Russia IYPT

Singing blades of grass

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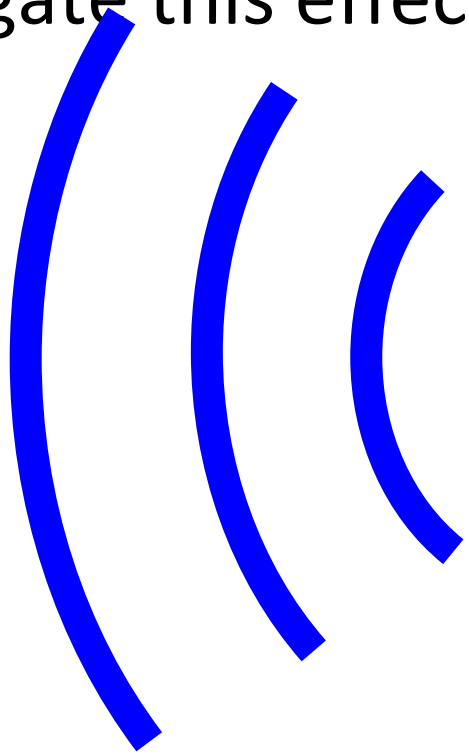
The problem

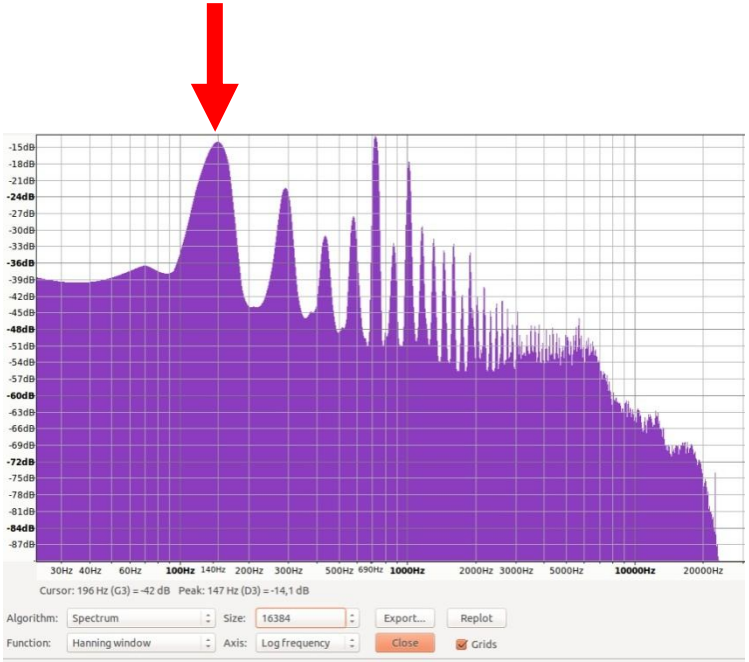
It is possible to produce a sound by blowing across a blade of grass, a paper strip or similar. Investigate this effect.



First observations

Strip vibrations (1000 fps)

Comparison of frequencies



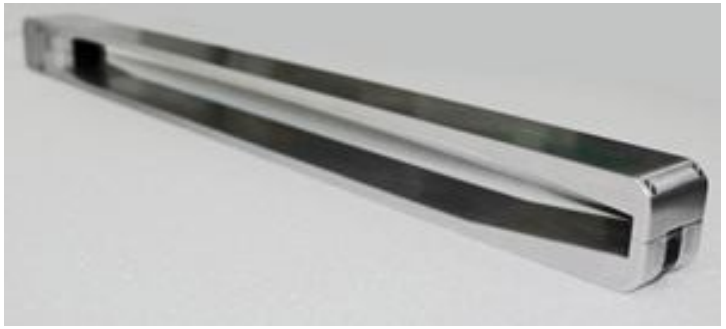
Sound
(audio analysis)
≈ 150 Hz

Vibrations
(video analysis)
≈ 150 Hz

Explanation of the effect

Air blows

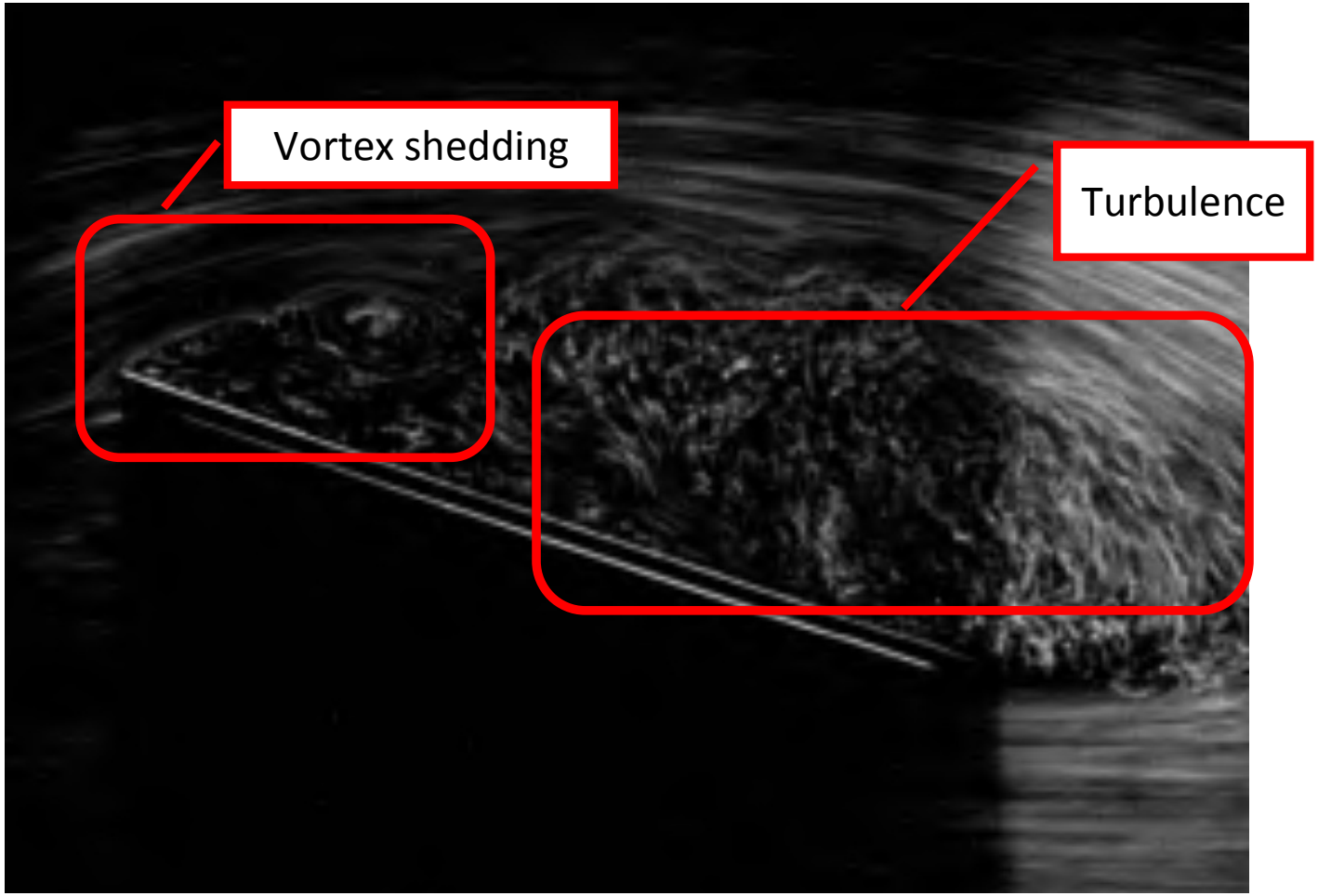
Strip vibrates



Sound appears

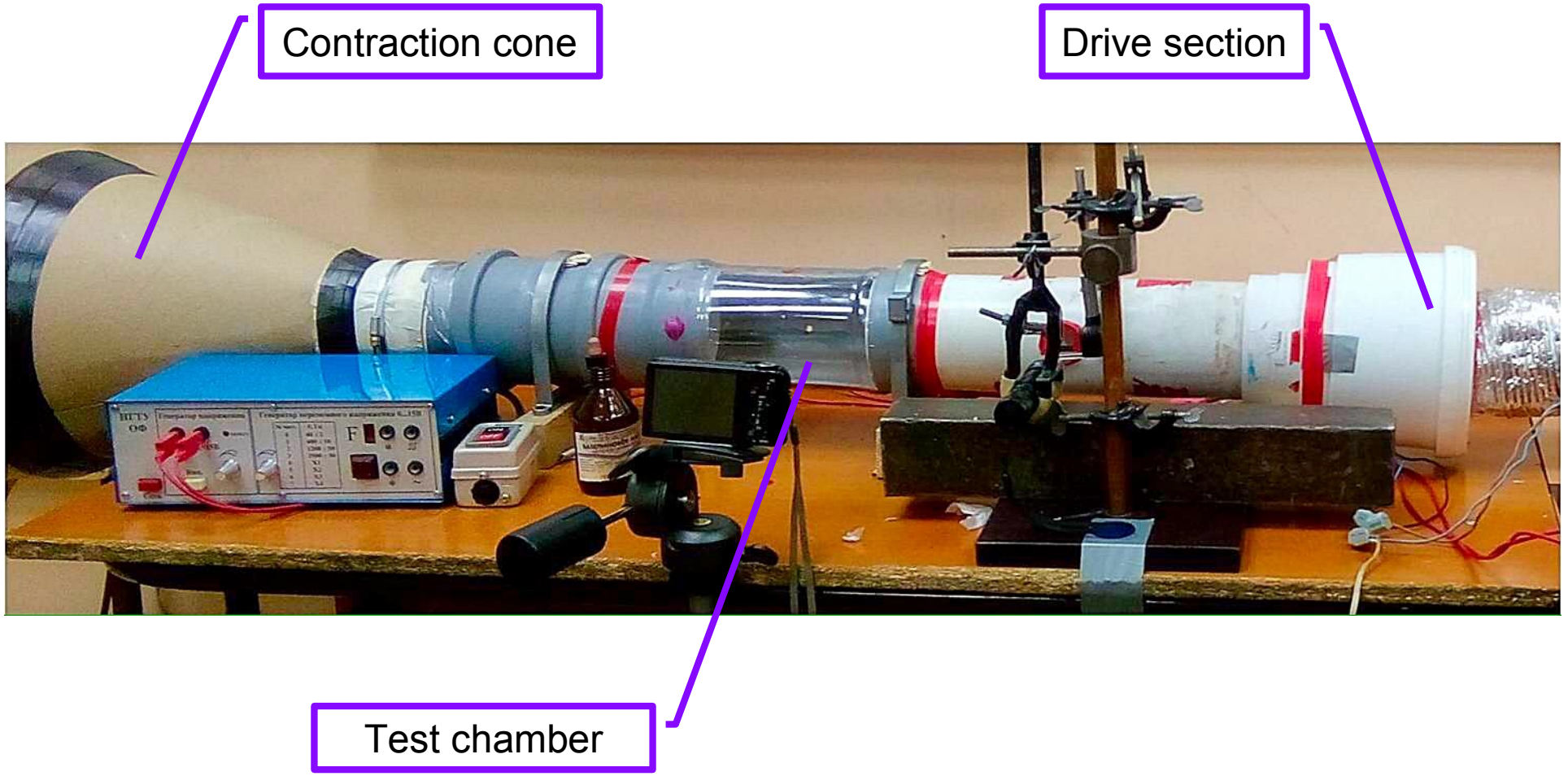
Strip – air flow interaction

Interaction of a plate with air flow

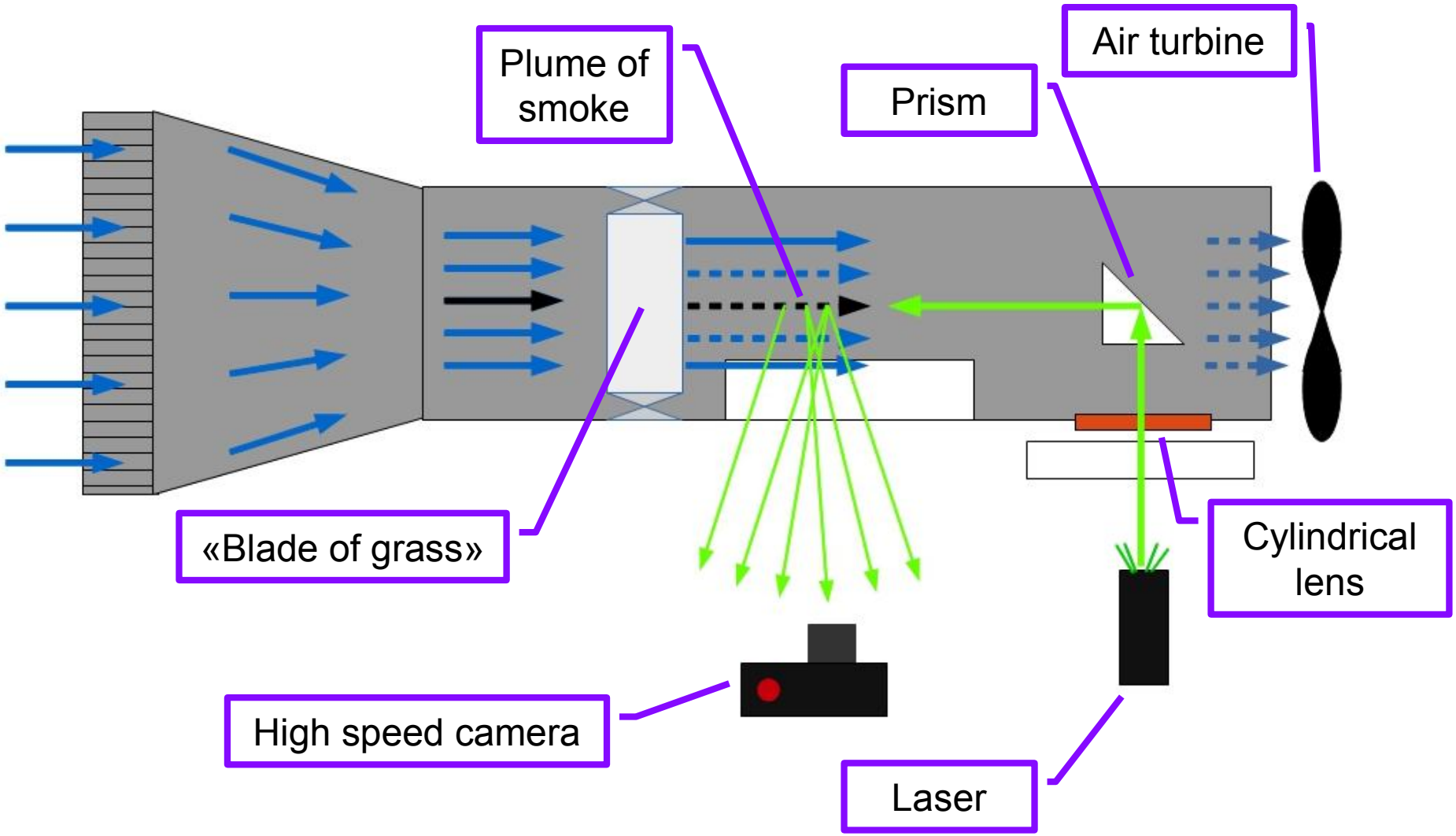


Van-Dyke M. (1982) “An album of fluid motion”

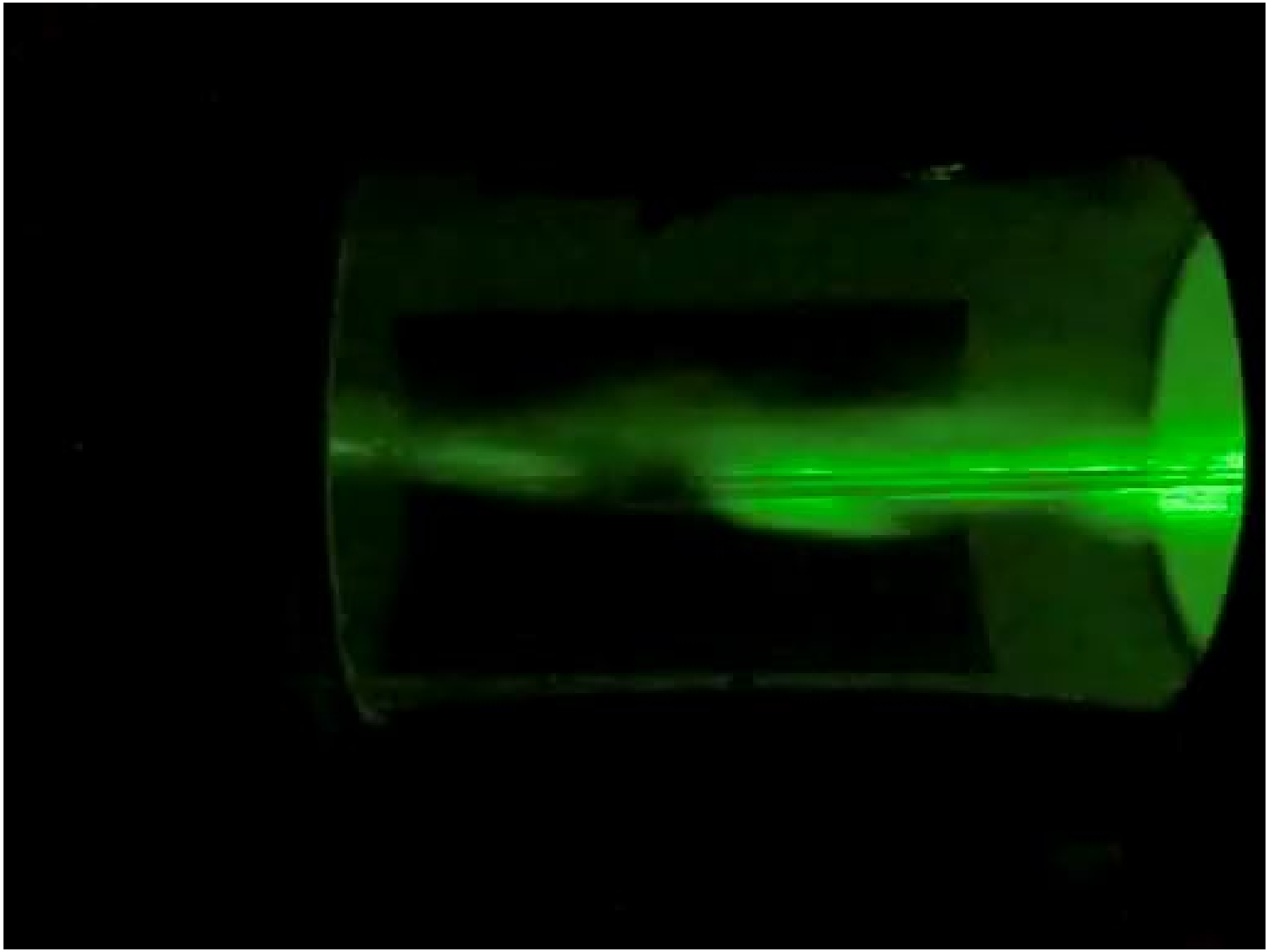
Setup #1: wind tunnel



Wind tunnel scheme

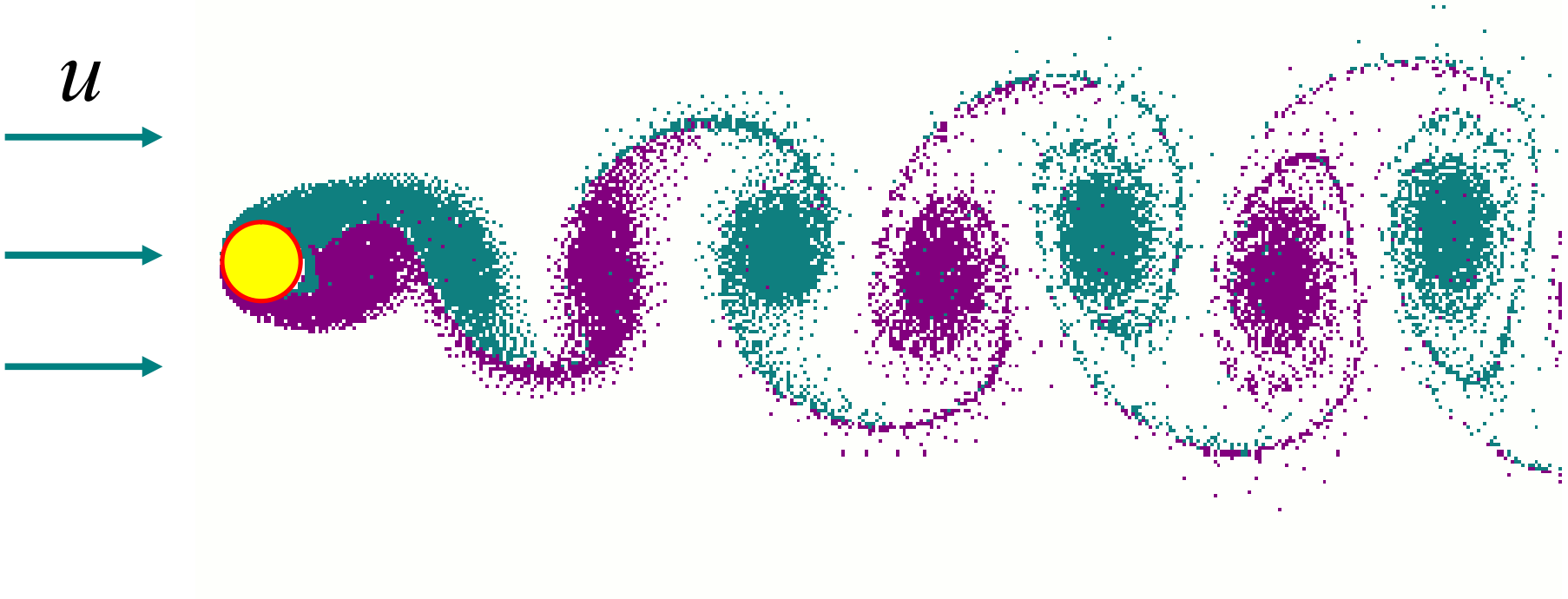


Vortex street (240 fps)

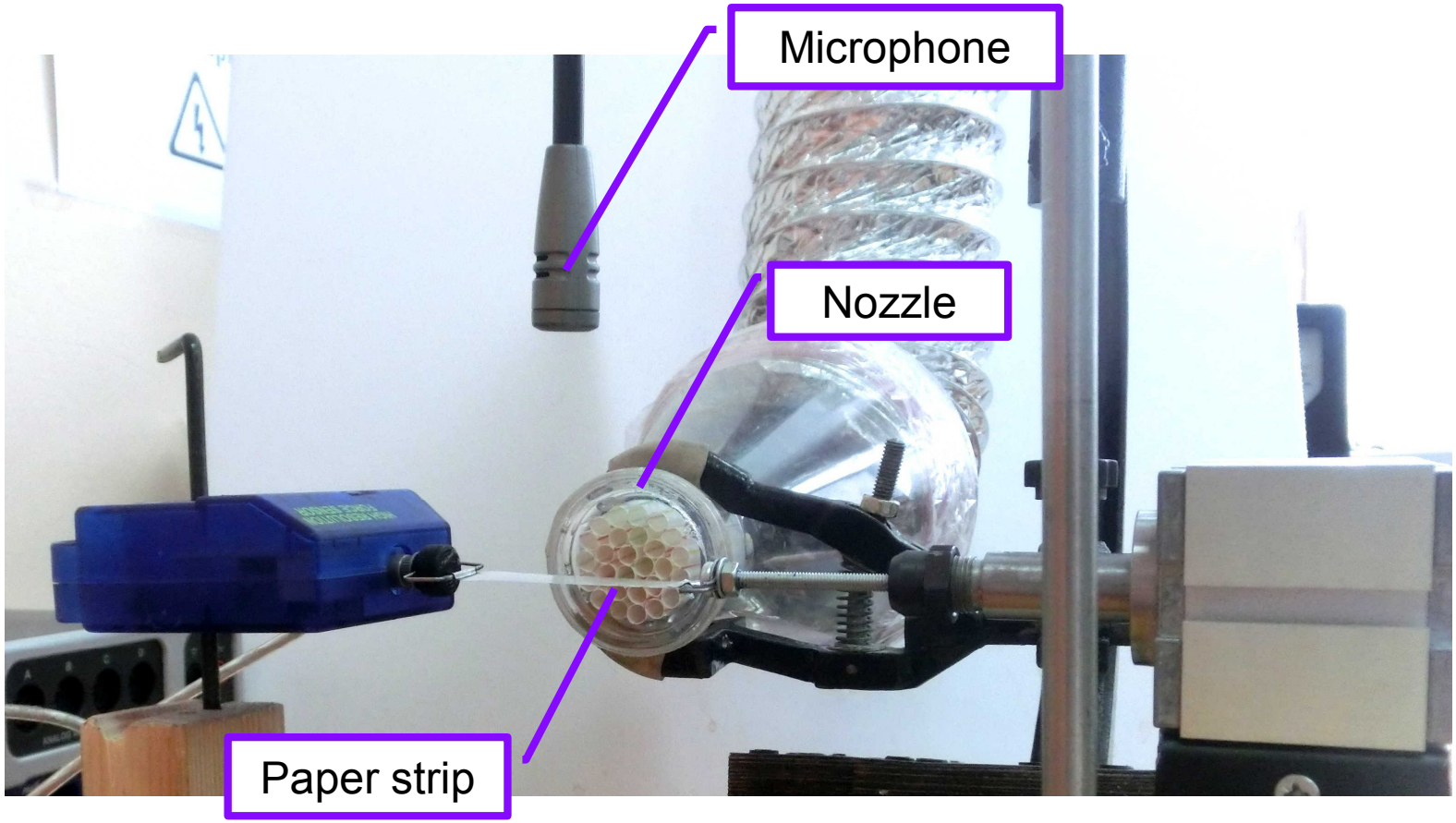


Is it Von Karman vortex street?

$$f \sim u$$

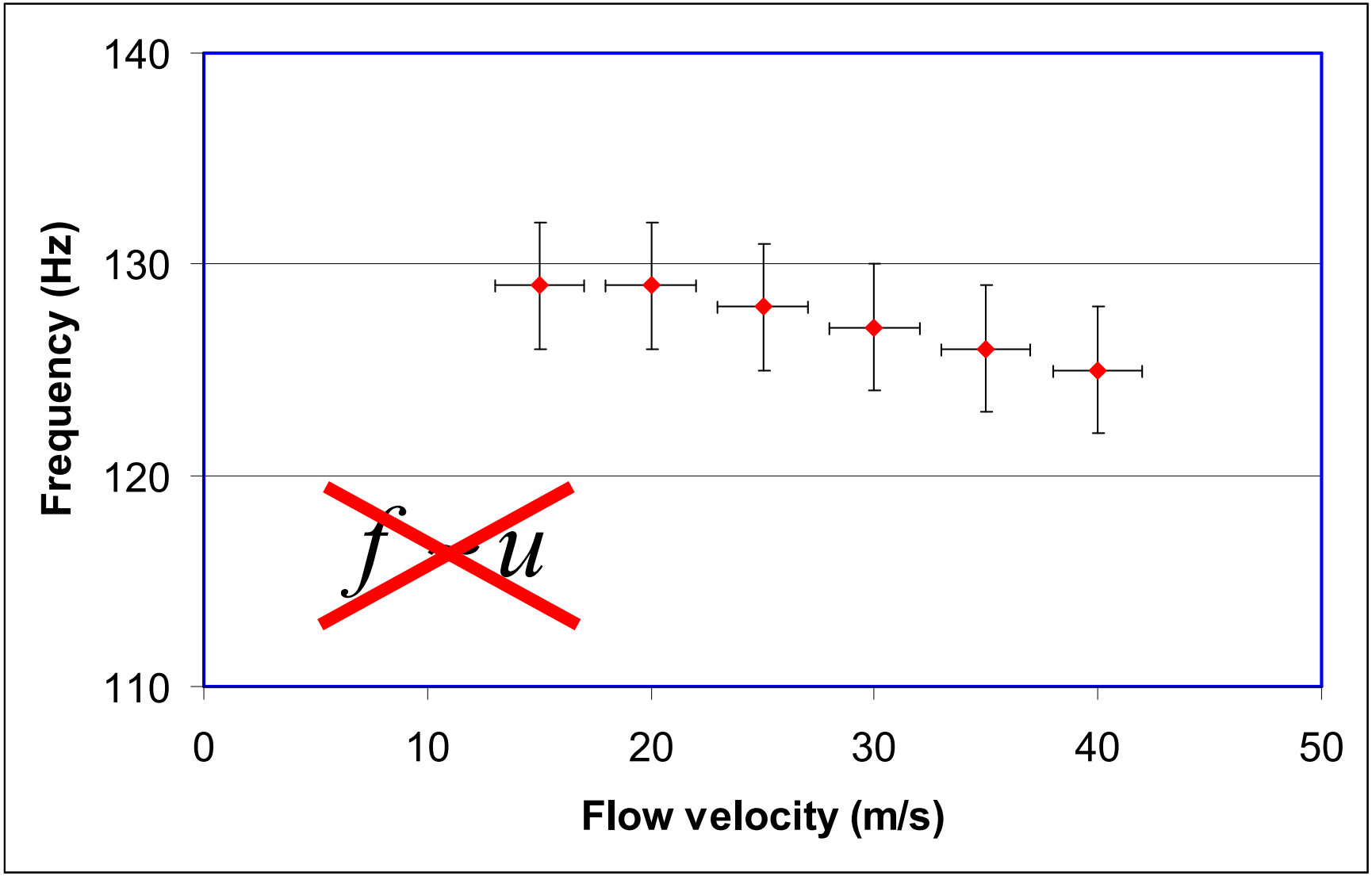


Setup #2



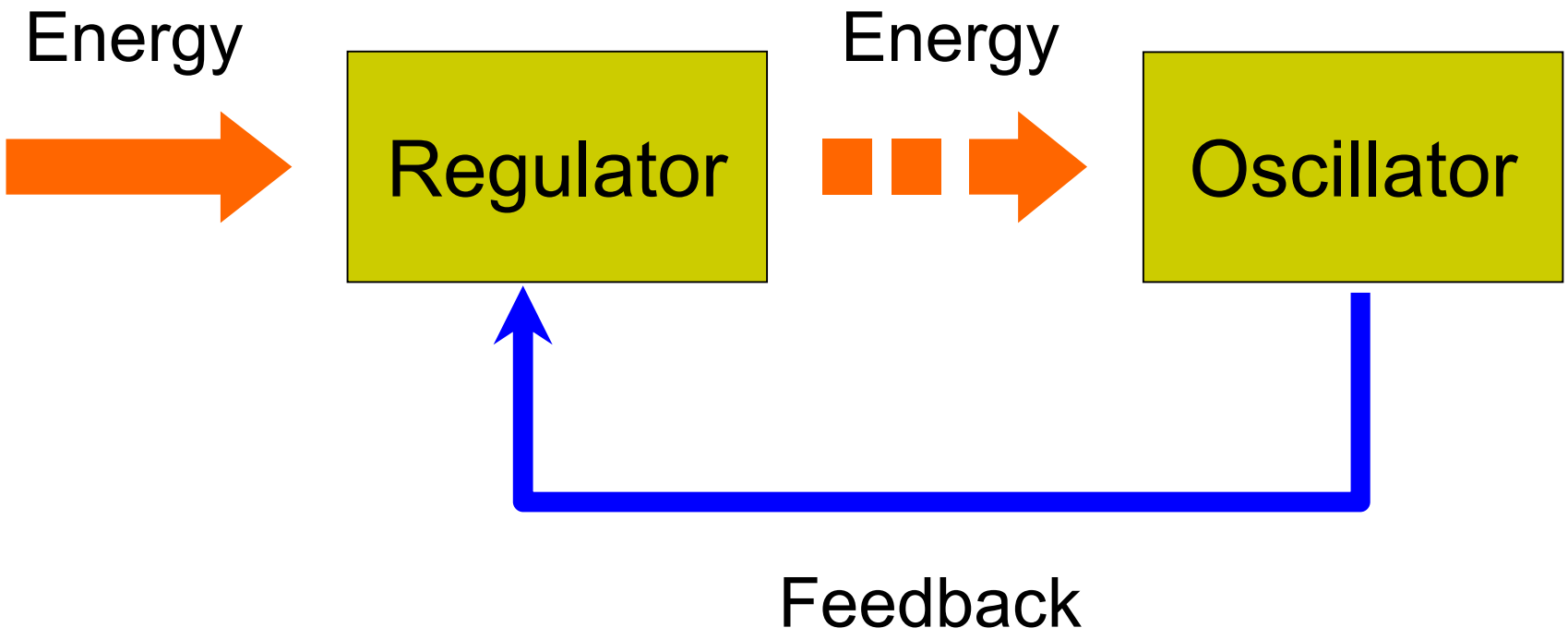
+ Low noise level
+ Flow velocity from 10 to 80 m/s

Sound frequency vs. flow velocity

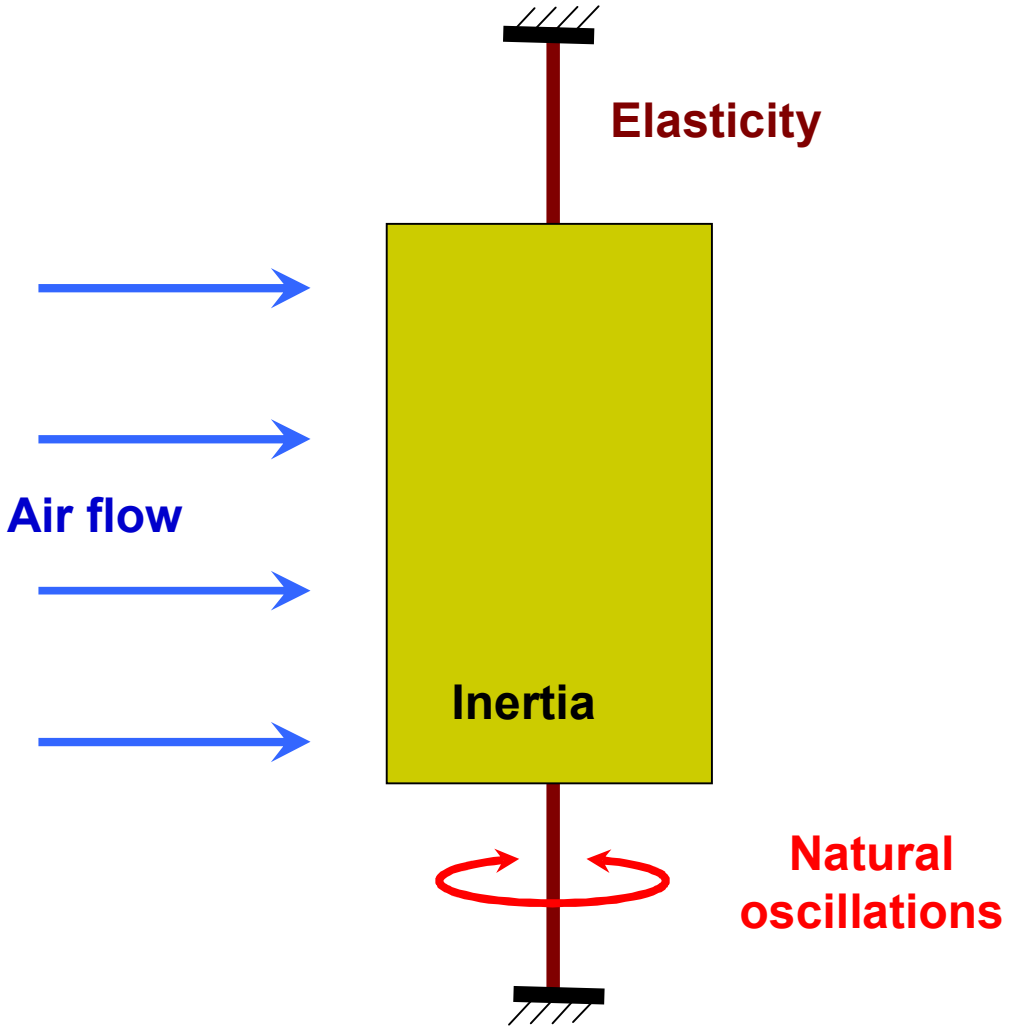


Self-oscillating system

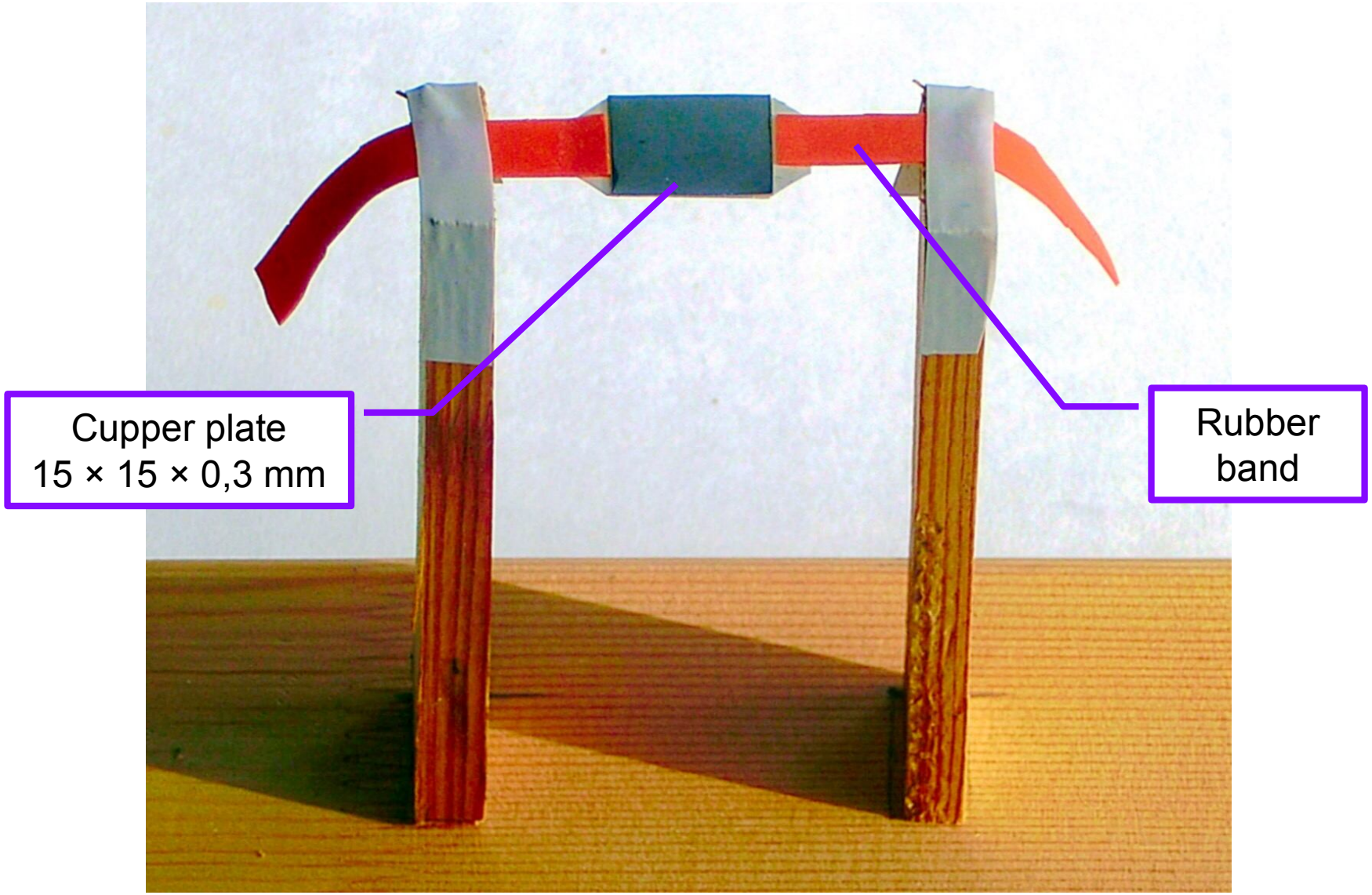
Self-oscillating system



Acting factors

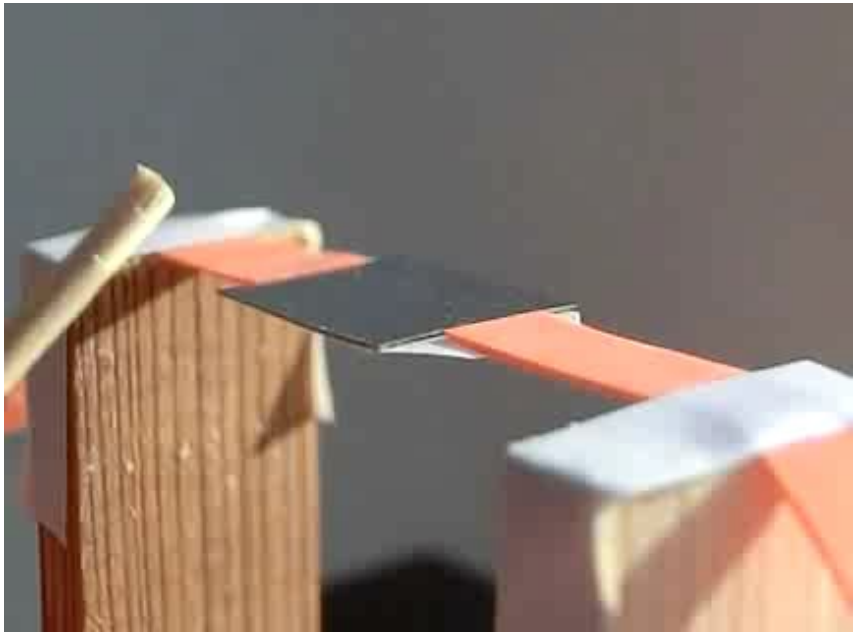


Setup #3



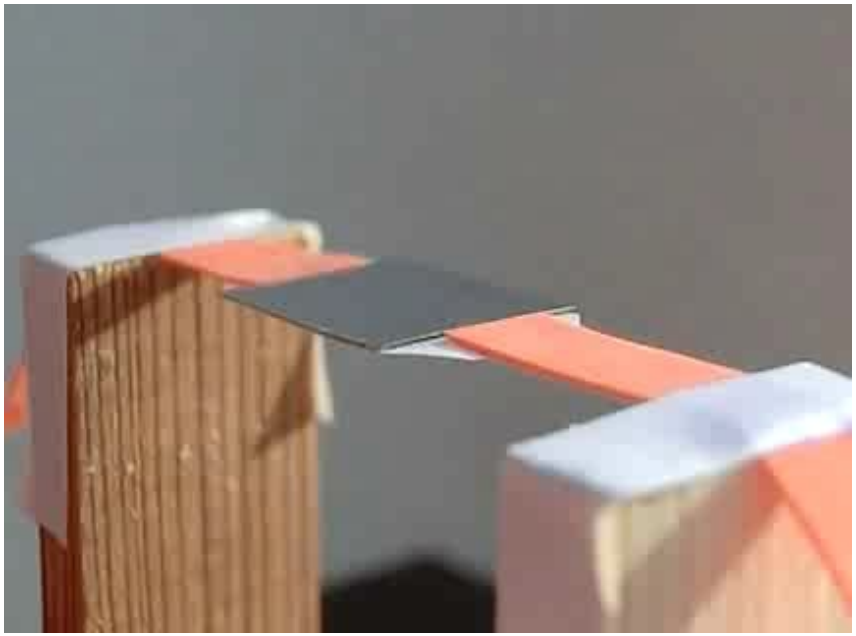
Video 240 fps

Natural oscillations



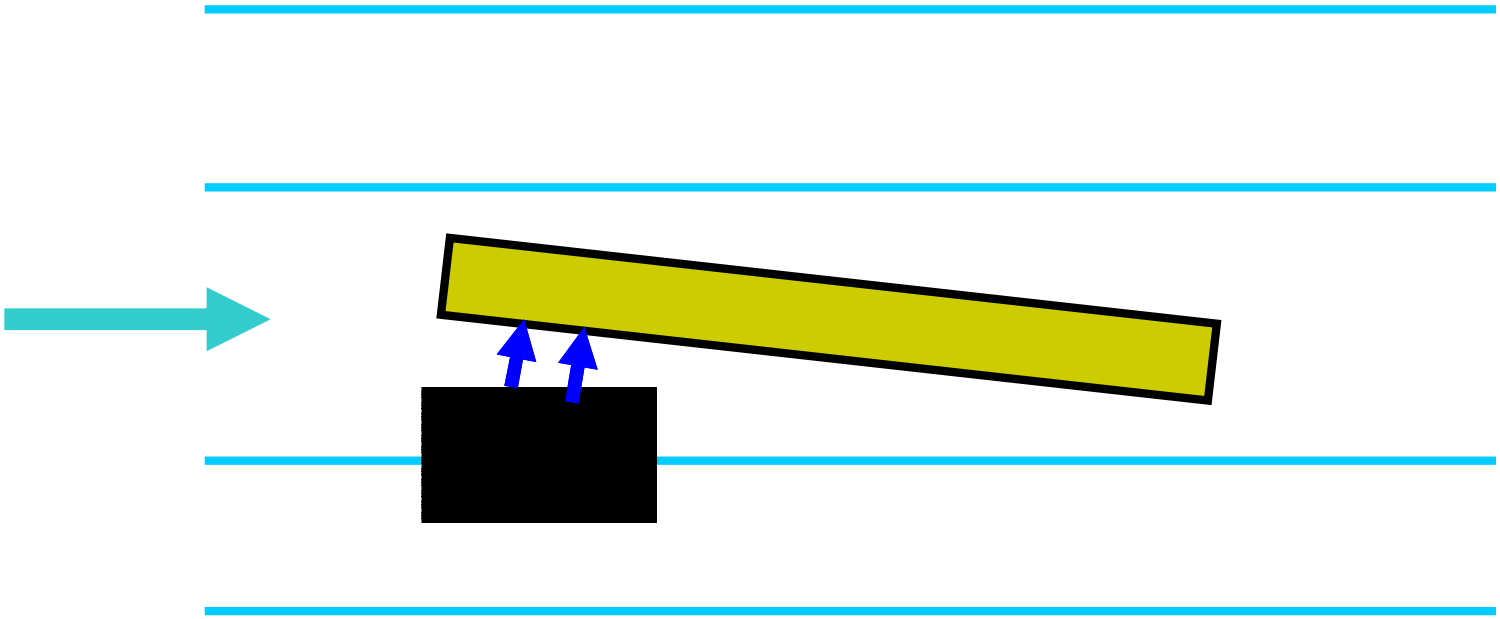
25 Hz

Excitation with air flow

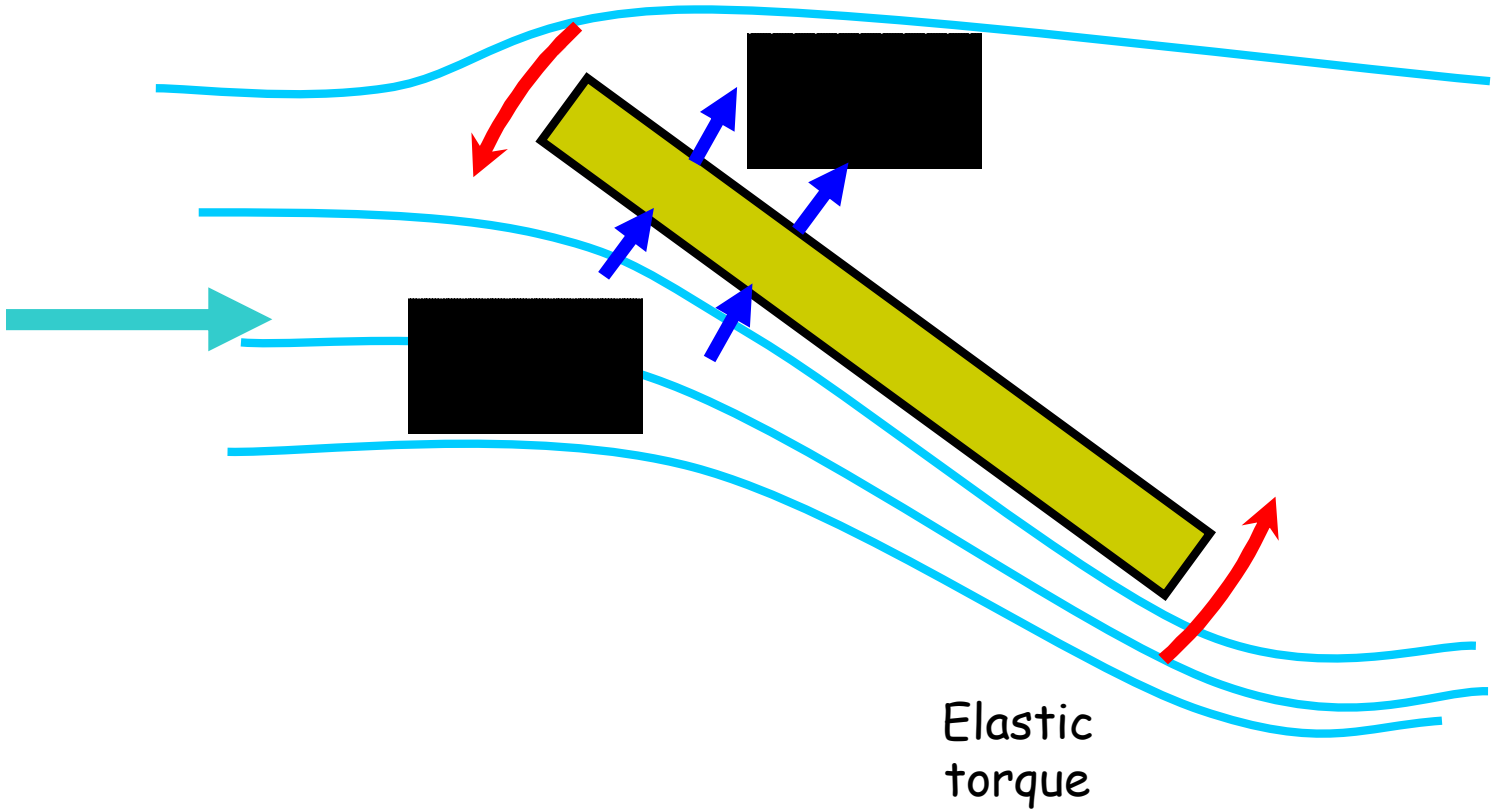


21 Hz

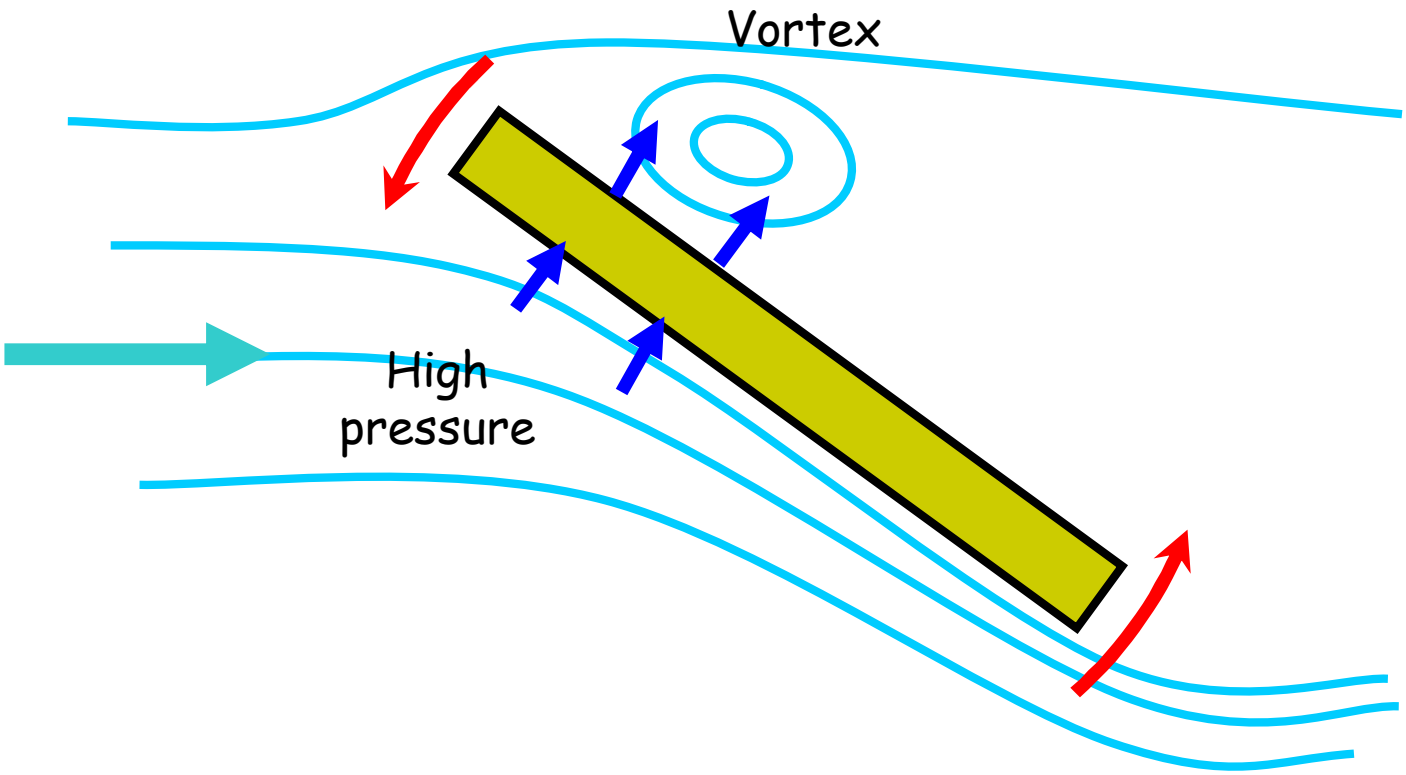
Initial deflection



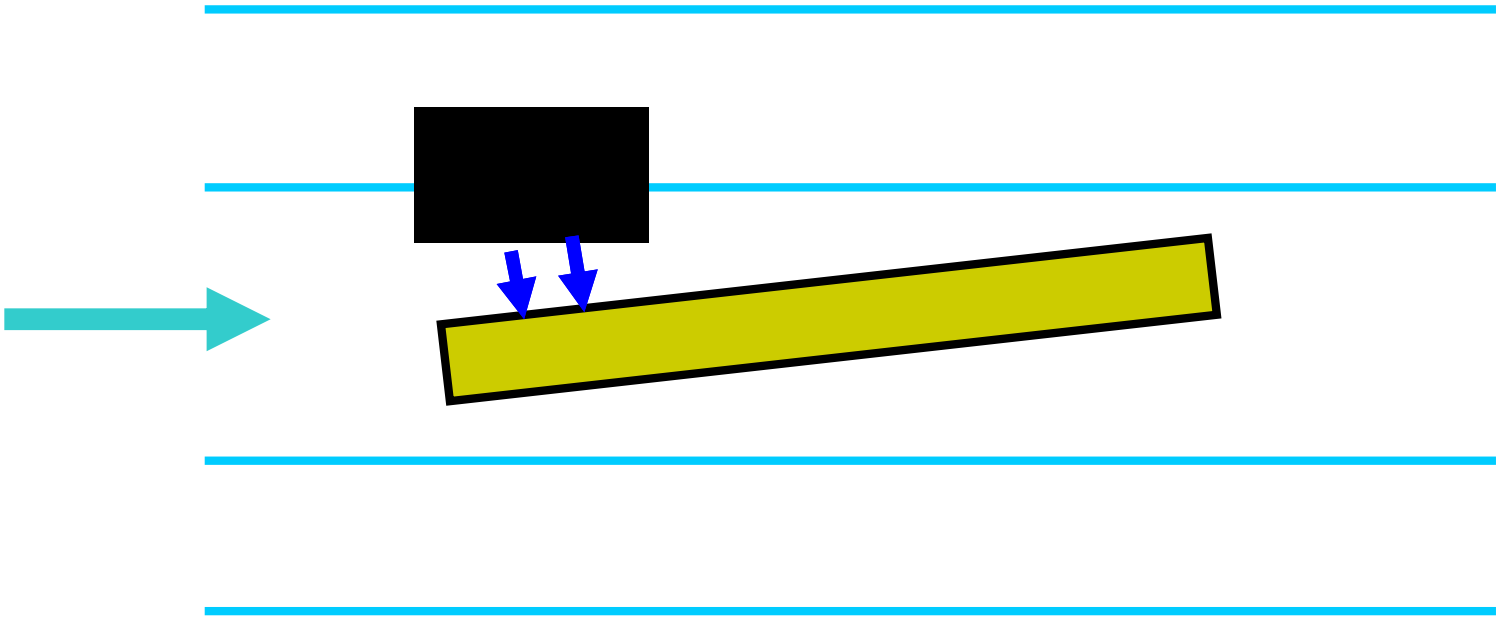
Increase in deflection



Vortex drift and restoring torque

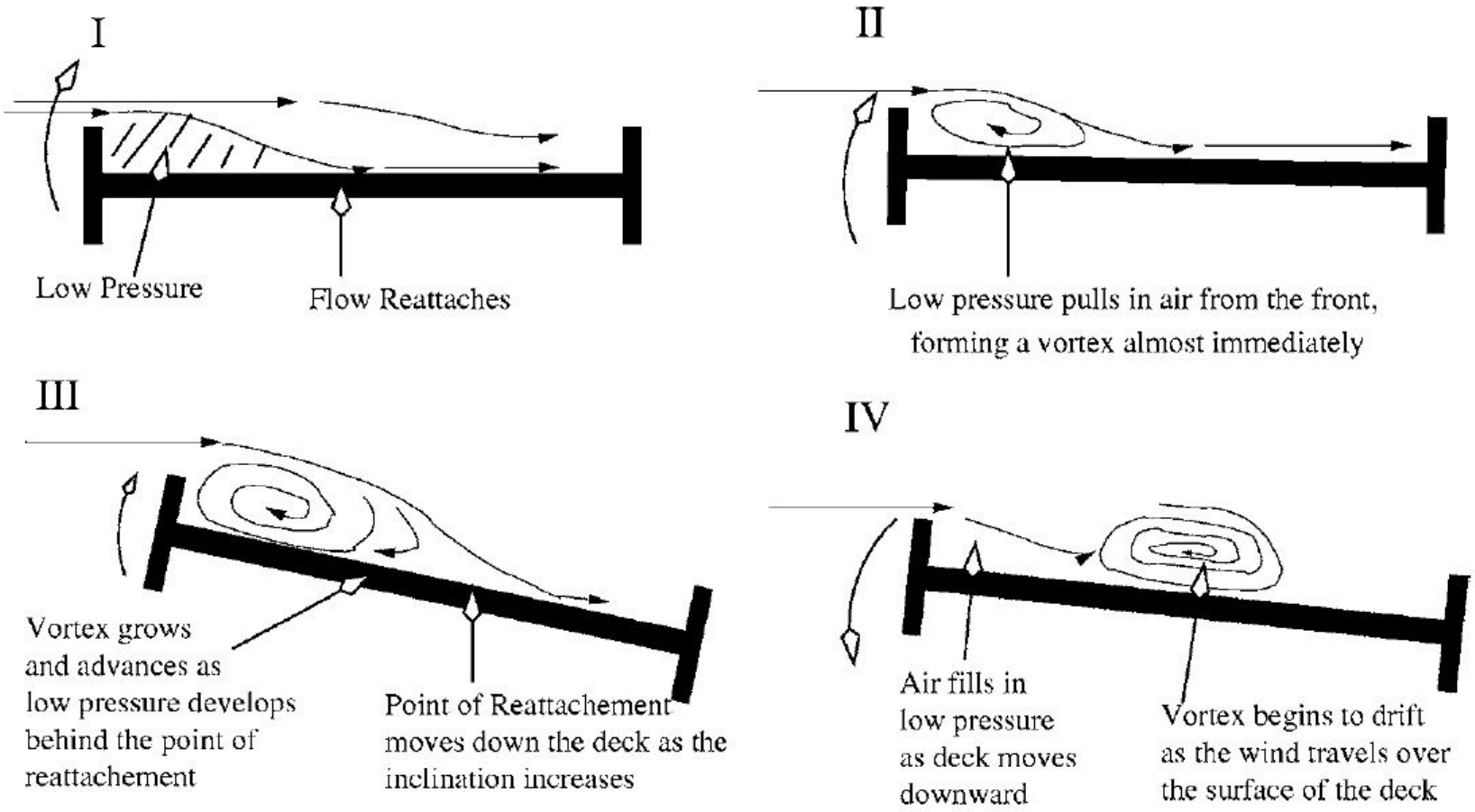


Next deflection



Failure of Tacoma bridge (1940)

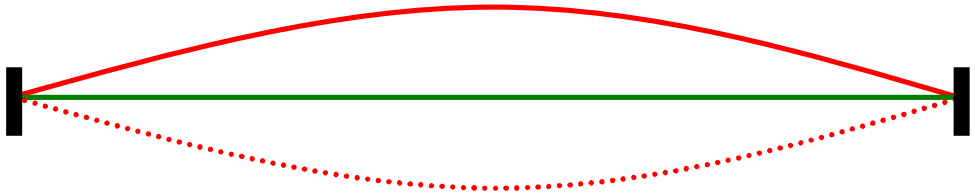
Vortex drift



Green D., Unruh W.G. (2006) “The failure of the Tacoma bridge: A physical model”.

Natural oscillations of elastic strip

Fundamental mode of the string



$$\xi(x,t) = \xi_1 \cos\left(\frac{\pi x}{L}\right) \cdot \sin(2\pi f_1 t + \varphi)$$

$$f_1 = \frac{c}{\lambda} = \frac{c}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\varepsilon}}$$

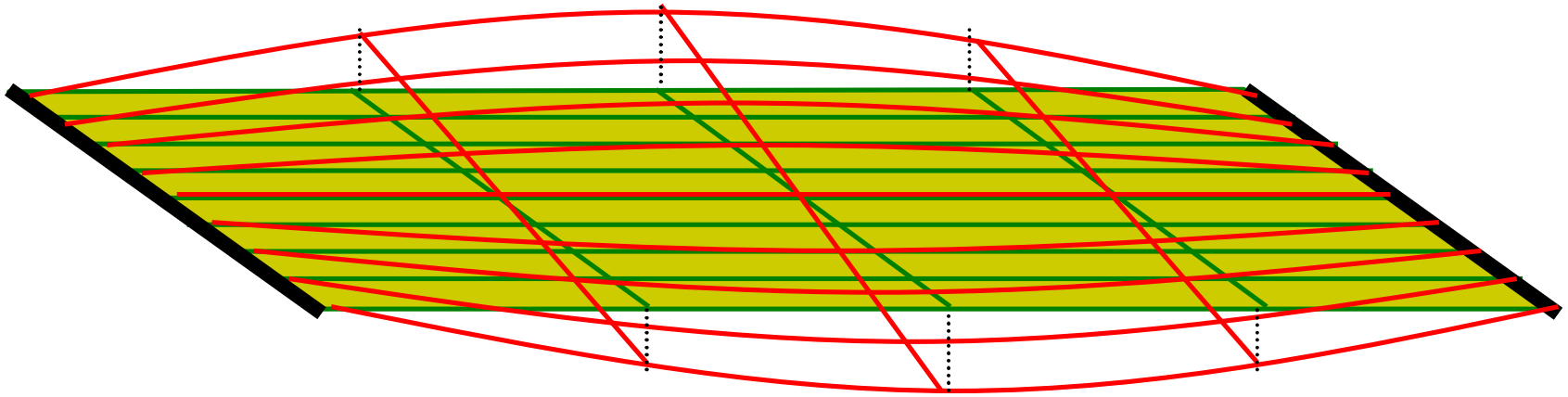
Wave velocity

Tension

Length

Linear density

“Continuum of strings” model



$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{h\sigma}}$$

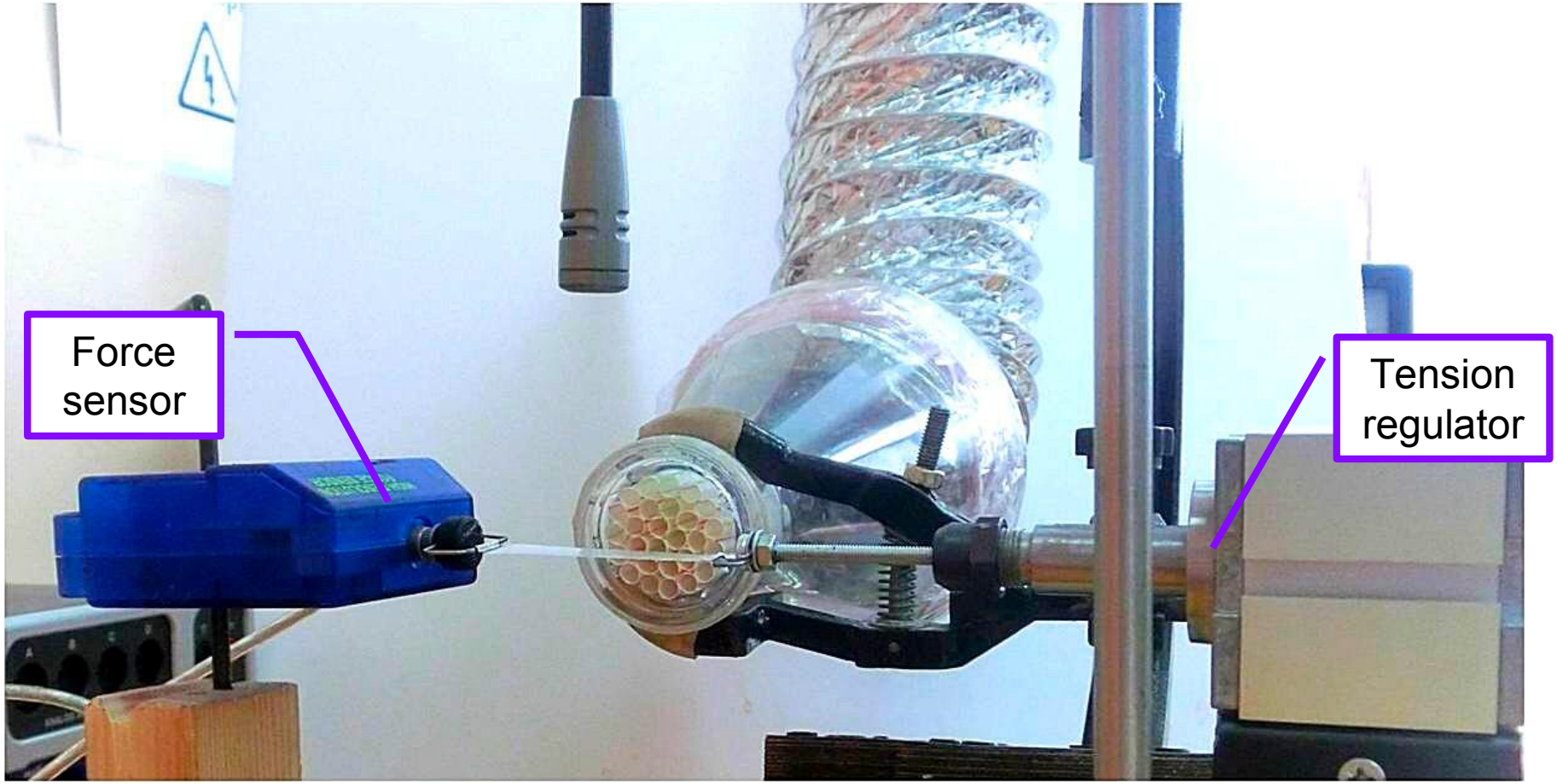
Tension

Length

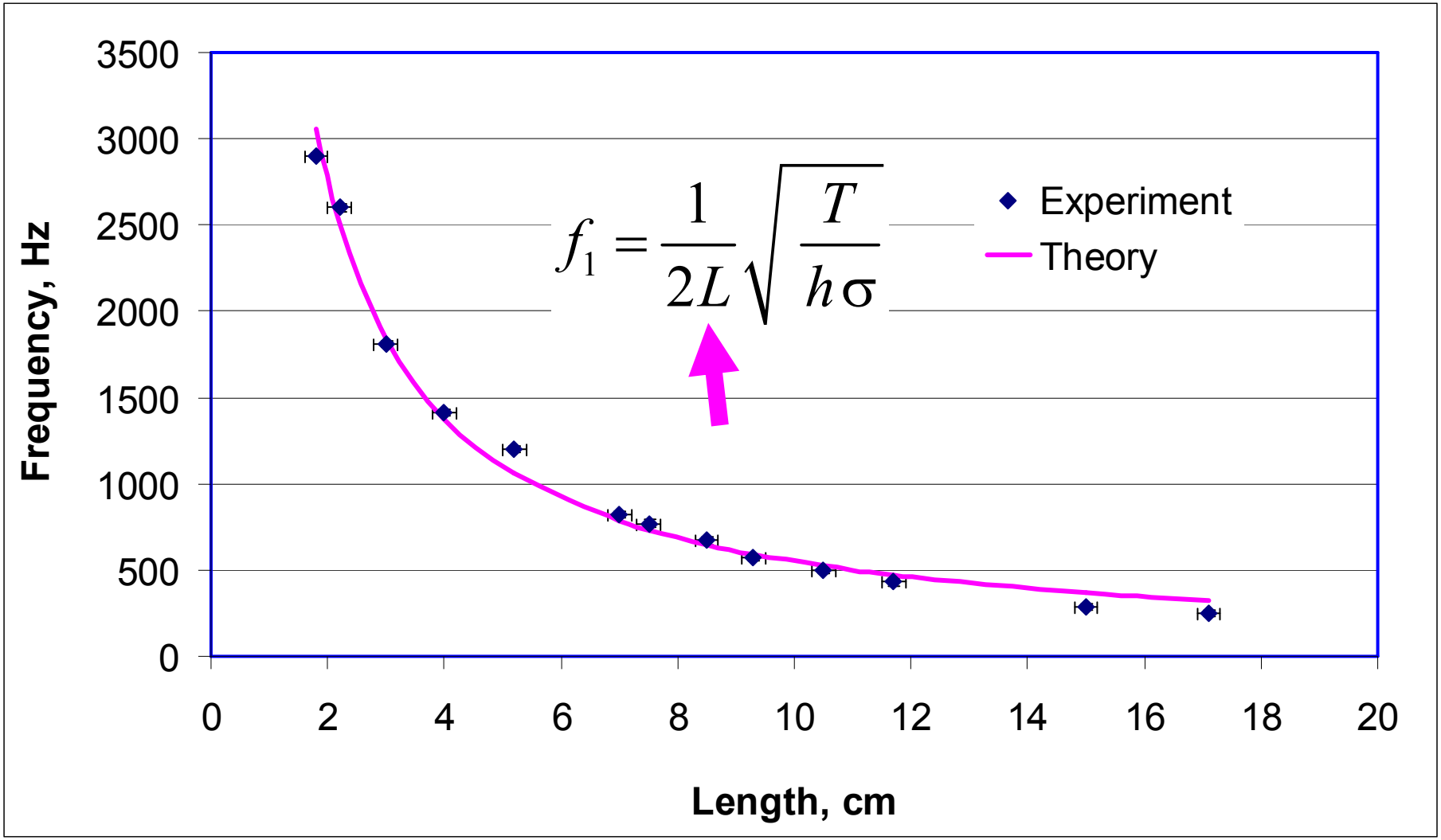
Surface density

Width

Setup #2

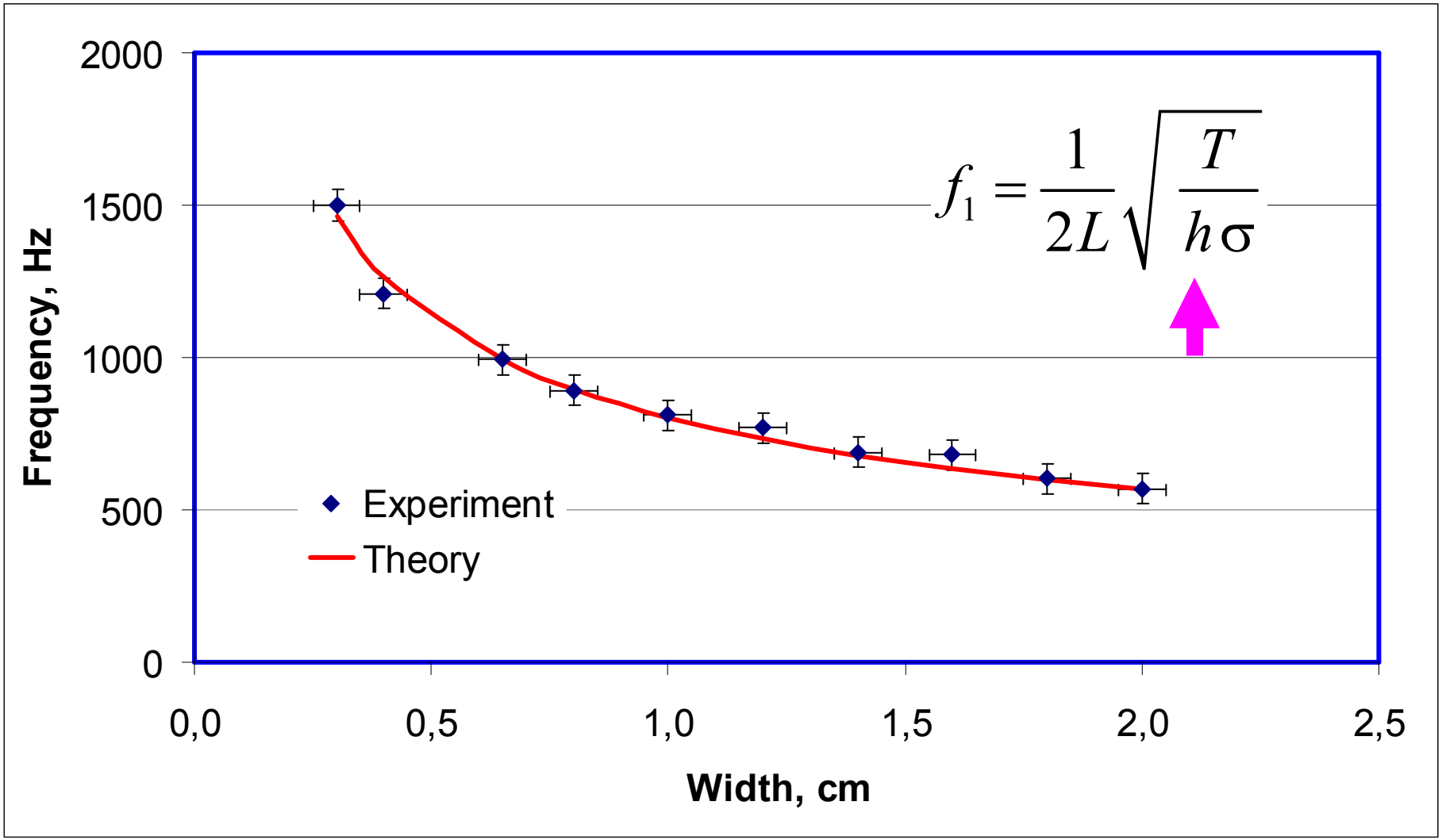


Frequency vs. length



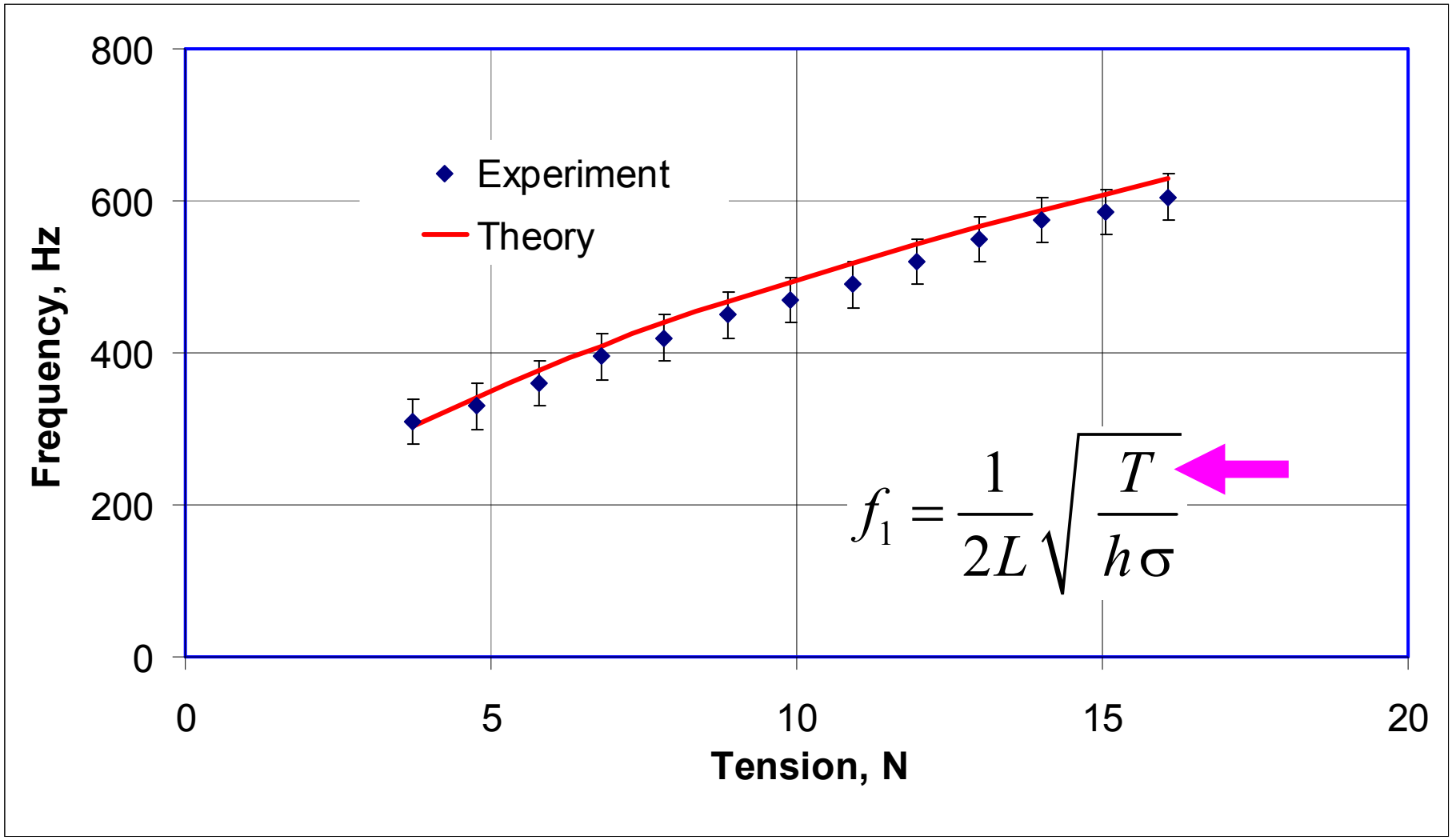
Paper 80 g/m^2, width 1 cm, tension 10 N

Frequency vs. width



Paper 80 g/m^2, length 5.3 cm, tension 5.8 H

Frequency vs. tension



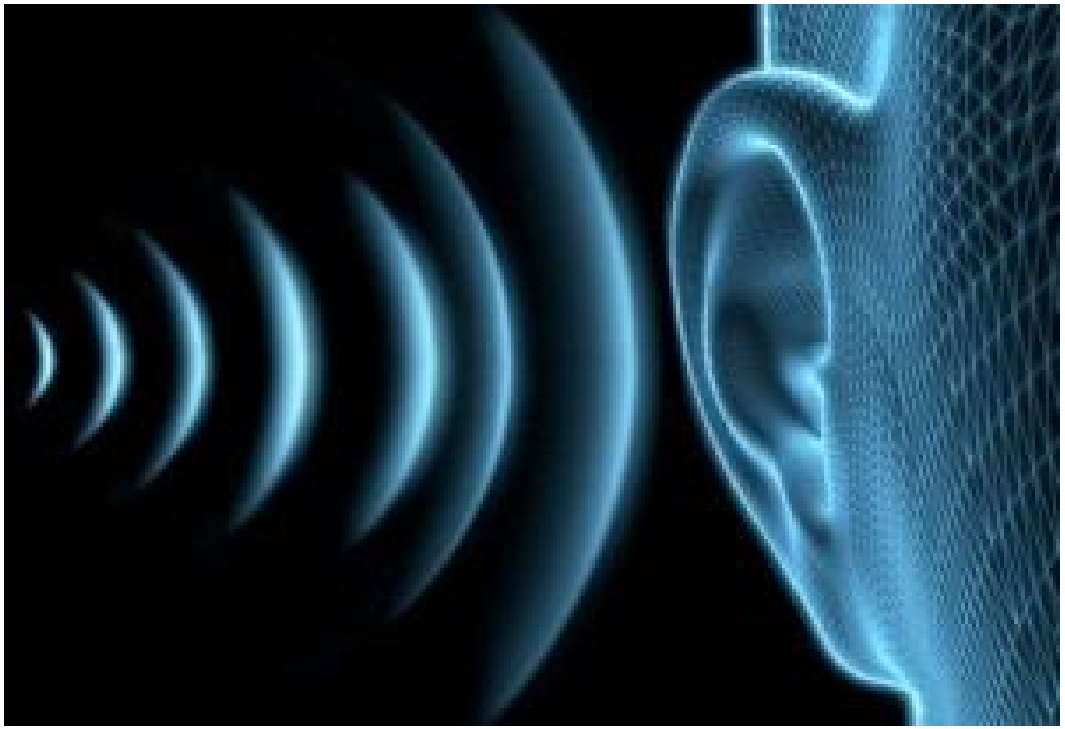
Paper 80 g/m^2, width 1.5 cm, length 9.2 cm

Generation of sound

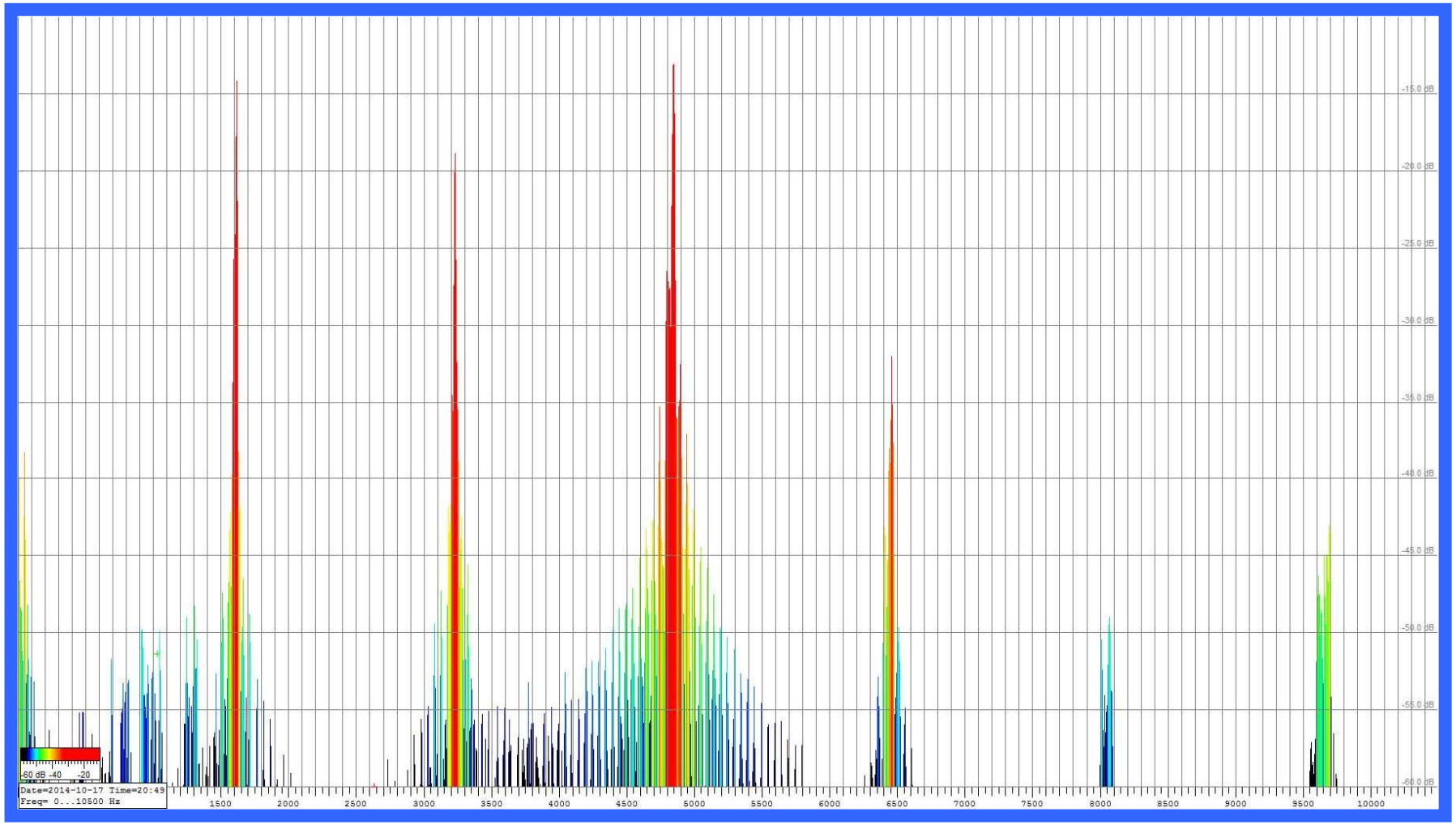
Generation of sound

Sound arises due to periodical compressions and depressions in the air.

Its frequency is equal to the frequency of these pulsations.

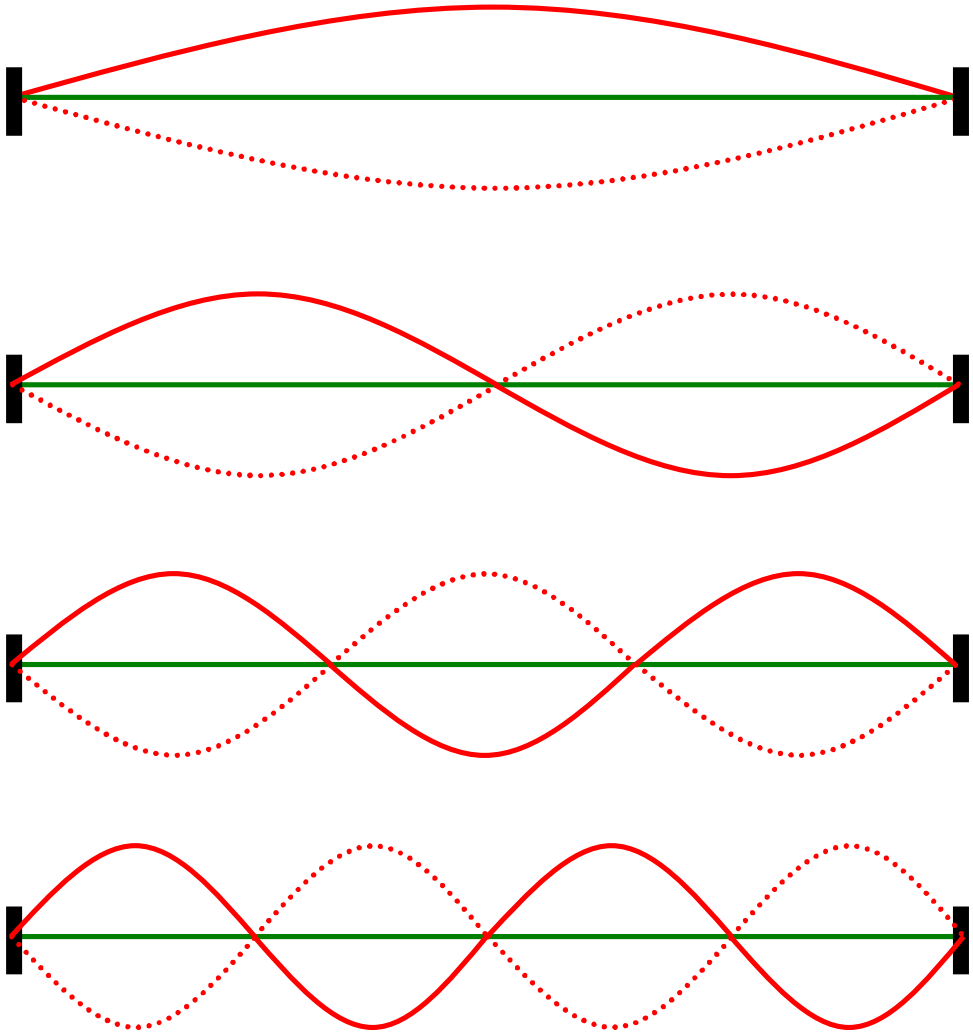


Typical sound spectrum



1600 Hz 3200 Hz 4800 Hz 6400 Hz 8000 Hz 9600 Hz

Natural modes of oscillations



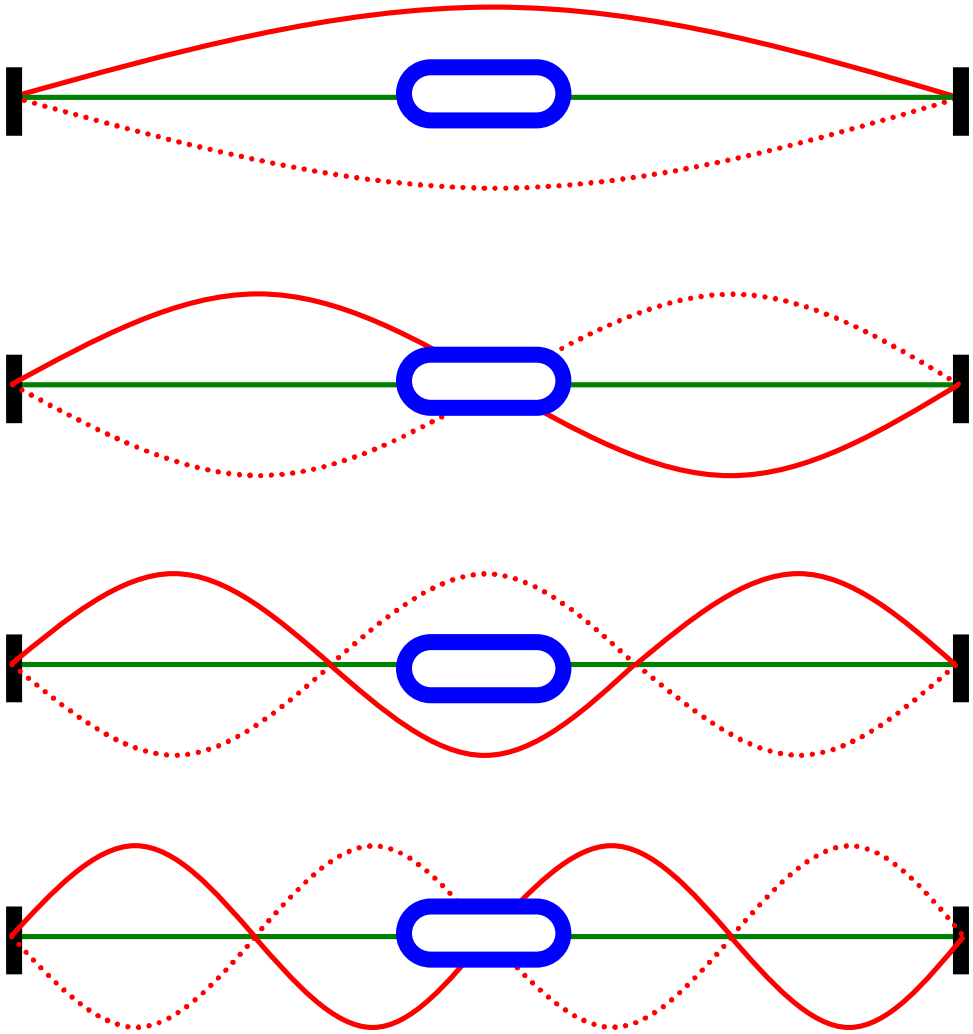
f_1

$f_2 = 2f_1$

$f_3 = 3f_1$

$f_4 = 4f_1$

Exclusion of even harmonics



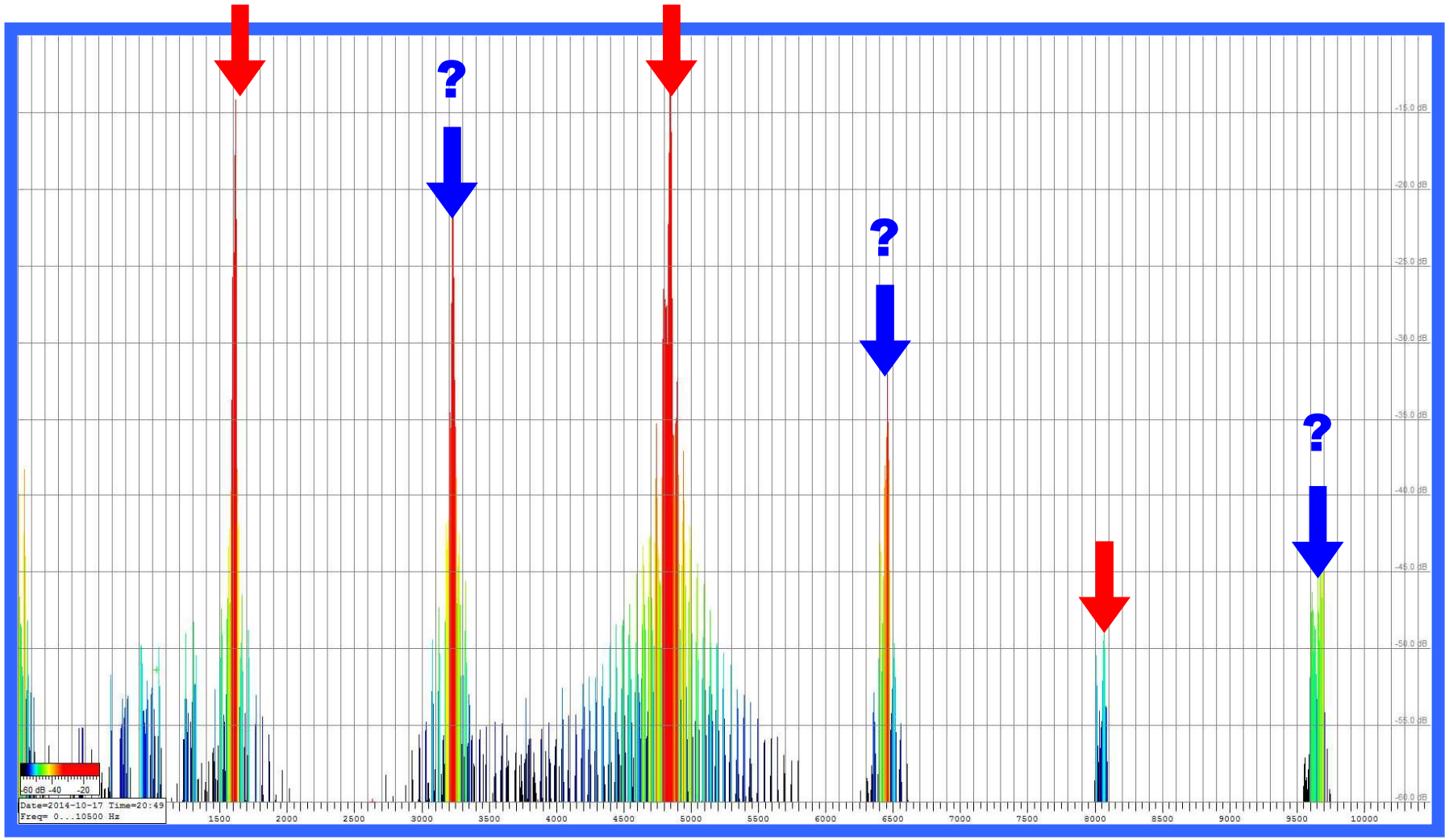
f_1

$f_2 = 2f_1$

$f_3 = 3f_1$

$f_4 = 4f_1$

Even harmonics are not excluded



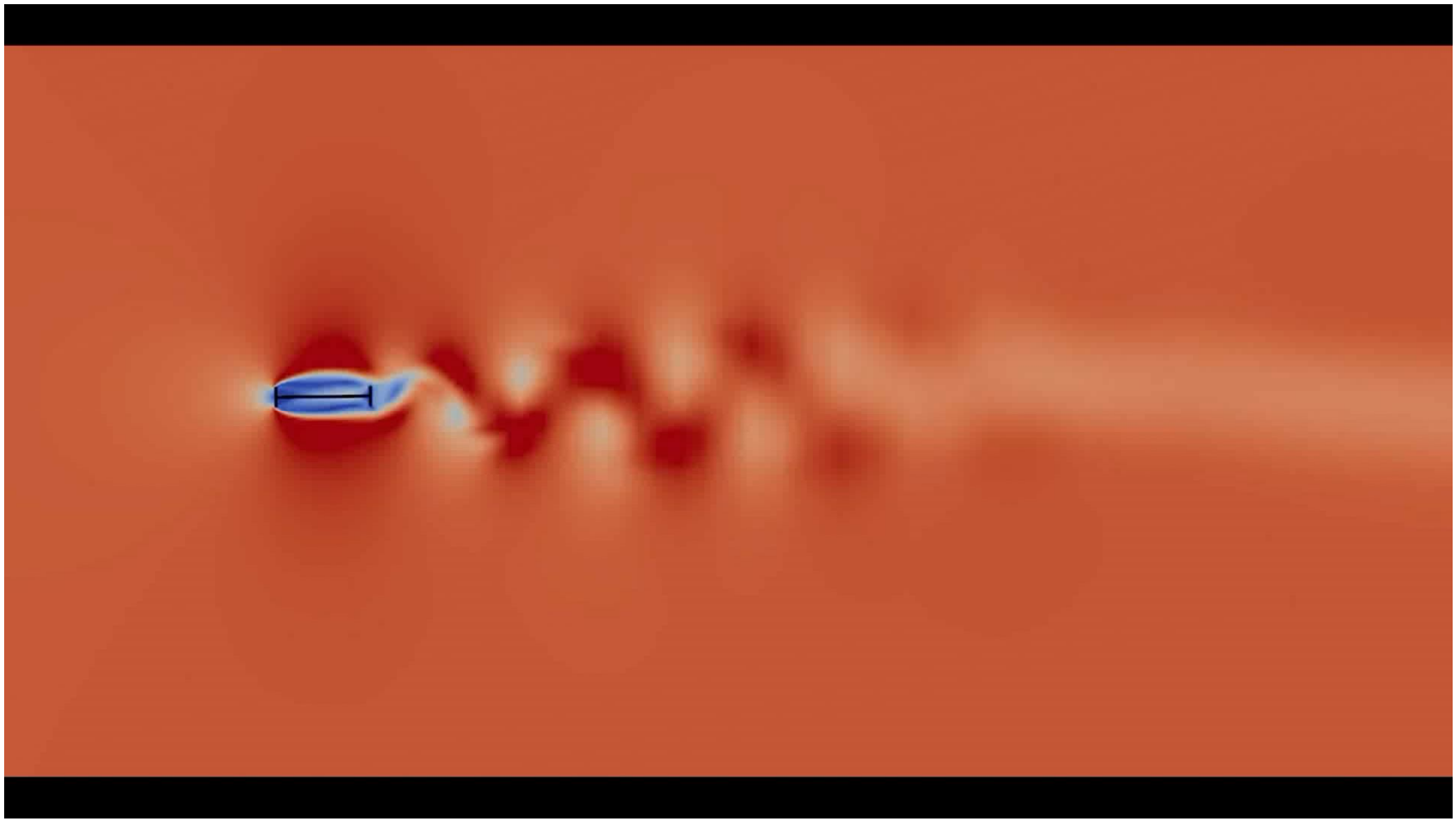
1600 Hz 3200 Hz 4800 Hz 6400 Hz 8000 Hz 9600 Hz

Vertices and even harmonics

2 vertices in a period — 2nd harmonic

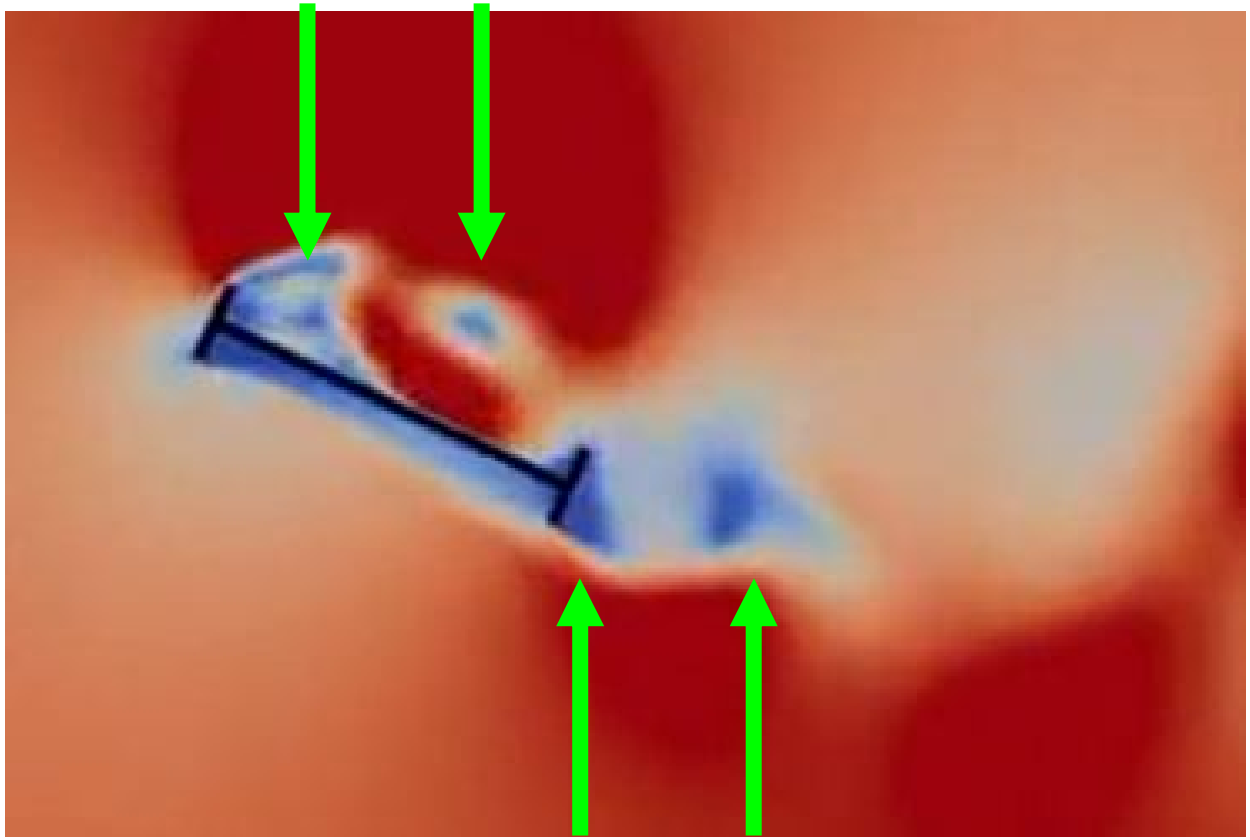
4 vertices in a period — 4th harmonic

Computer simulation (video)



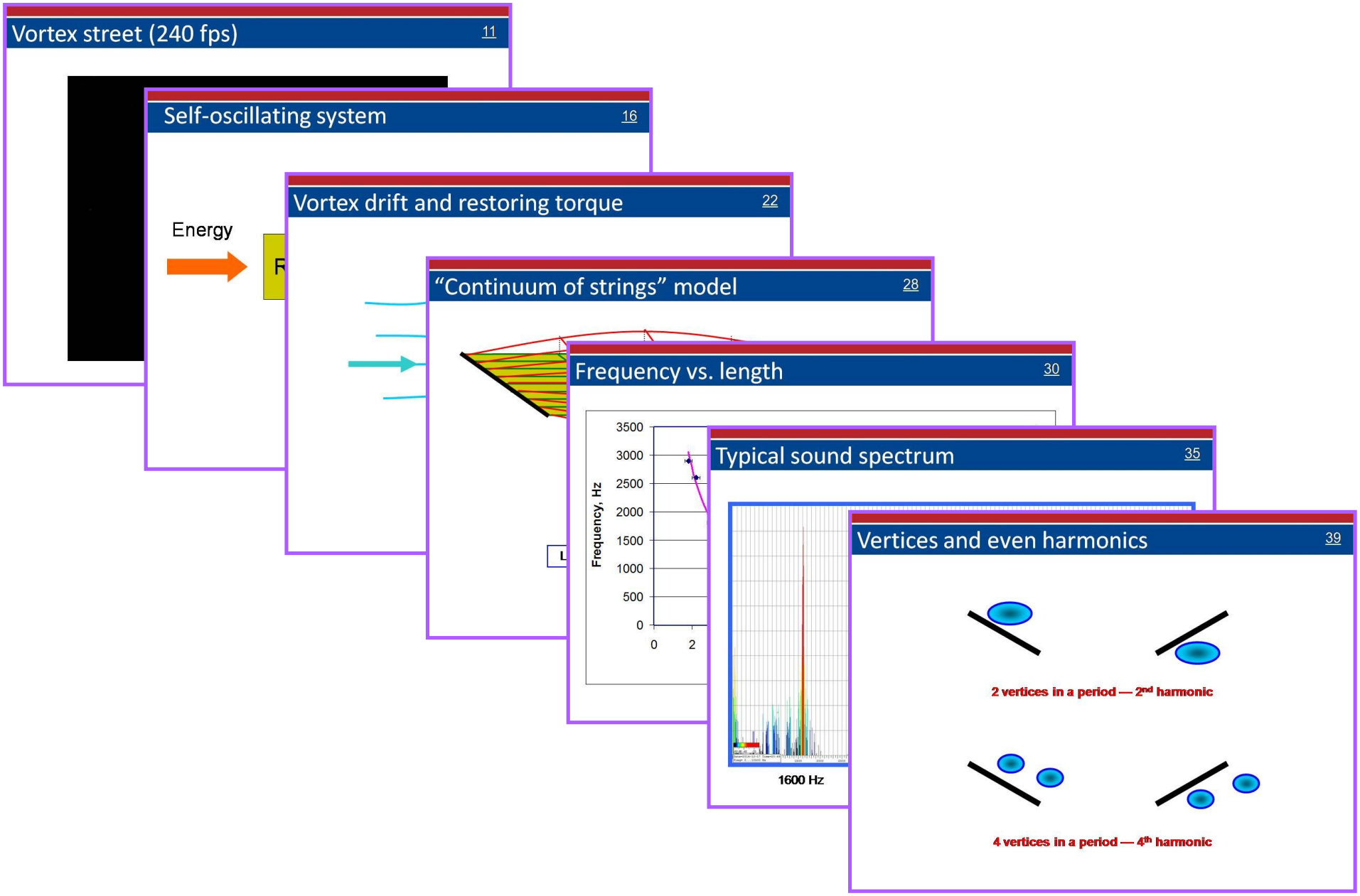
Daniel Wei (2011) http://www.youtube.com/watch?v=YzvFxF5LrRA

2 vortices at every side



Summary

Main results



References

- Billah K.Y., Scanlan R.H. (1991) “Resonance, Tacoma Narrows bridge failure, and undergraduate physics textbooks”. *Am. J. Phys*. **59**, 118–124.
- Green D., Unruh W.G. (2006) “The failure of the Tacoma bridge: A physical model”. *Am. J. Phys*. **74**, 706–716.

Thank you for your attention!