Flag flapping induced by pressure gradient and shed vortex

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Background

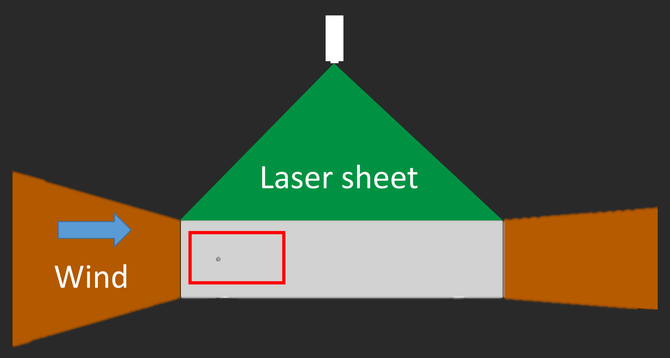
Flapping flag in the wind is a common phenomenon in daily lives. Different speeds of wind change the motion of flag.

Goal

1. Reason of flapping in the wind
2. Effects of different flagpoles, lengths of flag and speeds of wind

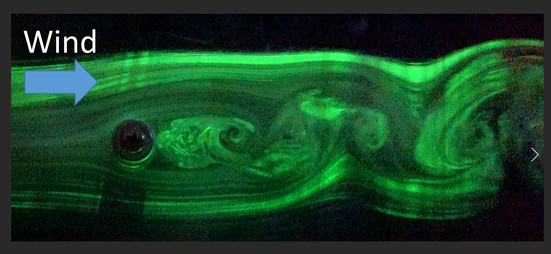
Setup

Fix a flag in wind tunnel and exert a wind field from left to right. Laser is set at the top.

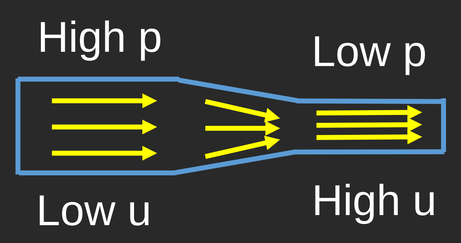


Vortex shedding

Fluid flows through a cylinder, there will exist alternating vortices behind the cylinder.

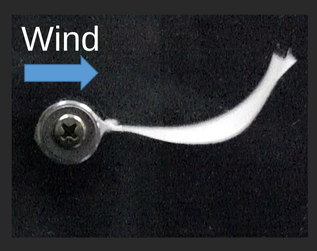


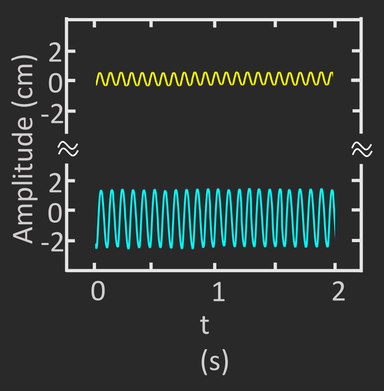
Bernoulli's theorem

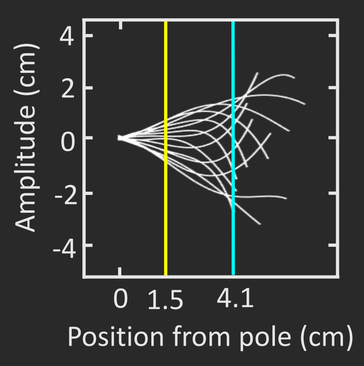


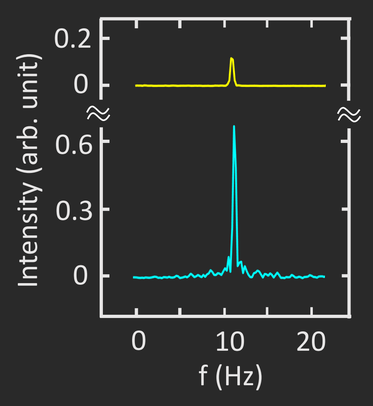
Motion of flag

Thick pole





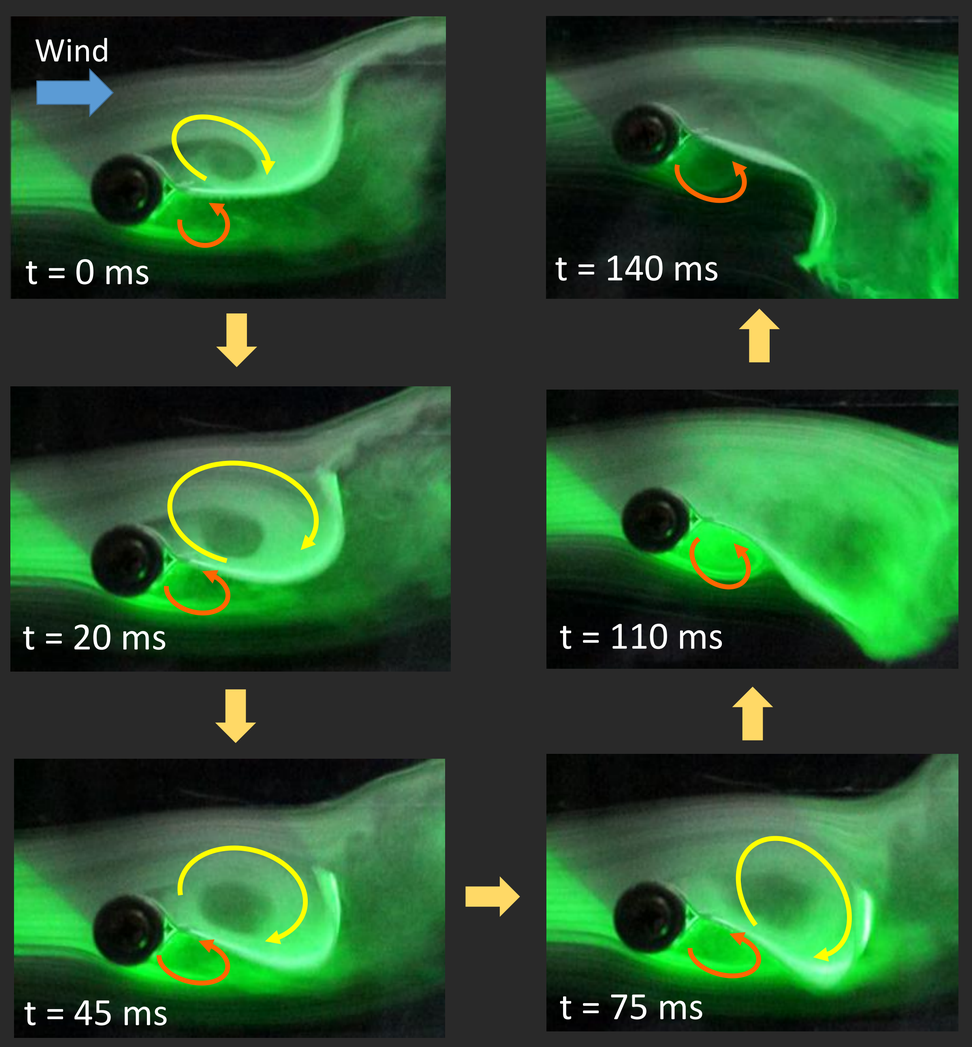




In this condition [speed of wind (u): 250 cm/s, length of flag (L): 6 cm, diameter of pole (d): 1.6 cm]. Frequency is the same, but amplitude is difference.

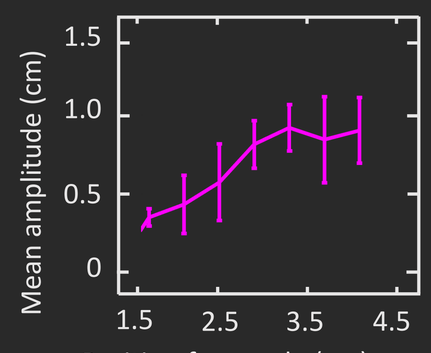
Flapping evolution

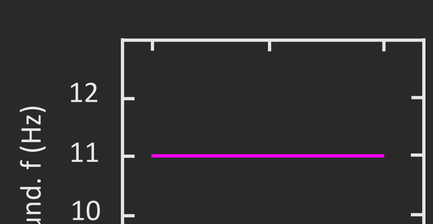
(u = 250 cm/s, L = 6 cm, d = 1.6 cm)



Motion with position

Different positions of flag exist different amplitudes and frequencies.

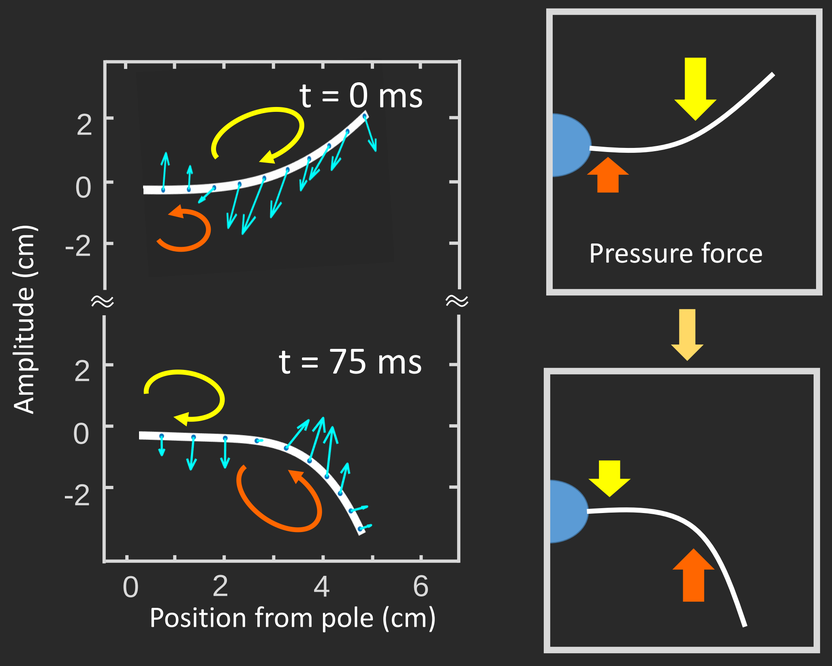




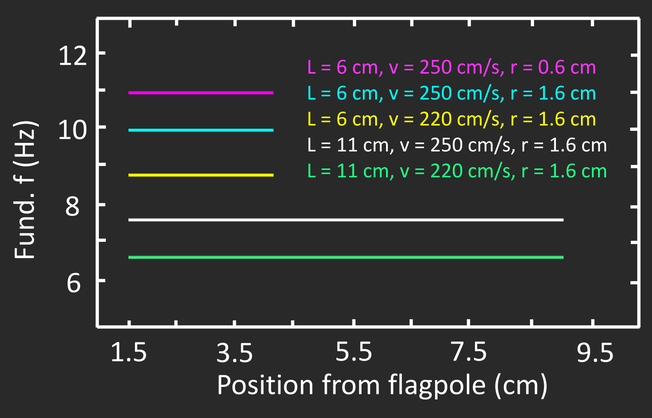
Force on flag

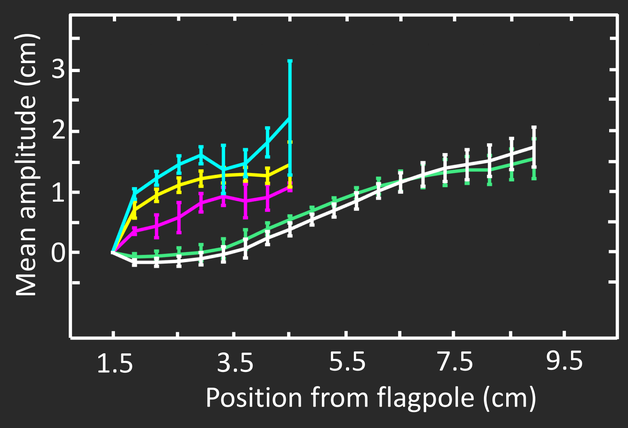
The vortices generated from the pole will exert force on flag and change the motion of flag. Reverse flow of vortices causes net pressure force on flag.

Upward vortex is growing, and producing pressure difference near the flag. Rear end of the flag endured larger pressure than front, and promote vortex growing. Vortex will separate at end of the flag. After separated, flag keep downward by inertia. It is evolution of a cycle.



Different poles, wind speeds and lengths





Thick pole causes larger amplitude and lower frequency than thin pole because of the significant vortex shedding. Long flags exist the lower frequency than short flags because of larger inertia.

Conclusion

1. Flagpole generates vortex shedding, and vortices produce pressure and cause flag flapping.
2. Thick pole generates larger amplitude.
3. Longer flag exists lower frequency.

References

1.Fluid dynamics for physics
2.2005 PRL Heavy flags undergo spontaneous oscillations
3.2000 Nature Flexible filaments in a flowing soap