Phenomenon of Alfvénic vortex shedding in solar corona

M. Gruszecki, V.M. Nakariakov, T. Van Doorsselaere, T.D. Arber

Centre for Fusion and Astrophysics, University of Warwick

1. Abstract.

Periodic generation of Alfvénic vortices by the interaction of plasma flows with obstacles, e.g. line-tying coronal loops is modelled. It is found that this phenomenon is a robust feature of the interaction in a broad range of plasma parameters: for plasma-beta from 0.025 to 0.5, and for the flow speeds from 0.1 to 0.99 fast magnetoacoustic speeds, with the Strouhal number about 0.2. Alfvénic vortices are weakly compressible and cause perturbations of the magnetic field strength and plasma density. The possibility of the resonant excitation of kink coronal loop oscillations by this phenomenon is justified.

2. Excitation of kink oscillations of loops.

One of the motivations of this study is the mechanism for the excitation of loop oscillations, which is still not understood. A widely accepted option is excitation of the oscillations by a flare-generated blast wave. Remaining a plausible option, this mechanism does not explain several important observational features of this phenomenon:

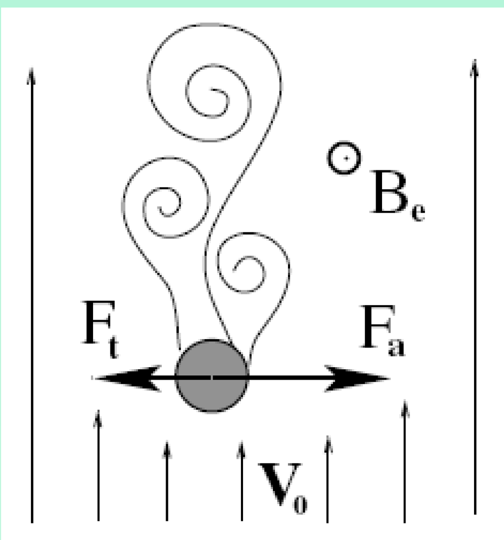
1) The reason why some loops respond to the excitation, while the majority of them do not,

2) The dominance of horizontal polarisation,

3) Initial growth of the oscillation amplitude.

3. Excitation of transverse oscillations.

Recently, Nakariakov et al. (A&A, 2009, 502, 661) proposed mechanism for excitation loop oscillation based upon the interaction of loops with Coronal Mass Ejection induced flow due to the effect of Alfvénic vortex shedding. Interacting with the loop, the flow experiences formation of vortices, which shed periodically from opposite sides of the loop.



As the period of the global kink mode is $2L/C_k$, where L is the loop length and C_k is the kink speed, the condition for the exact resonance is $V_0/C_k = d/(2\cdot St\cdot L)$. As the loop diameter is much less than its length, $d \ll L$, the resonant condition can be fulfilled for flow speeds which are much lower than the kink speed.

The loop is periodically pushed in the horizontal direction by the force

$\mathbf{F_a} = -\rho_e \mathbf{V_0} \times \mathbf{\Omega}$. The loop displacement causes appearance of the restoring MHD force $\boldsymbol{F_t}$.

4. Phenomenon of Alfvénic vortex shedding.

The key ingredient of this theory is the Strouhal number $St = d/(P\cdot V_0)$. So far, there has not been estimations of this parameter in magnetised high-Reynolds plasmas. We performed full magnetohydrodynamic numerical simulations of the interaction of plasma flow with a cylinder obstacle. To describe coronal plasmas the ideal MHD equations are most commonly used:

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho \mathbf{V}) = 0, \quad \frac{\partial \mathbf{B}}{\partial t} = \nabla\times(\mathbf{V}\times\mathbf{B}),$$

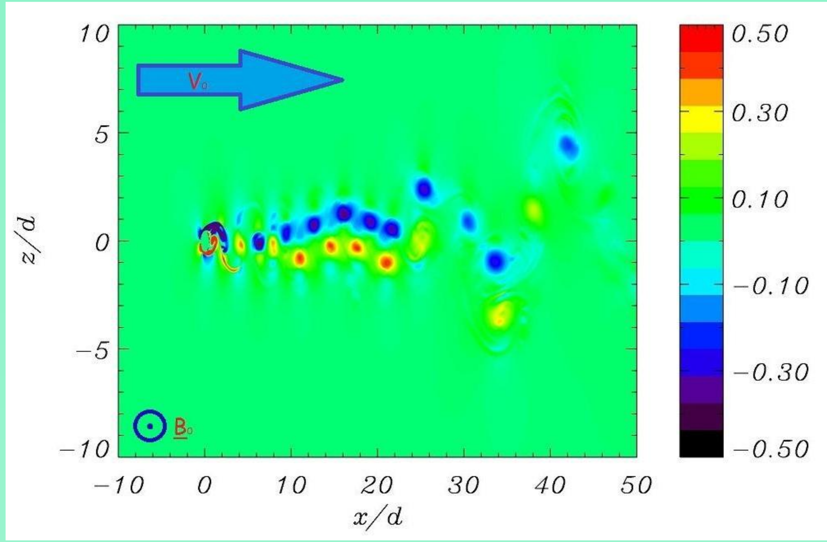
$$\rho\frac{\partial \mathbf{V}}{\partial t} + \rho(\mathbf{V}\cdot\nabla)\mathbf{V} = -\nabla p + \frac{1}{\mu}(\nabla\times\mathbf{V})\times\mathbf{V},$$

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho\mathbf{V}\nabla\varepsilon = -p\nabla\cdot\mathbf{V}, \quad \nabla\cdot\mathbf{B} = 0.$$

We limit our discussion to a 2.5-D magnetically structured medium in which all plasma variables are invariant in the y-direction, $\partial/\partial y = 0$, but the perturbed velocity and magnetic field y-components are not identically zero. In our models we neglect non-ideal effects and the gravity force.

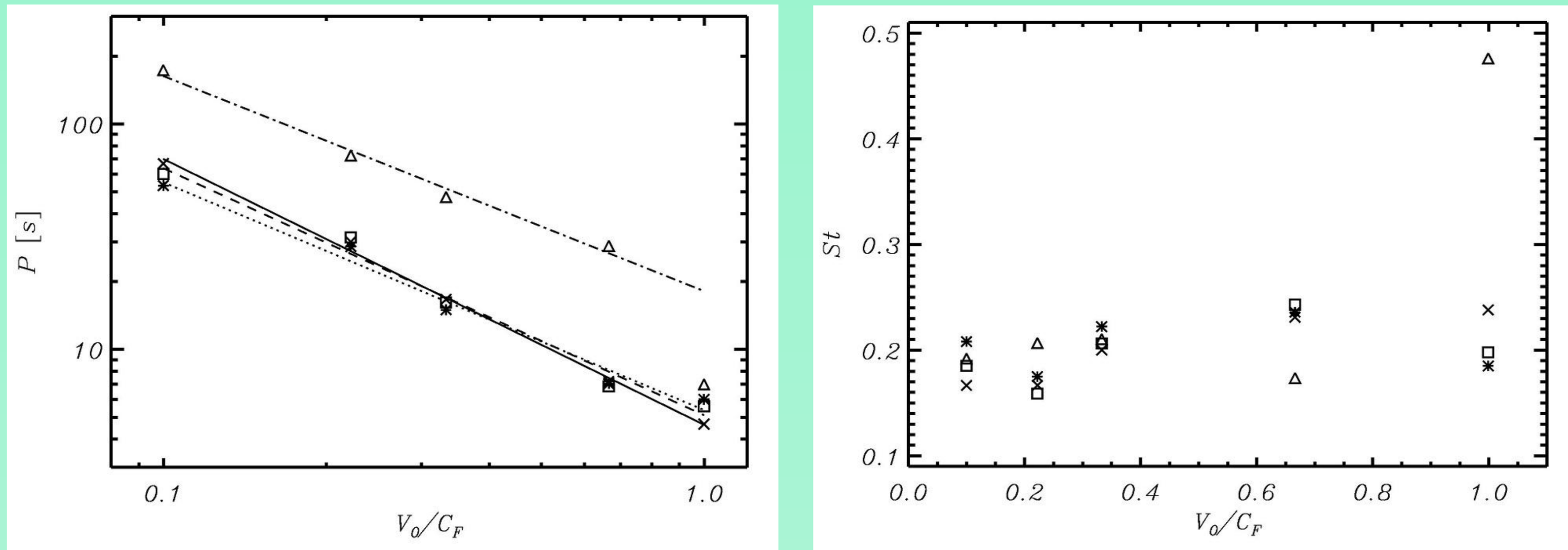
5. Numerical results.

Snapshot of the von Karman vortex street



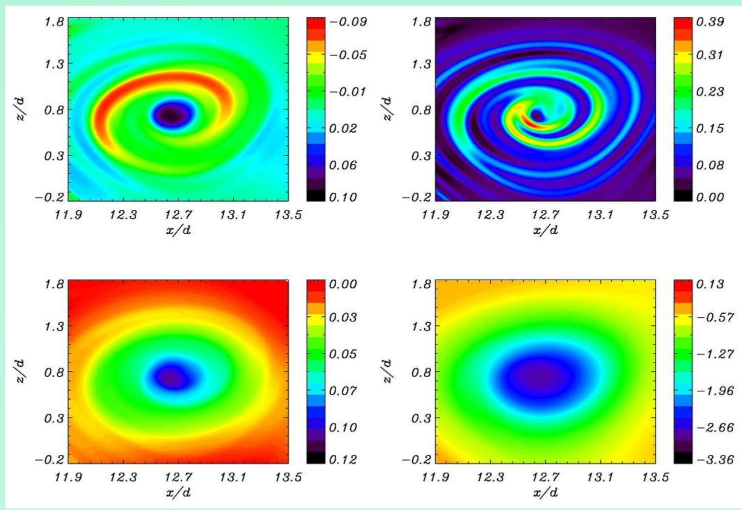
The colours show the vorticity $\omega = \mathrm{rot}\ \mathbf{V}$ in the flow at t=220s. Vorticity is messured in 1/s. The key element of this phenomenon is the magnetic field in the flow to be parallel to the axis of the bluff cylinder.

Parametric studies

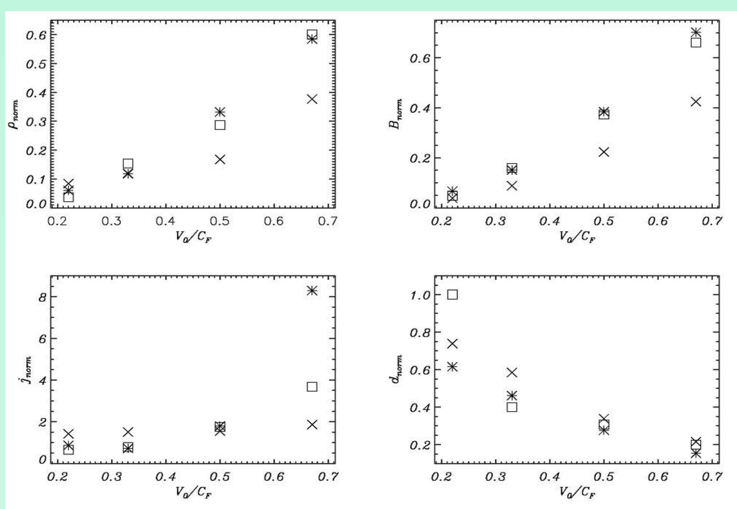


Period P (left panel) and Strouhal number St (right panel) vs flow speed V_0 which is measured in units of fast speed C_F (0.901 Mm/s). The stars correspond to d=1 Mm and the triangles to d=3 Mm for β = 0.025. The squares and crosses correspond to β = 0.1 and β =0.5, respectively for d=1 Mm. The slope parameters for straight lines are equal: -1.17 (solid line), -1.01 (dotted line), -1.1 (dashed line) and -0.95 (dash-dotted line).

Fine structure of the vortices



Normalized value of: density $(\rho_0-\rho)/\rho$ (top left panel), electric current $j\cdot d/B_0$ (top right panel), magnetic induction $(B_0-B)/B_0$ (bottom left panel) and vorticity $\omega\cdot d/V_0$ (bottom right panel) for one of the vortex from first figure.



Normalized minimum value of density $(\rho_0-\rho)/\rho$ (top left panel), minimum value of magnetic induction $(B_0-B)/B_0$ (top right panel), maximum value of electric current $j\cdot d/B_0$ (bottom left panel) and vortex diameter d_{vortex}/d (bottom right panel) vs V_0.The stars, squares and crosses corresponds to β = 0.025, β =0.1 and β = 0.5, respectively.

CONCLUSIONS

Full MHD numerical simulations show that the interaction of steady plasma flows with a bluff cylinder causes the periodic generation of Alfvénic vortices.

1) The phenomenon is demonstrated to occur in the rarefied and magnetised plasmas of the solar corona.

2) The value of St is about 0.2, and is independent of the bluff cylinder diameter, the flow speed and the plasma β.

3) Vortices cause perturbations of the plasma density and magnetic field and generate electric current.

4) Alfvénic vortex shedding can be responsible for the resonant excitation of the kink oscillation.

Acknowledgments: MG is supported by the Royal Society grant NF090143.