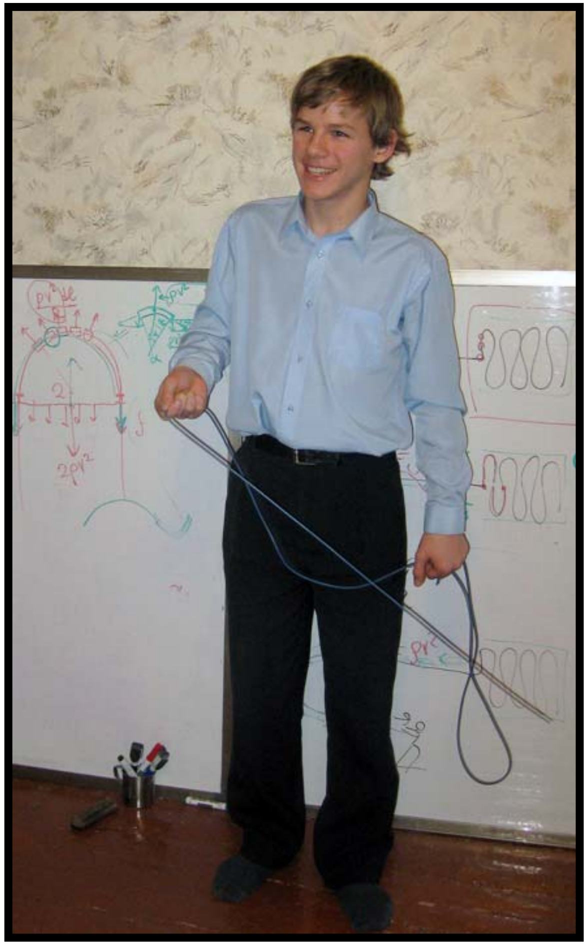
Cutting the air

When a piece of thread is whirled around with a small mass attached to its free end, a distinct noise is emitted. Study the origin of this noise and the relevant parameters.

Yuliya Sorochikhina, Russia

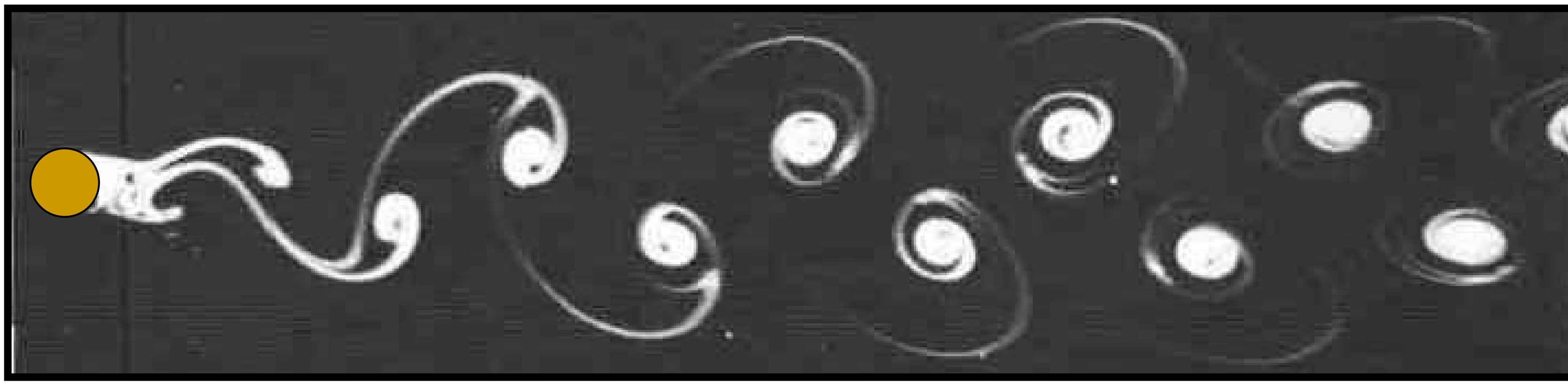
First observations



- The higher is the rotating frequency, the higher and louder is the sound.
- The longer is the thread, the higher and louder is the sound.
- The bigger is the diameter of the thread, the lower is the sound.

Generation of Aeolian tones

If Re > 50, behind a moving thread von Karman vortex street appears. Frequency of the tone is equal to the frequency of vortex shedding.



Empirical Strouhal formula (1878):

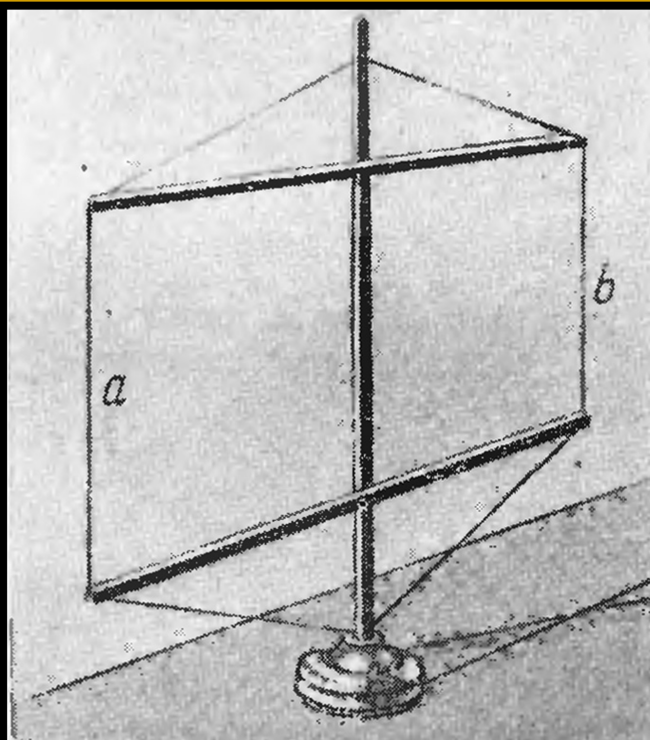
Tone frequency

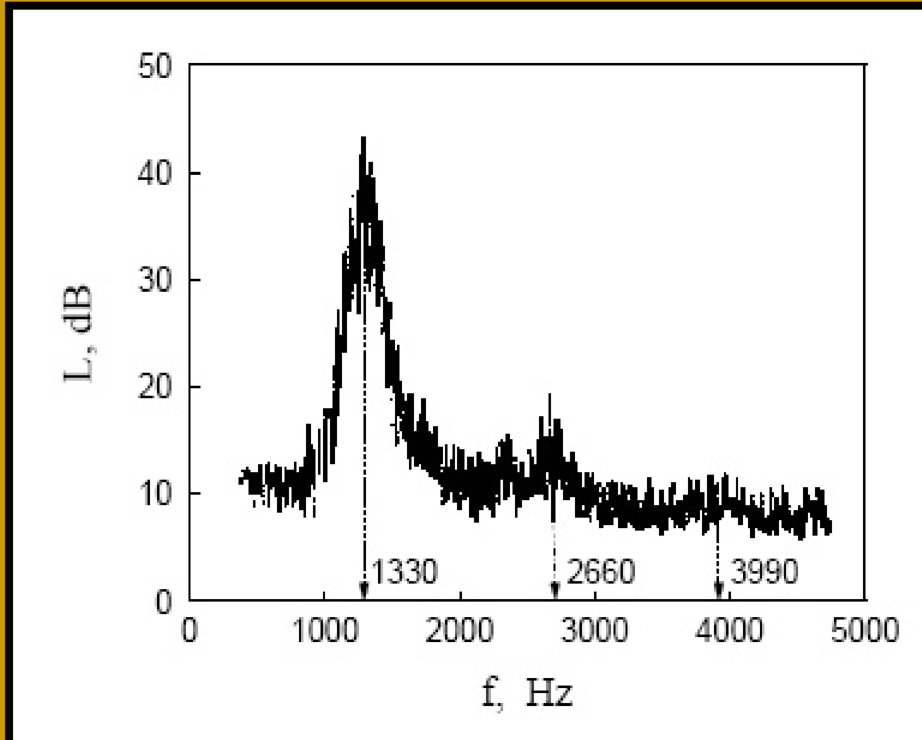
$$f \approx \frac{v}{5 \cdot d}$$

Thread velocity

Thread diameter

Strouhal experiment

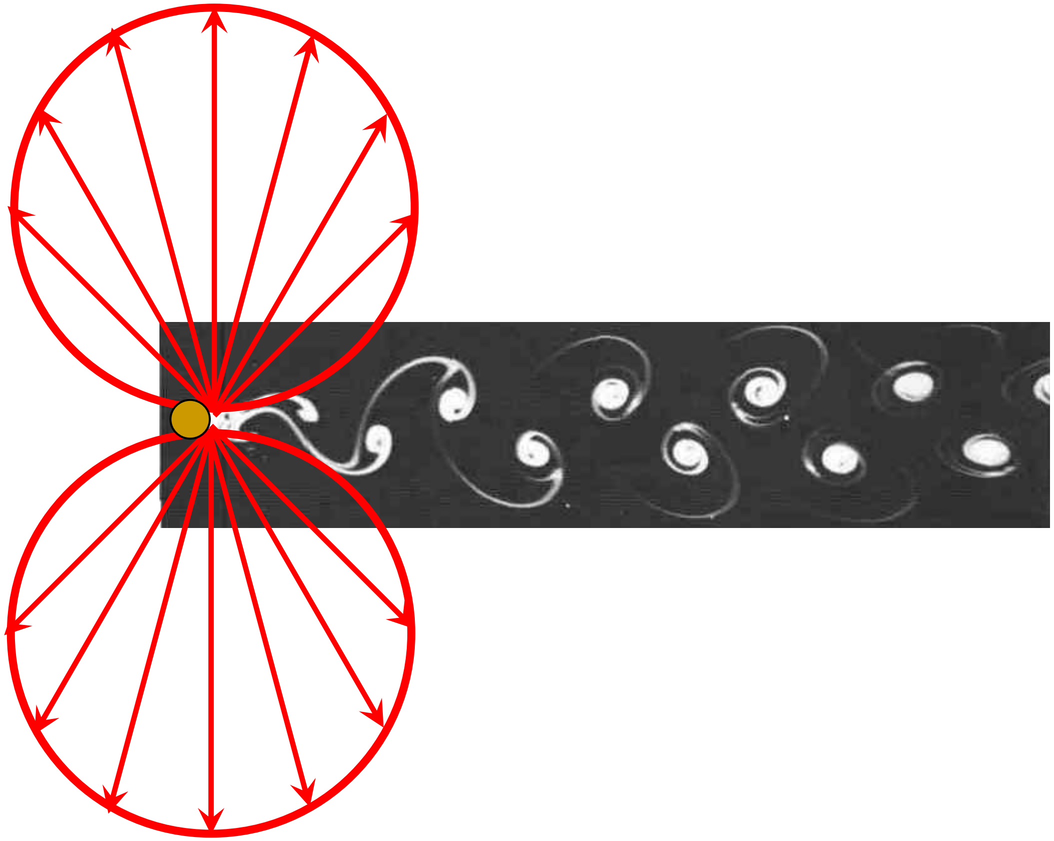




V. Strouhal (1878)

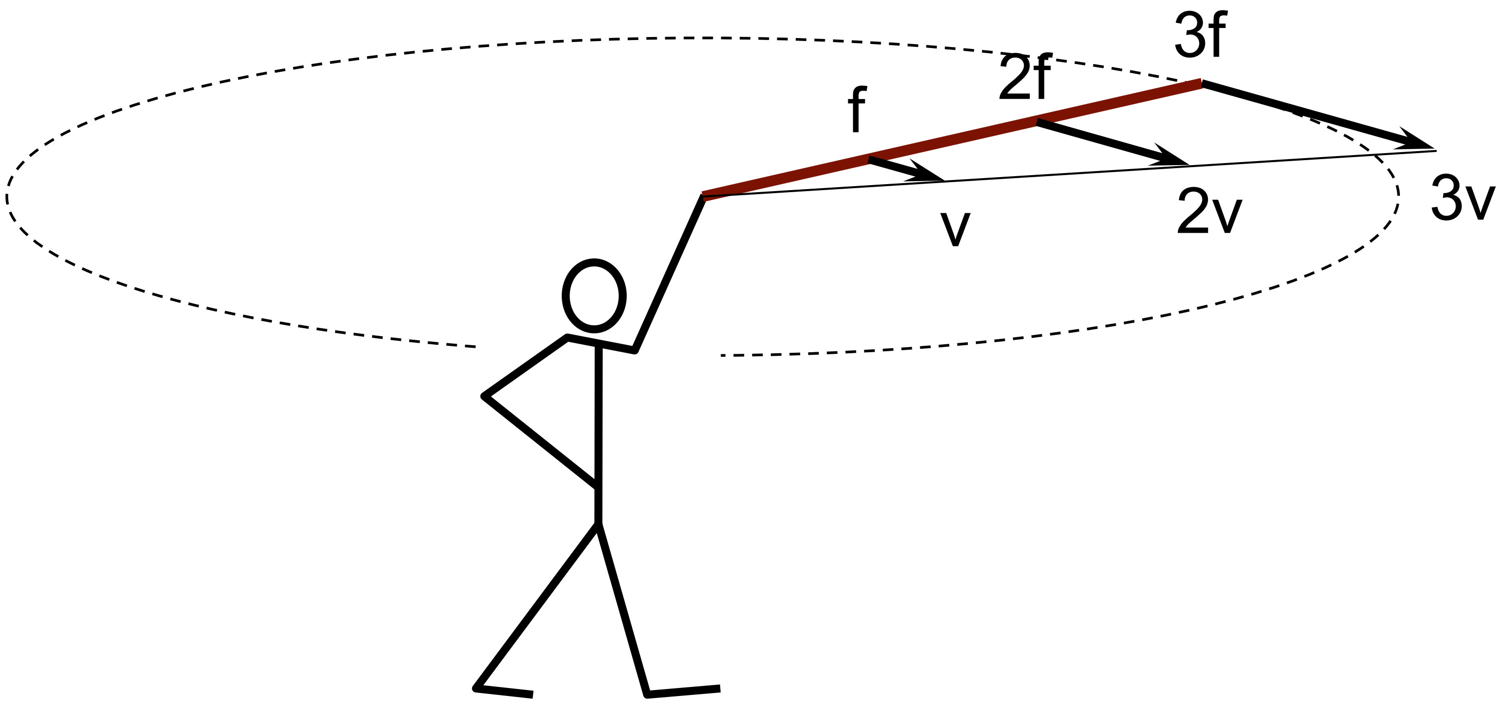
W. Holle (1938)

Radiation pattern



The sound is generated by transverse pressure pulsations at the downstream side of the thread. It propagates mainly perpendicular to the thread and the flow.

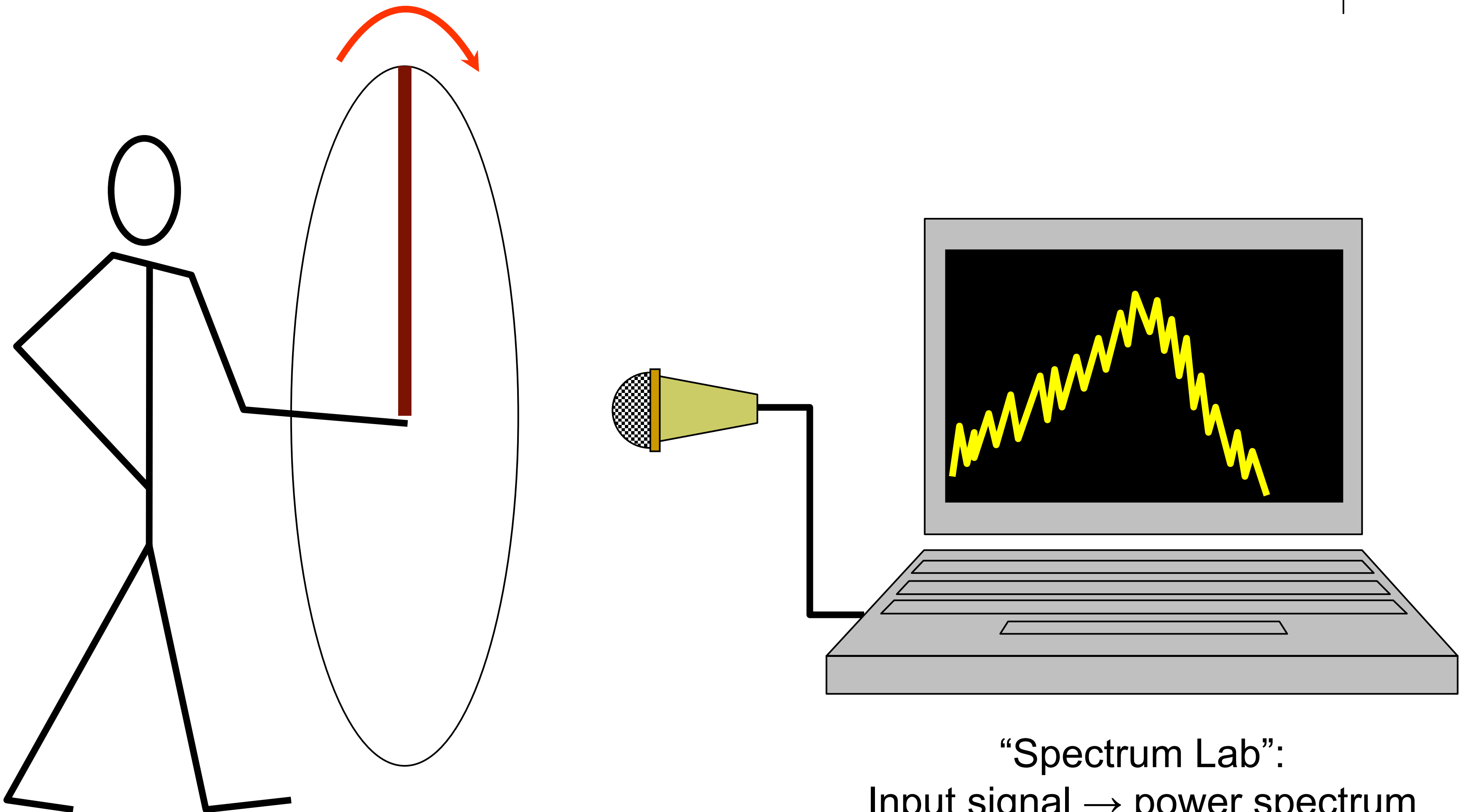
Different parts of the thread generate different tones



Sound frequency is proportional to the thread velocity.
The thread velocity is proportional to the radius.

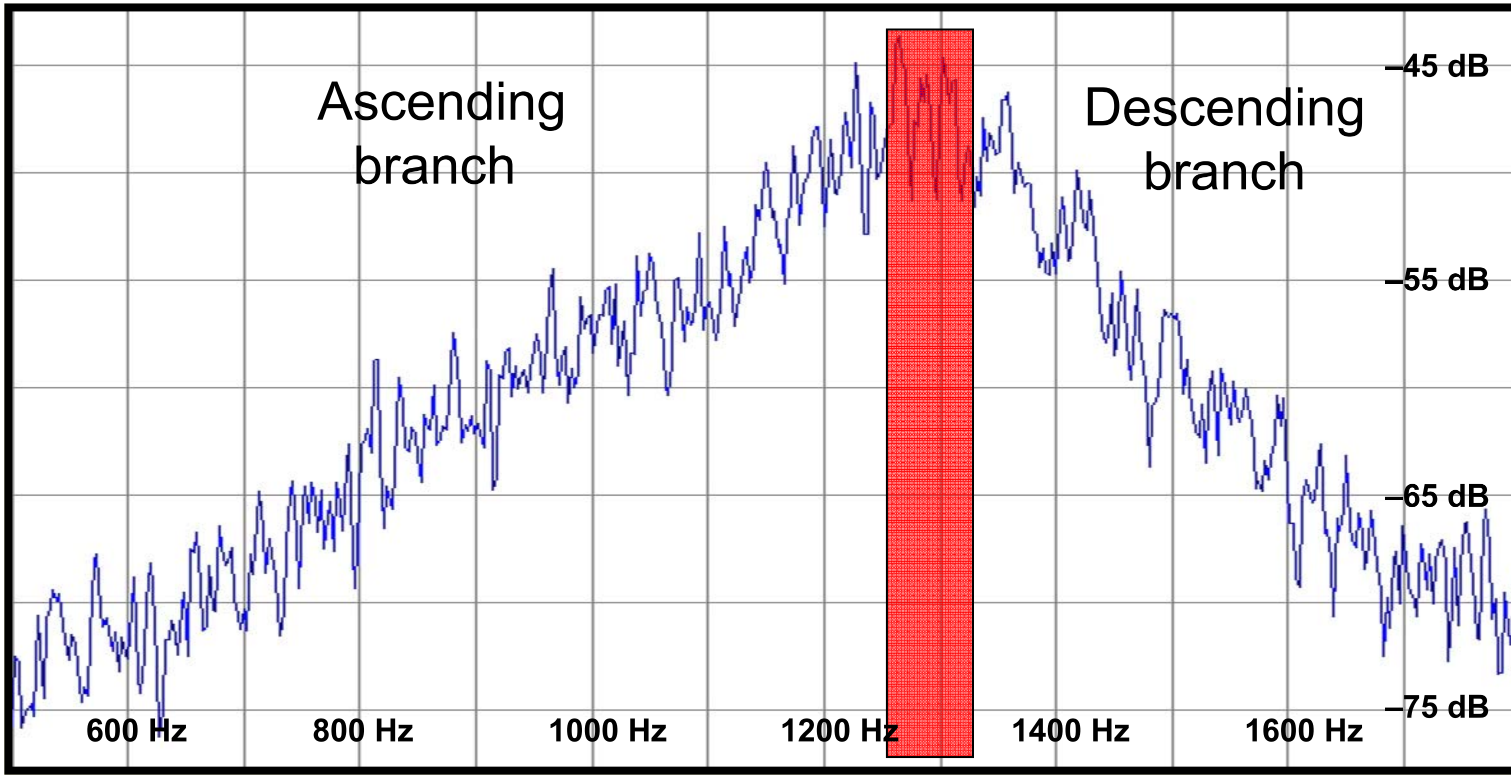
Sound frequency is proportional to the radius.

Scheme of the experiment



“Spectrum Lab”:
Input signal → power spectrum
(by Fourier transformation)

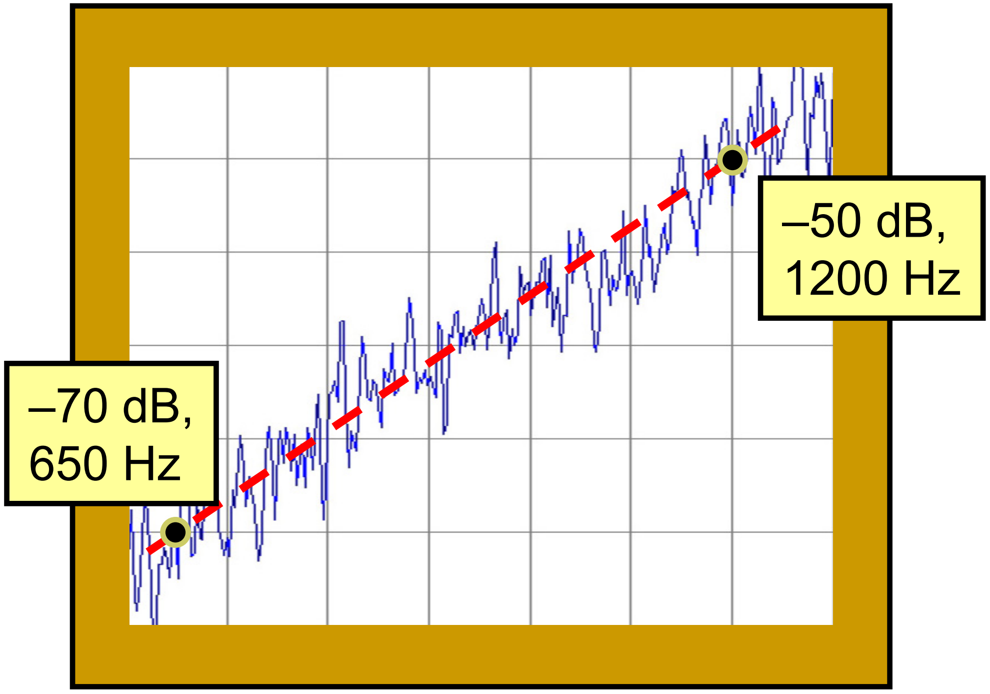
Spectrum of the rotated thread



Diameter of the rope = 4 mm, length = 80–85 cm. Rotation frequency = 5 Hz. Theoretically predicted sound frequency at the end of the rope = **1250–1330 Hz**.

Power-law frequency-intensity dependence

$$I \sim f^{\alpha} \Rightarrow \frac{I_1}{I_2} = \left(\frac{f_1}{f_2}\right)^{\alpha}$$



$$\Delta I = 20 \text{ dB}$$

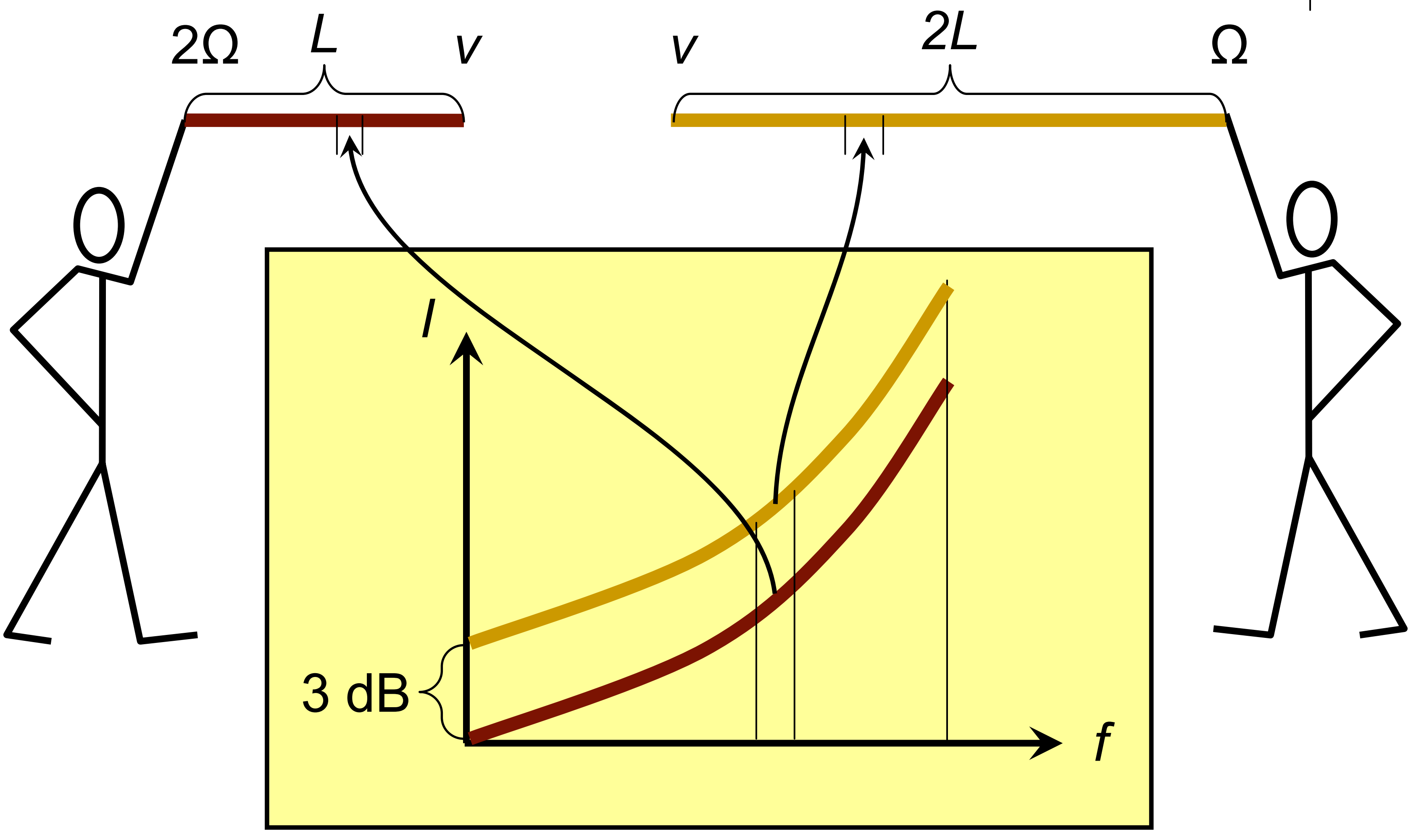
$$\frac{I_1}{I_2} = 100$$

$$\frac{f_1}{f_2} = 1.85 \pm 0.1$$

$$100 = (1.85)^{\alpha}$$

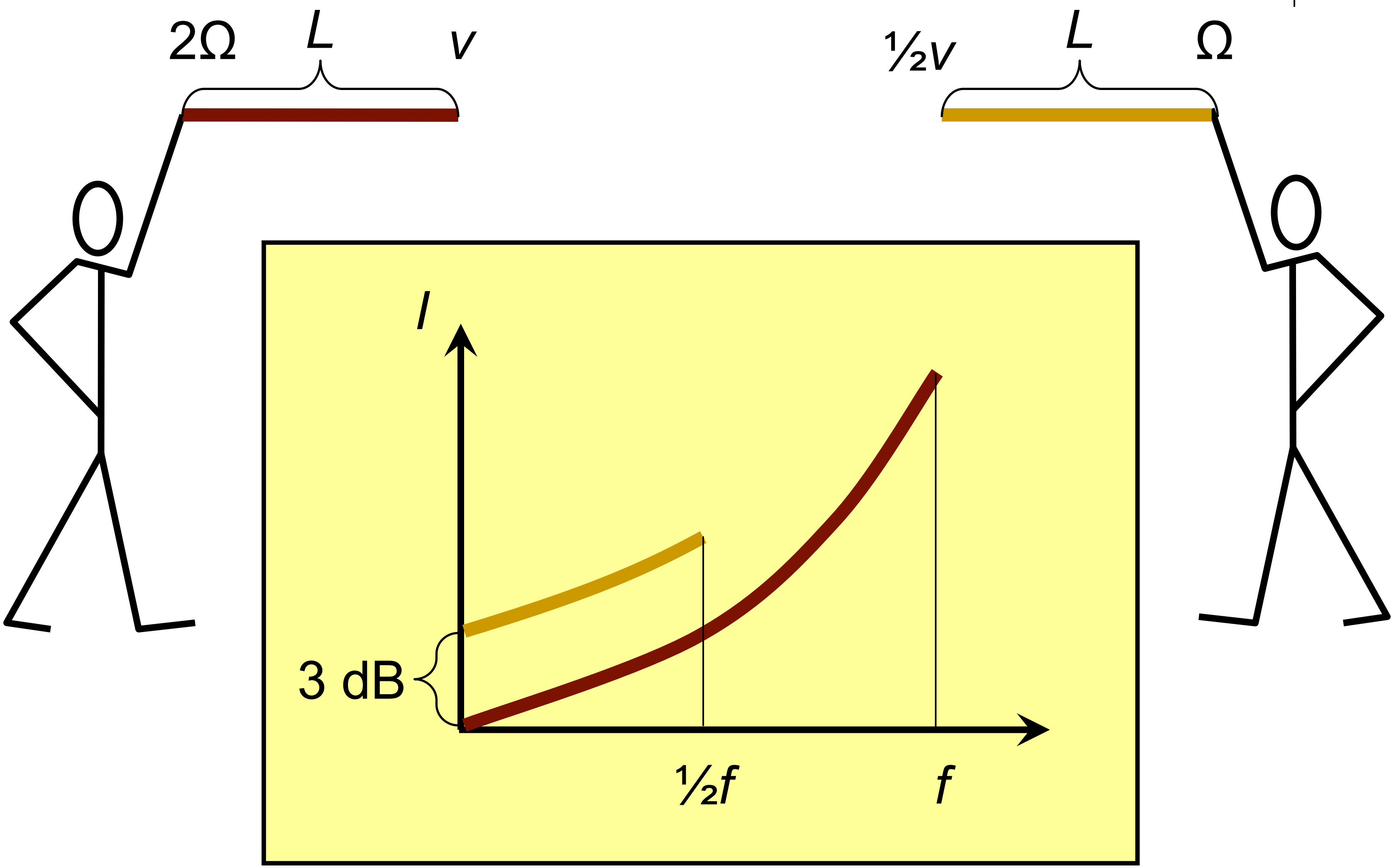
$\alpha = 7.5 \pm 0.5$

The same end velocity, different rotation frequencies

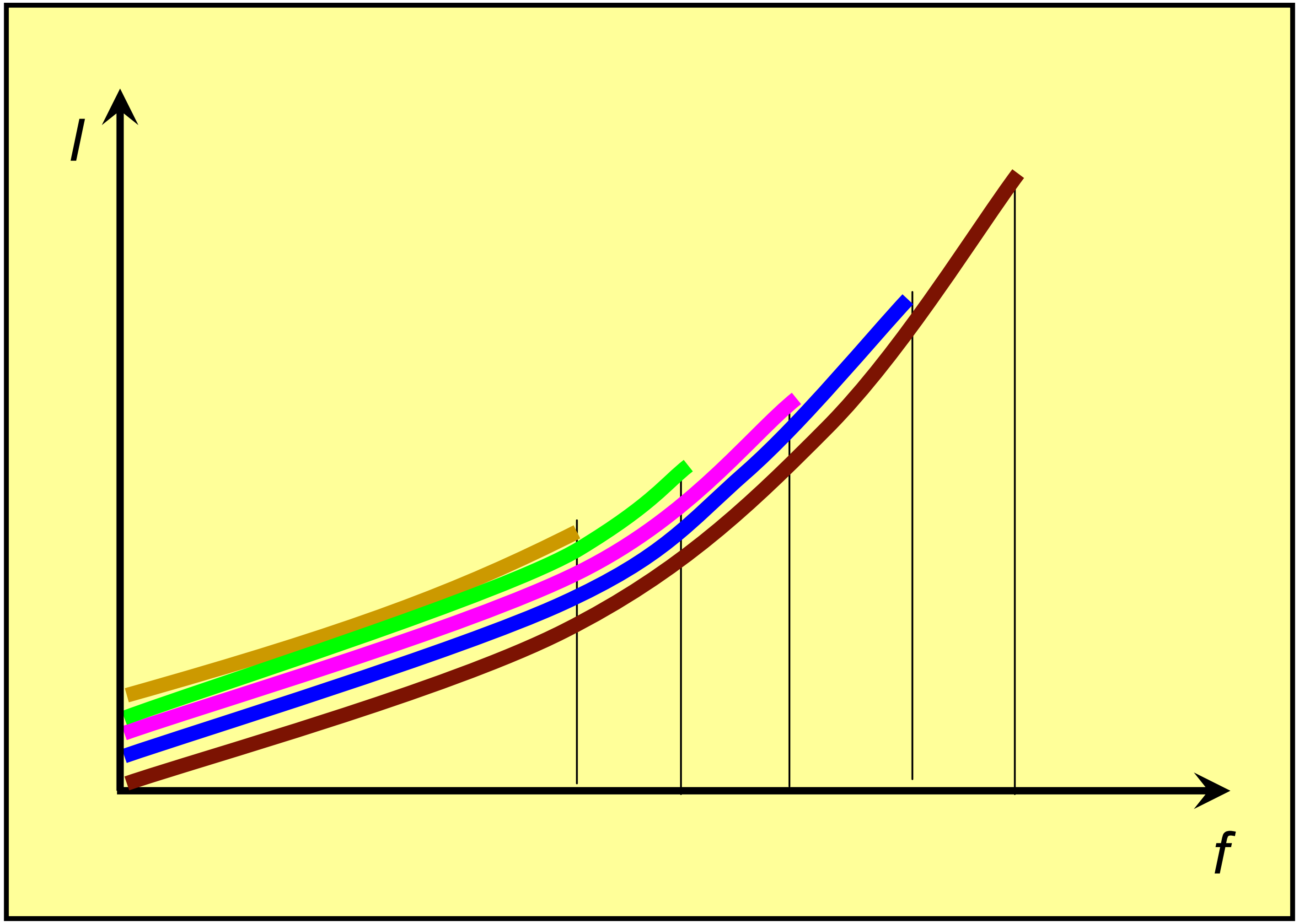


2 times louder ≈ 3 dB higher

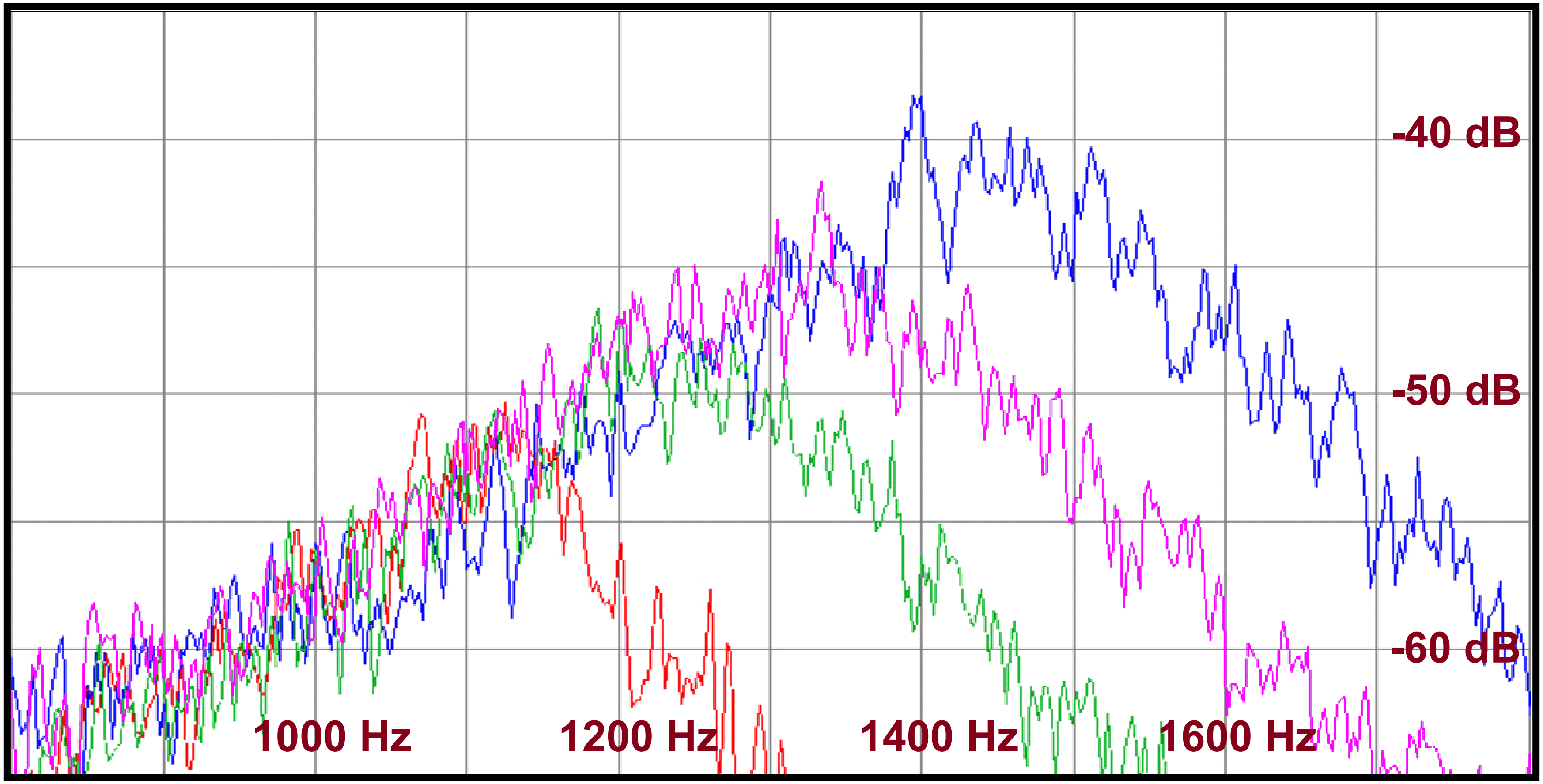
The same length, different rotation frequencies



The same length, different rotation frequencies

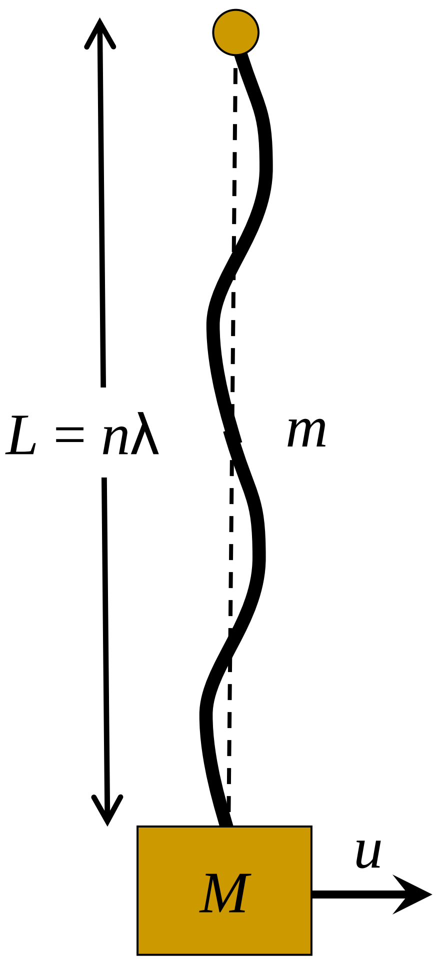


The same length, different rotation frequencies



Diameter of the rope = 4 mm, length = 90 cm.

Excitation of natural oscillations of the thread



Wave velocity: $c = \sqrt{\dfrac{T}{\rho}} = \sqrt{\dfrac{Mu^2}{\rho L}} = u\sqrt{\dfrac{M}{m}}$

Wave frequency: $f_w = \dfrac{c}{\lambda} = \dfrac{nu}{L}\sqrt{\dfrac{M}{m}}$

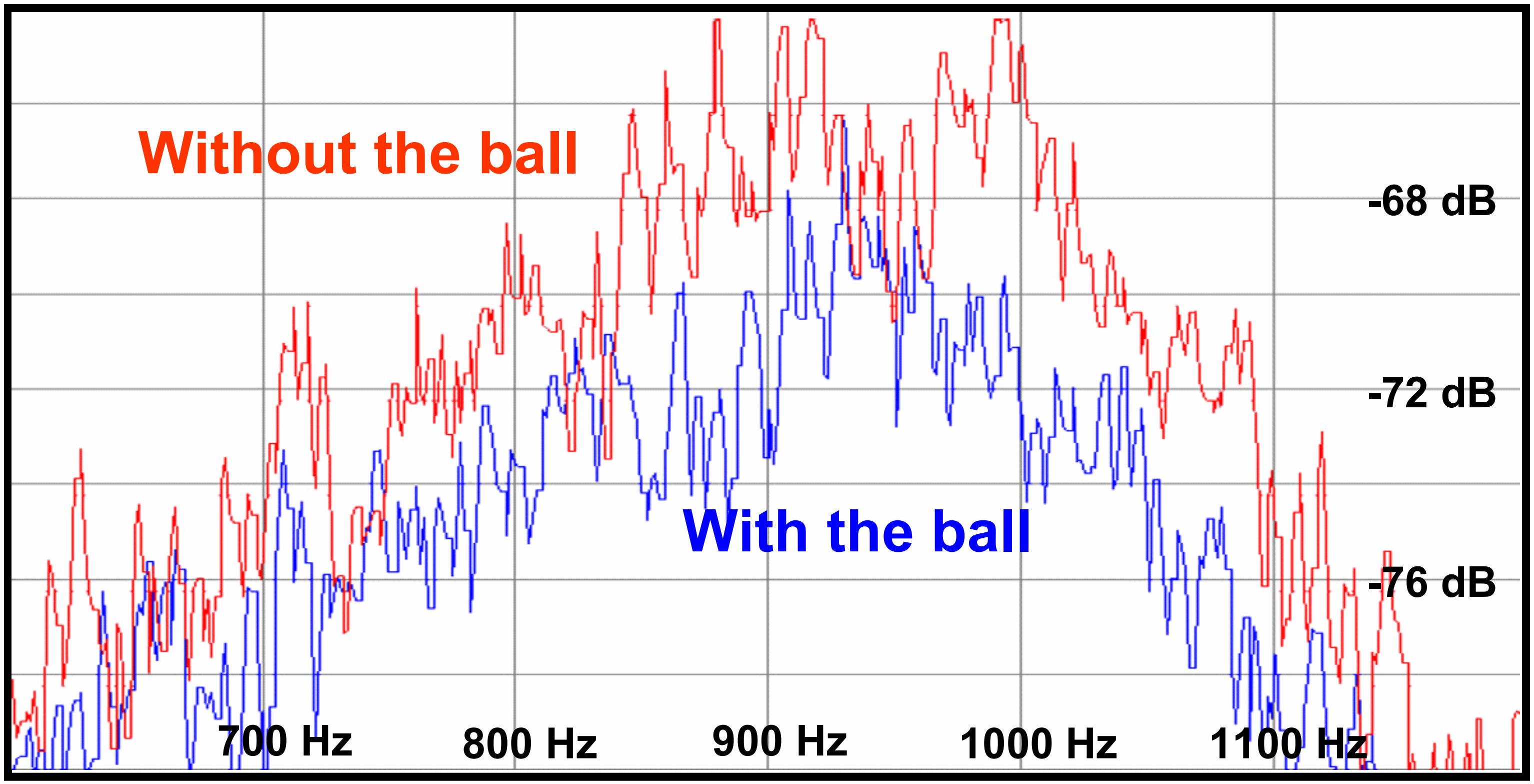
Vortex shading frequency: $f_v = \dfrac{u}{5d}$

If $f_w = f_v$ then $n = \dfrac{L}{5d}\sqrt{\dfrac{m}{M}} \approx 50$

Effect of the end mass

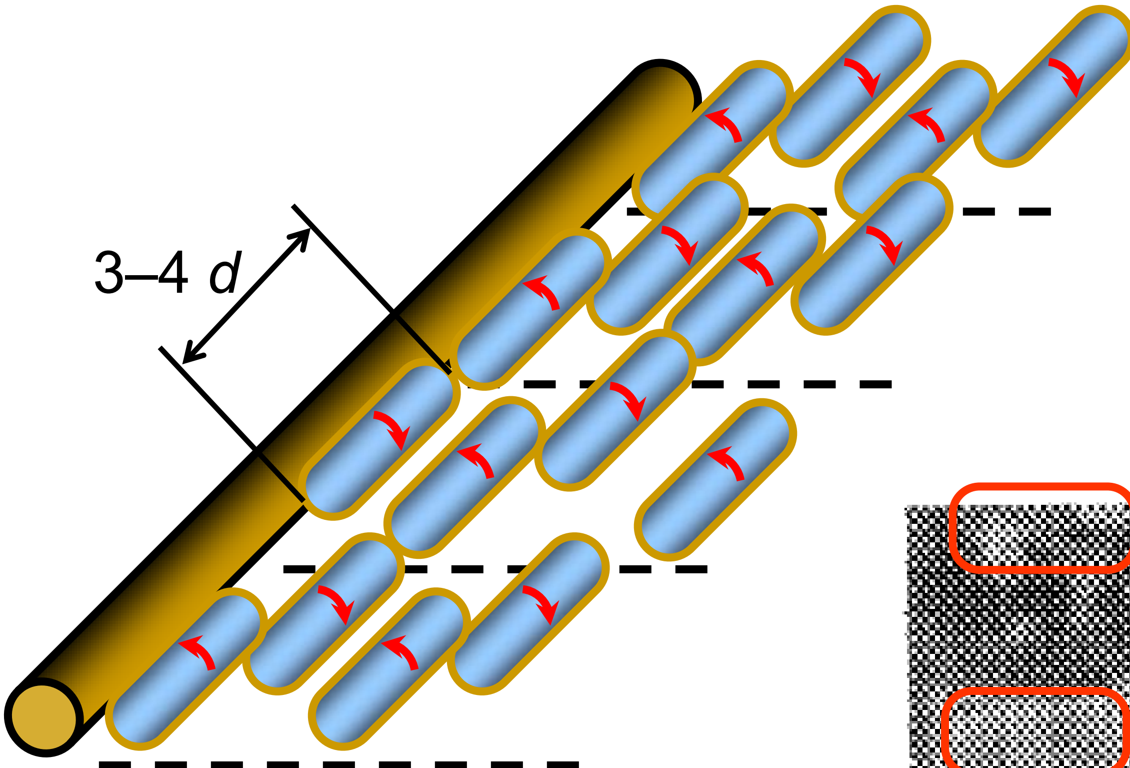
The rope: diameter = 4 mm, length = 70 cm
The end ball: diameter = 5 cm, mass = 17.3 g

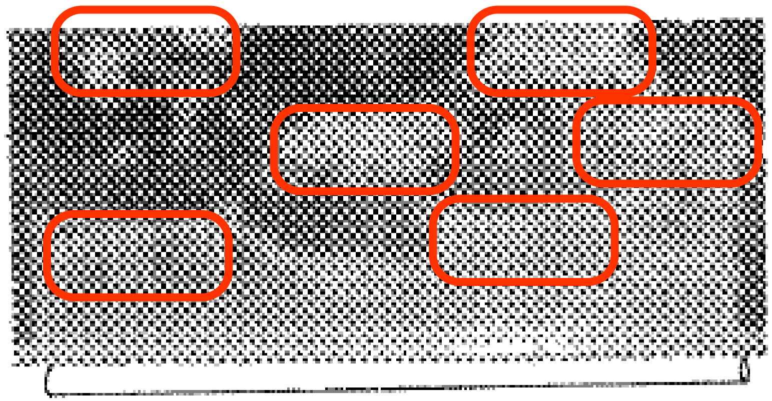
Effect of the end mass



Intensity of sound decreases by ~5 dB.

Correlation length and vortex cells

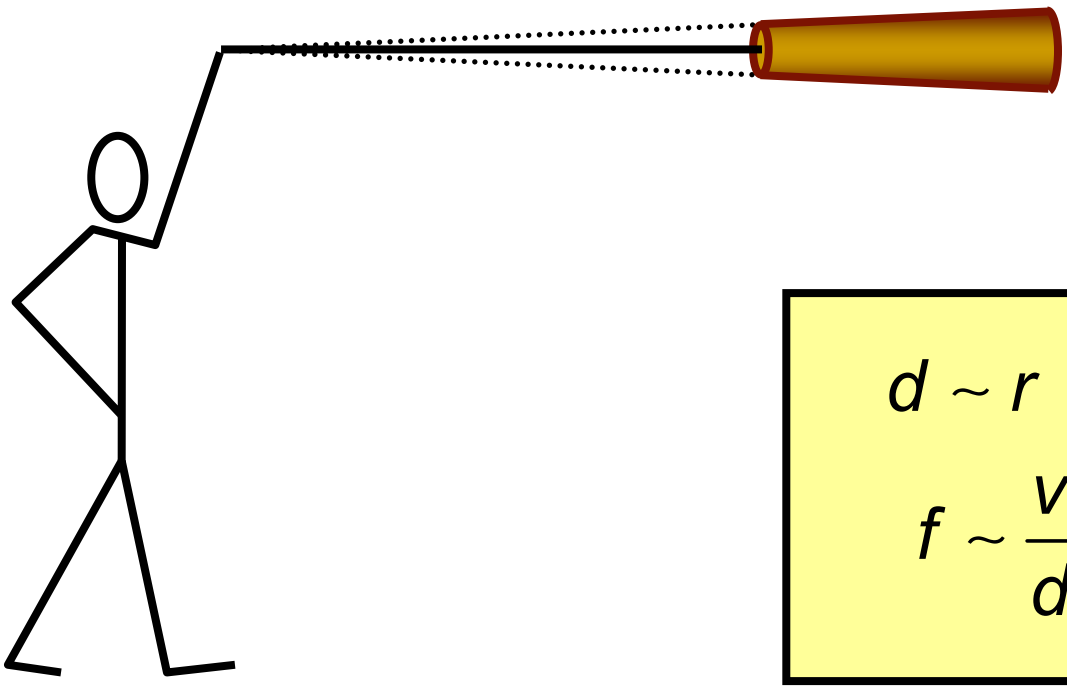




Sumer & Fredsøe 1997

Experiment with a truncated cone

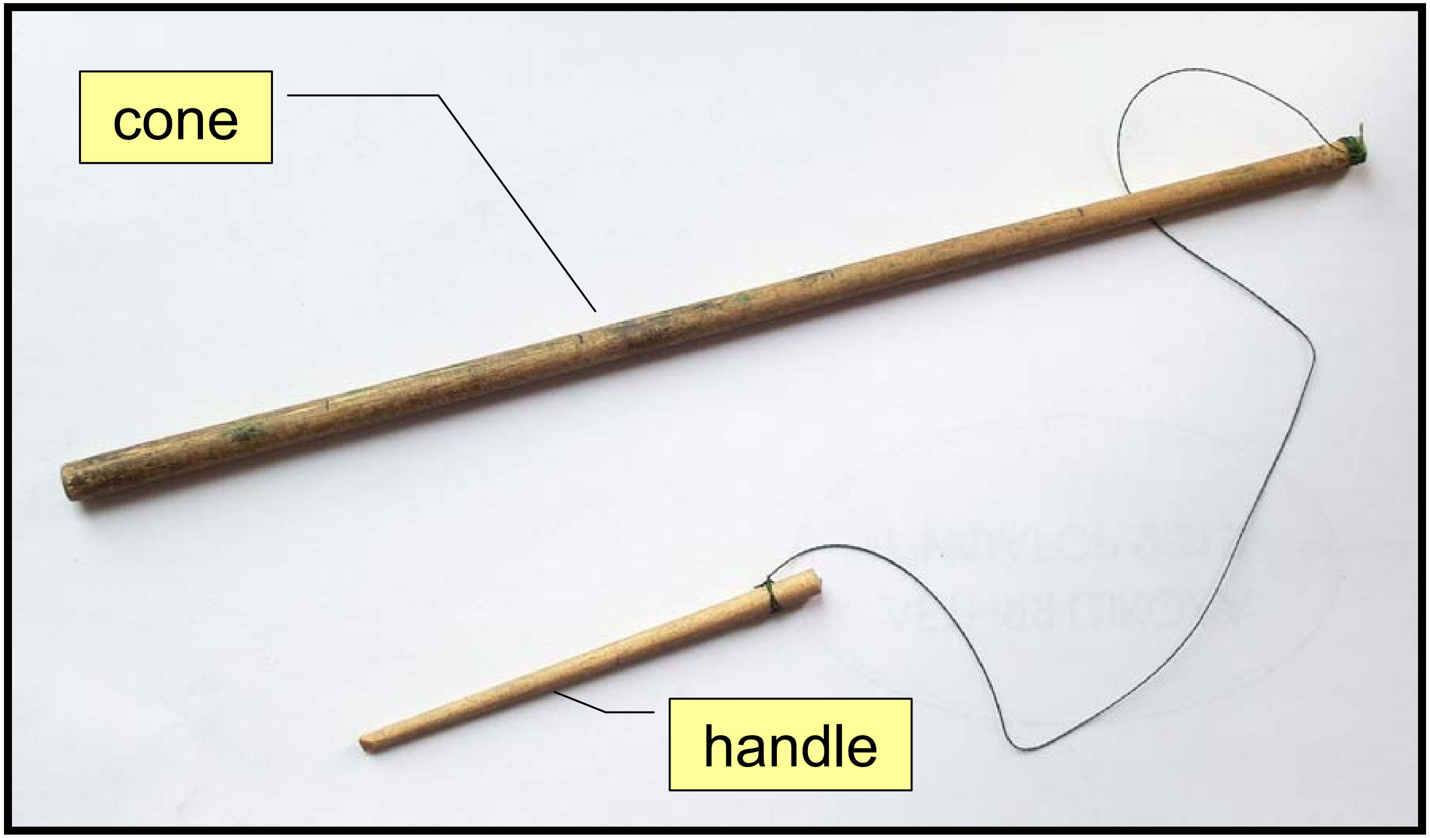
Can we make Strouhal experiment rotating the body at one end?



$$d \sim r \qquad v \sim r$$

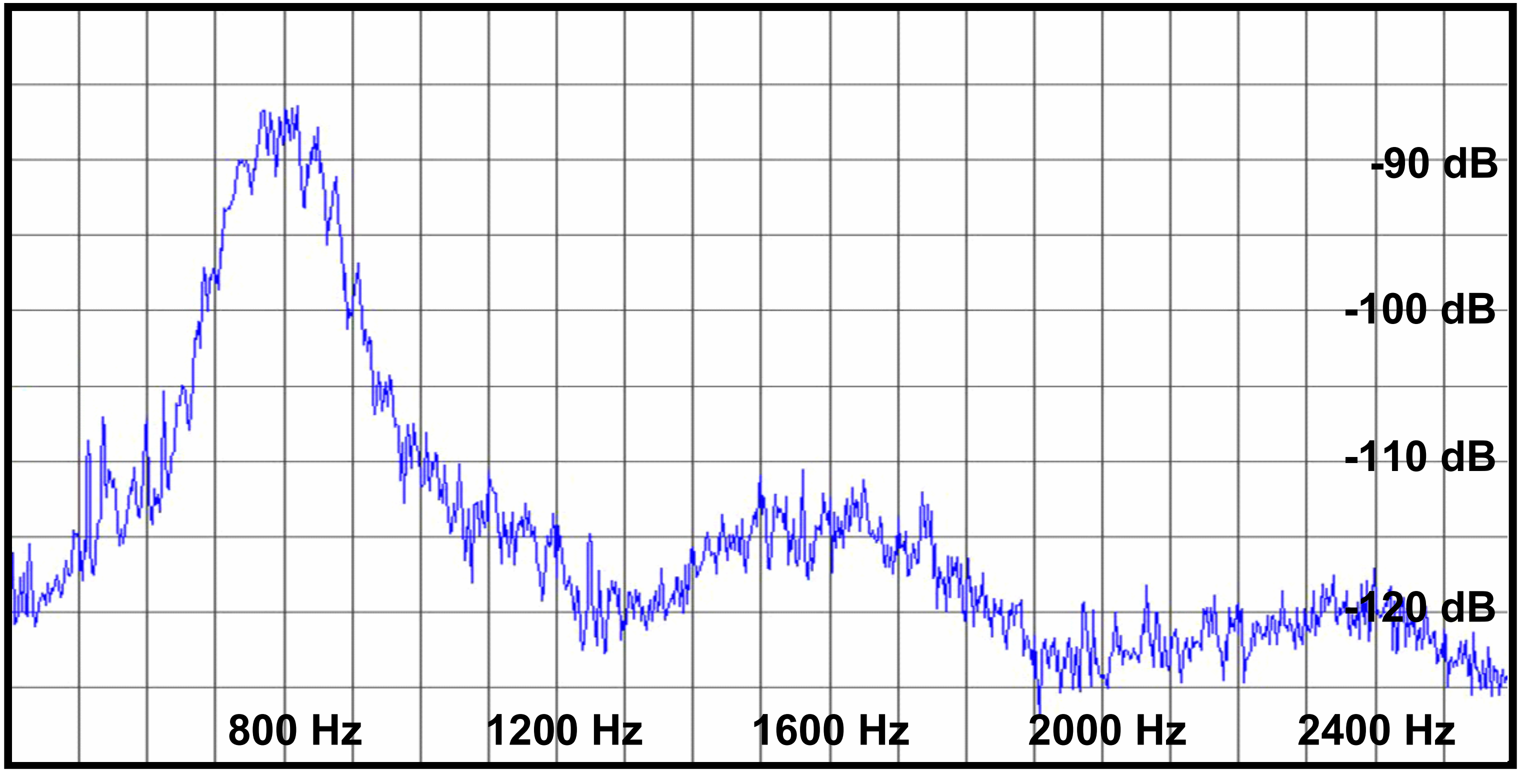
$$f \sim \frac{v}{d} = \text{const}$$

Experiment with a truncated cone

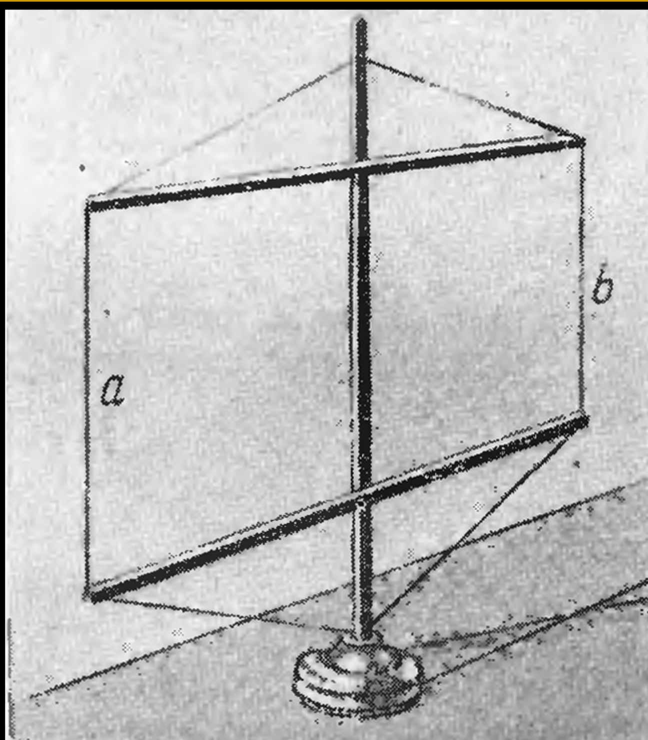


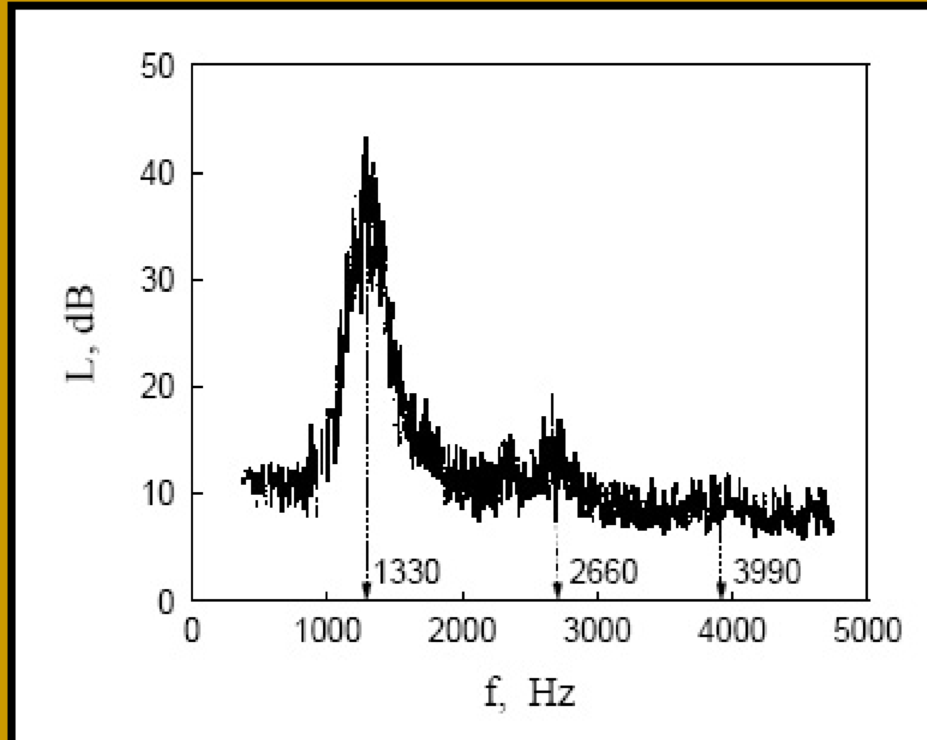
Truncated cone length = 25 cm, thread length = 50 cm,
The cone diameter changes from 4 mm to 6 mm.

Experiment with a truncated cone



Strouhal experiment





V. Strouhal (1878)

W. Holle (1938)

Summary

- First observations with a rope
- Vortex shedding and Strouhal formula
- Thought experiments
- Power spectrum of the rotated rope
- Effect of the end mass
- Correlation length
- Experiment with a truncated cone (new!)

Bibliography

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- Sumer M. B., Fredsøe J. (1997) *Hydrodynamics around cylindrical structures*.
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