

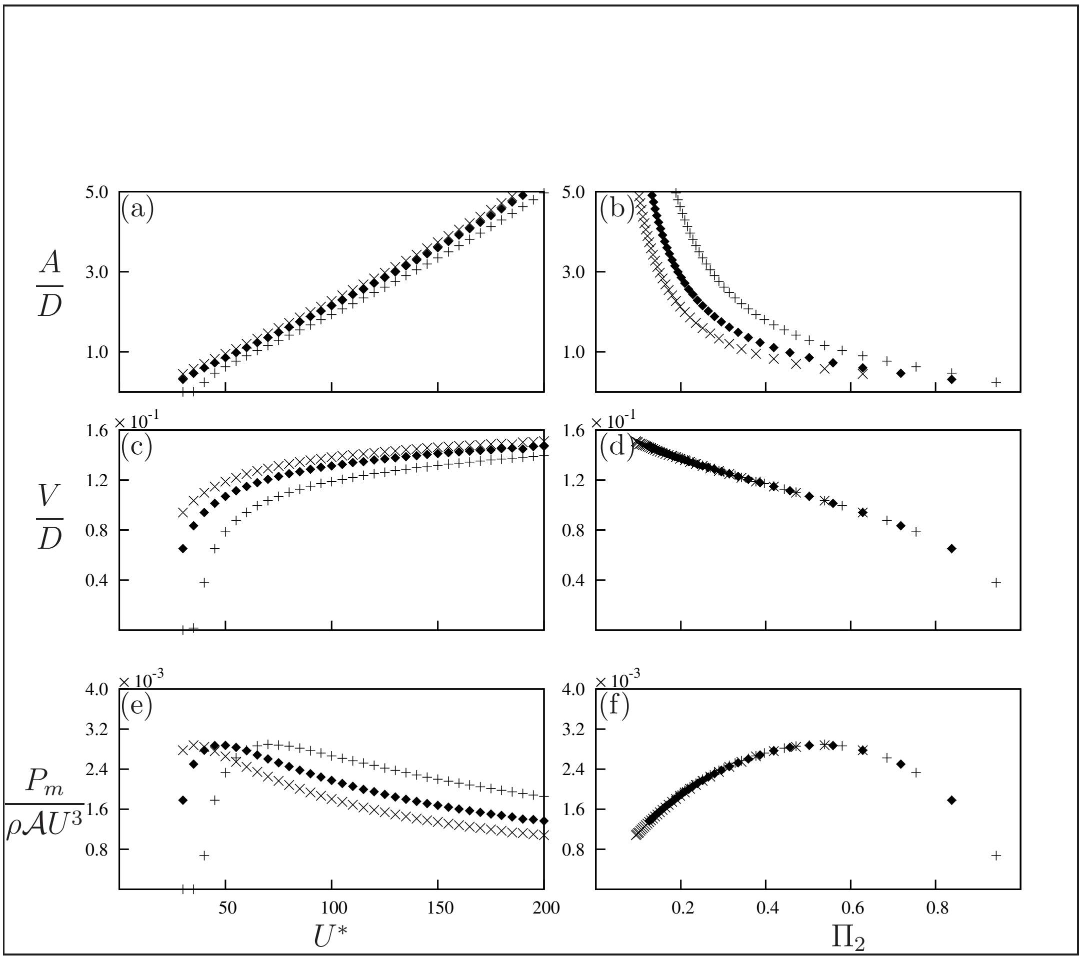

Figure 1: Displacement amplitude, velocity amplitude and mean power data as functions of two different independent varibles. Data presented in (a), (c) and (e) using the classical VIV parameter U^*, obtained at $Re = 200$ and $m^* = 20$ at three different damping ratios: $\zeta = 0.075$ ($\times$), $\zeta = 0.1$ ($\blacklozenge$) and $\zeta = 0.15$ ($+$). (b) (d) and (f) are the same data presented using the combined mass-damping parameter (Π_2) as the independent variable.

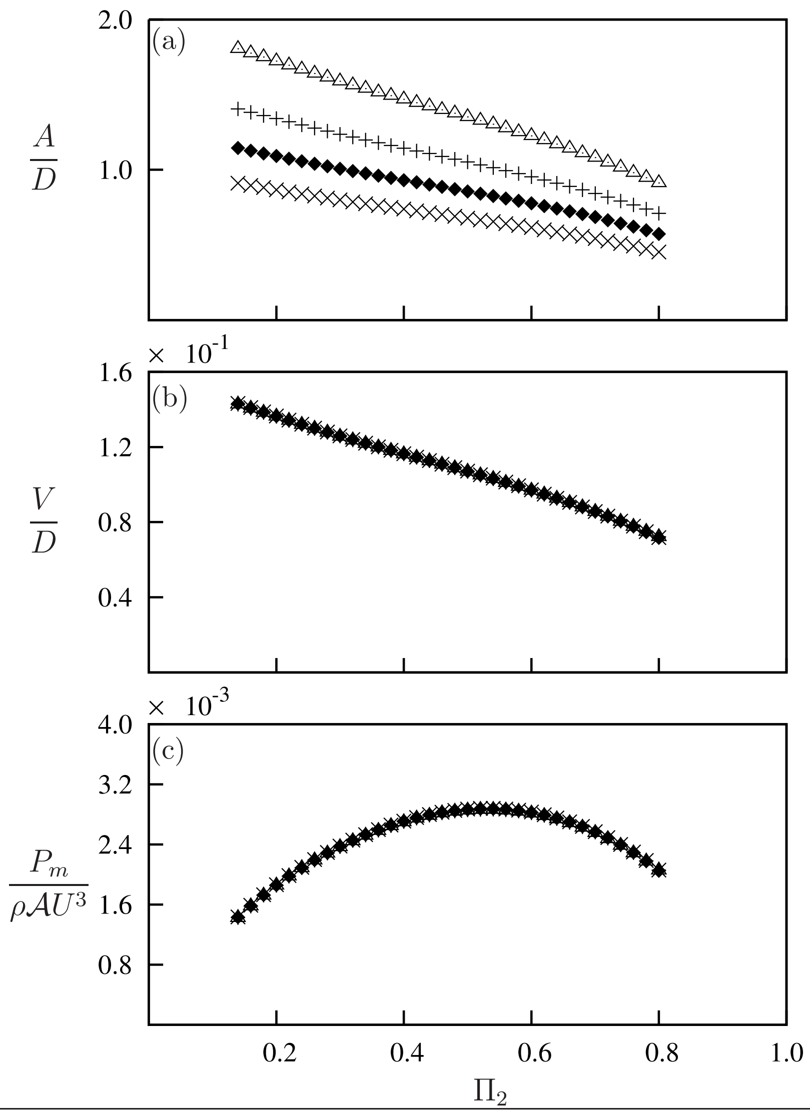

Figure 2: QSS data at high Π_1 levels. (a) displacement amplitude, (b) velocity amplitude and (c) mean power as a function of Π_2. Data presented at four different combined mass-stiffness levels. $\Pi_1 = 10$ $(m^* = 20,\ U^* = 40)$ $(\times)$, $\Pi_1 = 100$ $(m^* = 80,\ U^* = 50)$ $(+)$, $\Pi_1 = 500$ $(m^* = 220,\ U^* = 60)$ $(\blacklozenge)$ and $\Pi_1 = 1000$ $(m^* = 400,\ U^* = 40)$ $(\triangle)$.

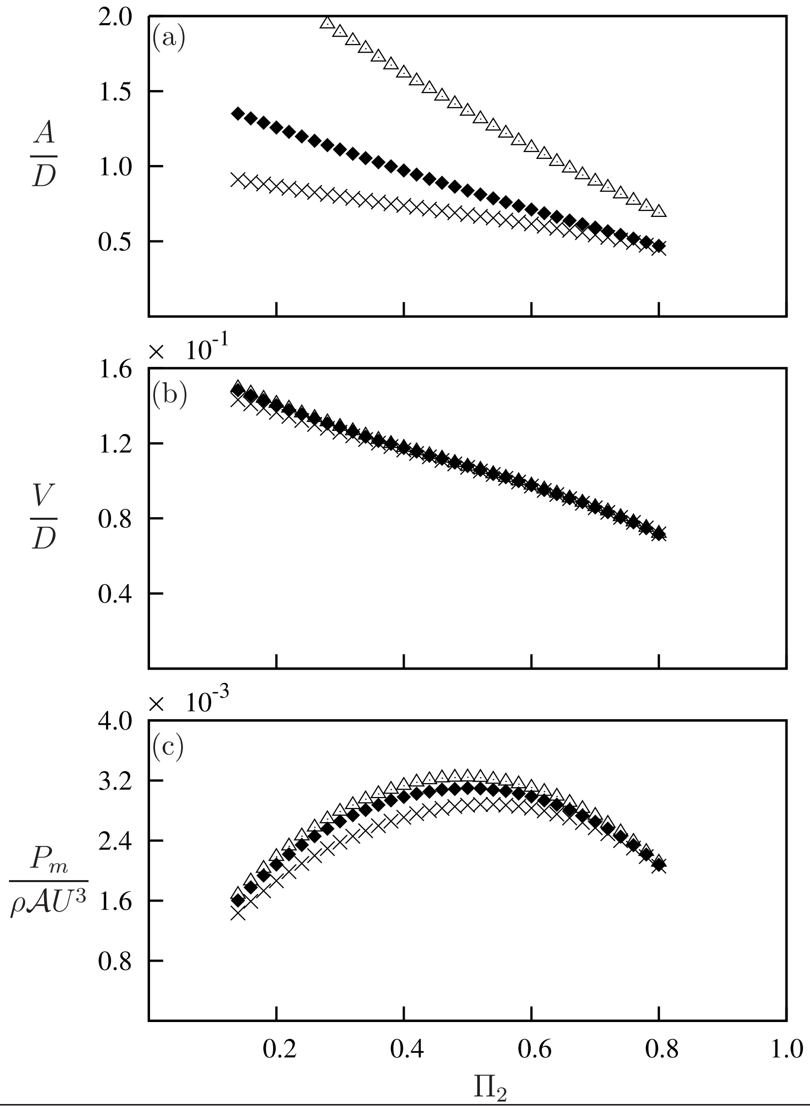

Figure 3: QSS data at high and low Π_1. (a) displacement amplitude, (b) velocity amplitude and (c) mean power as a function of Π_2. Data presented at $\Pi_1 = 10$ ($\times$), $\Pi_1 = 0.1$ ($\blacklozenge$), and $\Pi_1 = 0.05$ ($\triangle$).

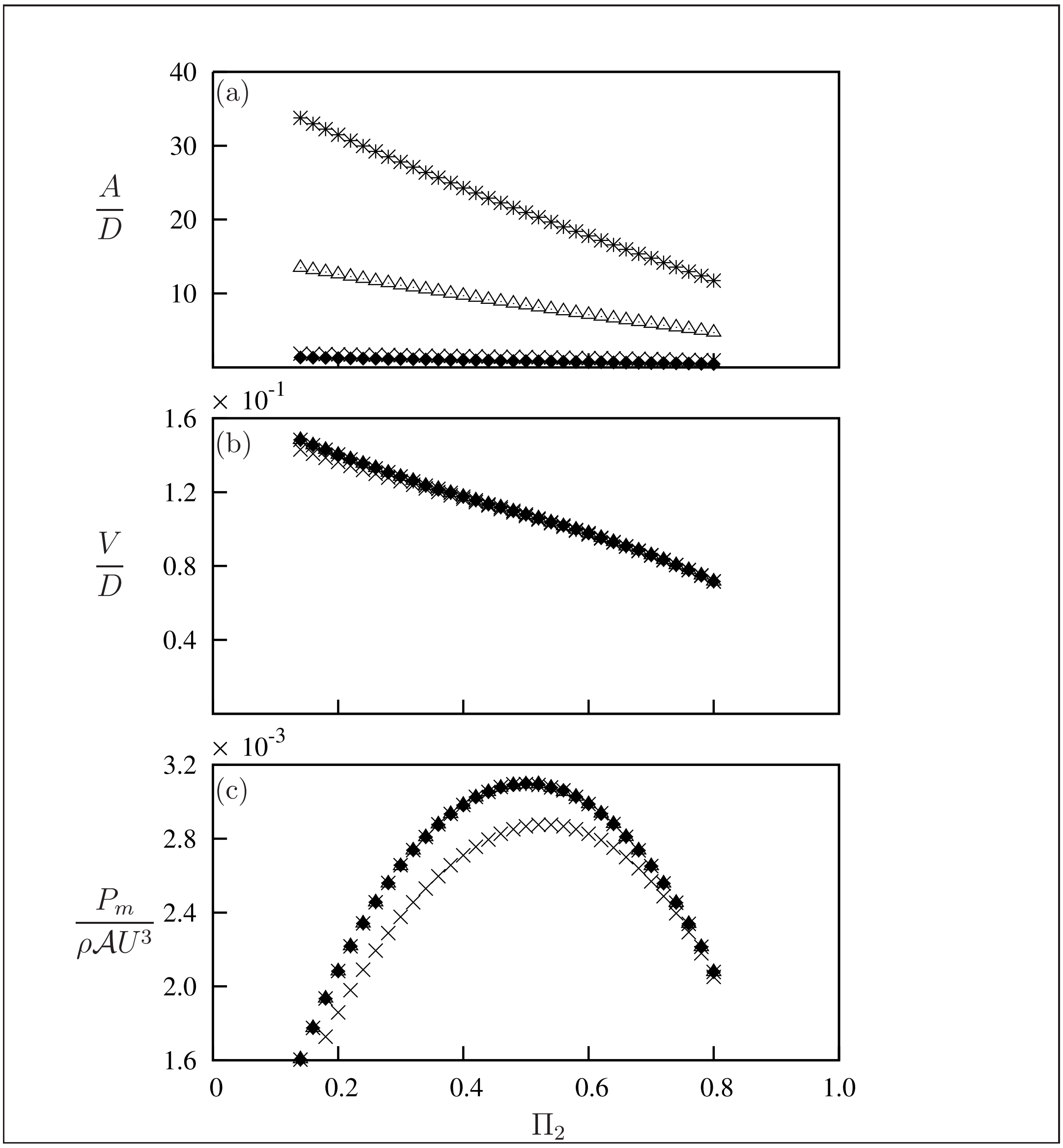

Figure 4: Comparison of QSS data at high and low Π_1. (a) displacement amplitude, (b) velocity amplitude and (c) mean power as a function of Π_2. Data presented at $\Pi_1 = 100$ ($\times$) $m^* = 130(+)$, $\Pi_1 = 0.1$ $m^* = 2$ (◆), $\Pi_1 = 0.1$ $m^* = 20$ ($\triangle$) and $\Pi_1 = 0.1$ $m^* = 50$ ($*$). The mass ratio does not have an effect on $\Pi_1$even at low Π_1

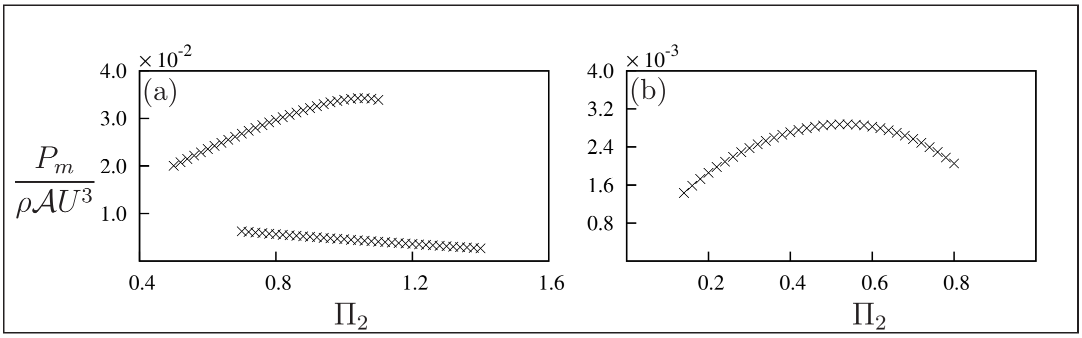

Figure 5: Mean power as a function of Π_2. Data presented at (a) $Re = 22300$, $\Pi_2 = 20000$ and (b) $Re = 200$, $\Pi_2 = 100$. Hysteresis could be observed at high Re

Π_1	% error
10	30.19%
60	10.71%
250	5.48%
1000	1.16%

Table 1: Error values of power between QSS and DNS data calculated using equation **??** at different $\Pi_1$and Π_2. data obtained at $U^* = 40$ and $Re = 200$

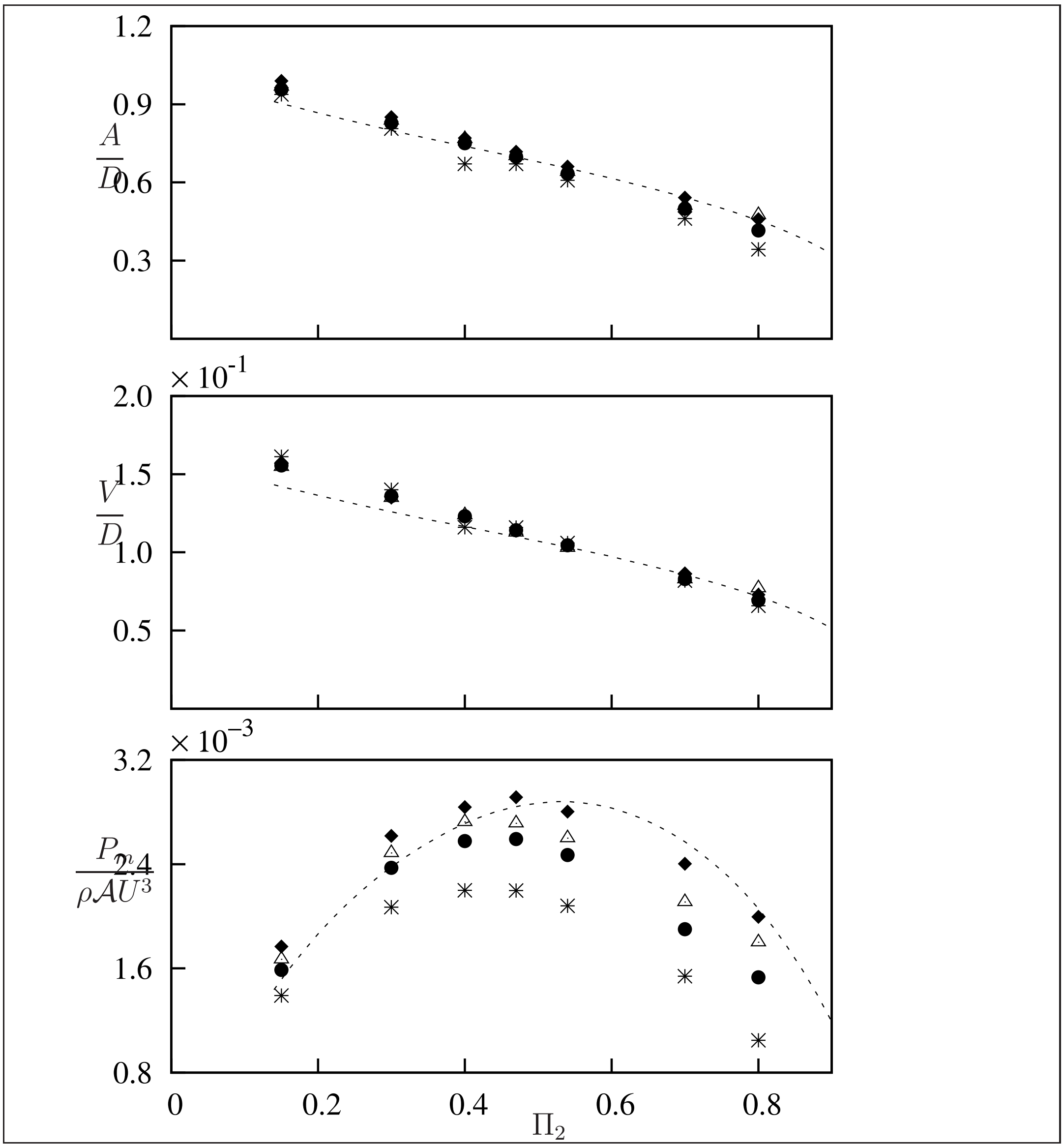

Figure 6: Comparison of data generated using the quasi-static theory and full DNS simulations . (a) Displacement amplitude, (b) velocity amplitude and (c) mean power as functions of Π_2. Data were obtained at Re = 200 at three different combined values $\Pi_1 = 10$ ($m^* \approx 20$) (✳), $\Pi_1 = 60$ ($m^* \approx 50$) (●), $\Pi_2 = 250$ ($m^* \approx 100$) (△), $\Pi_1 = 1000$ ($m^* \approx 250$) and $\Pi_1 = 6200$ ($m^* \approx 500$). The QSS data at $\Pi_1 = 10$ are represented by (- - -)

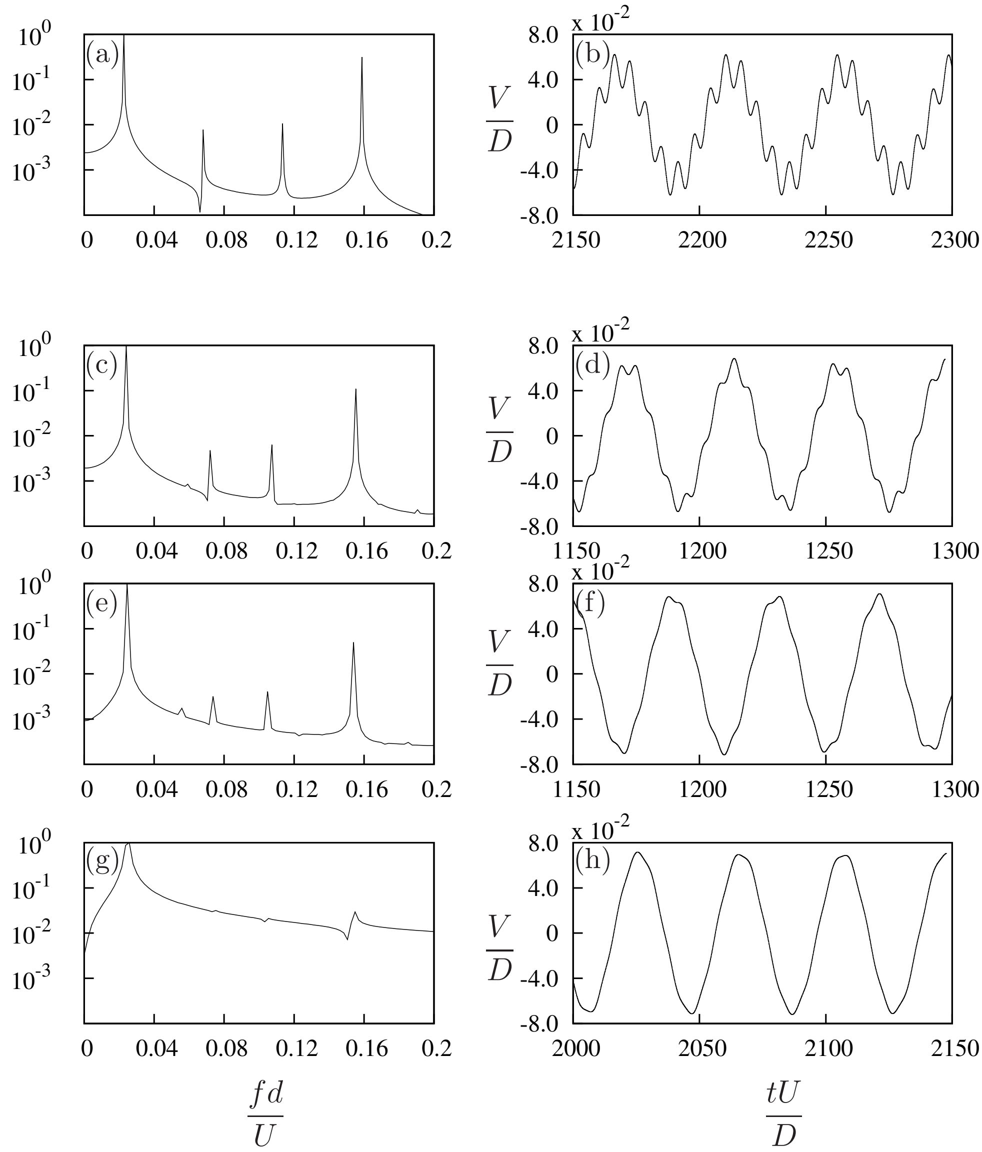

Figure 7: Velocity signal (right) and the corresponding power spectrum (left) of the DNS data at 3 different Π_1 at $\Pi_2 = 0.8$. (a) and (b) $\Pi_1 = 10$, (c) and (d) $\Pi_1 = 60$, (e) and (f) $\Pi_1 = 250$, (g) and (h) $\Pi_1 = 1000$. U^* is kept at 40 therefore the mass ratio increases as Π_1 increases. It is evident that the influence of vortex shedding reduces as the inertia of the system increases.

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