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2 Rayleigh Disk

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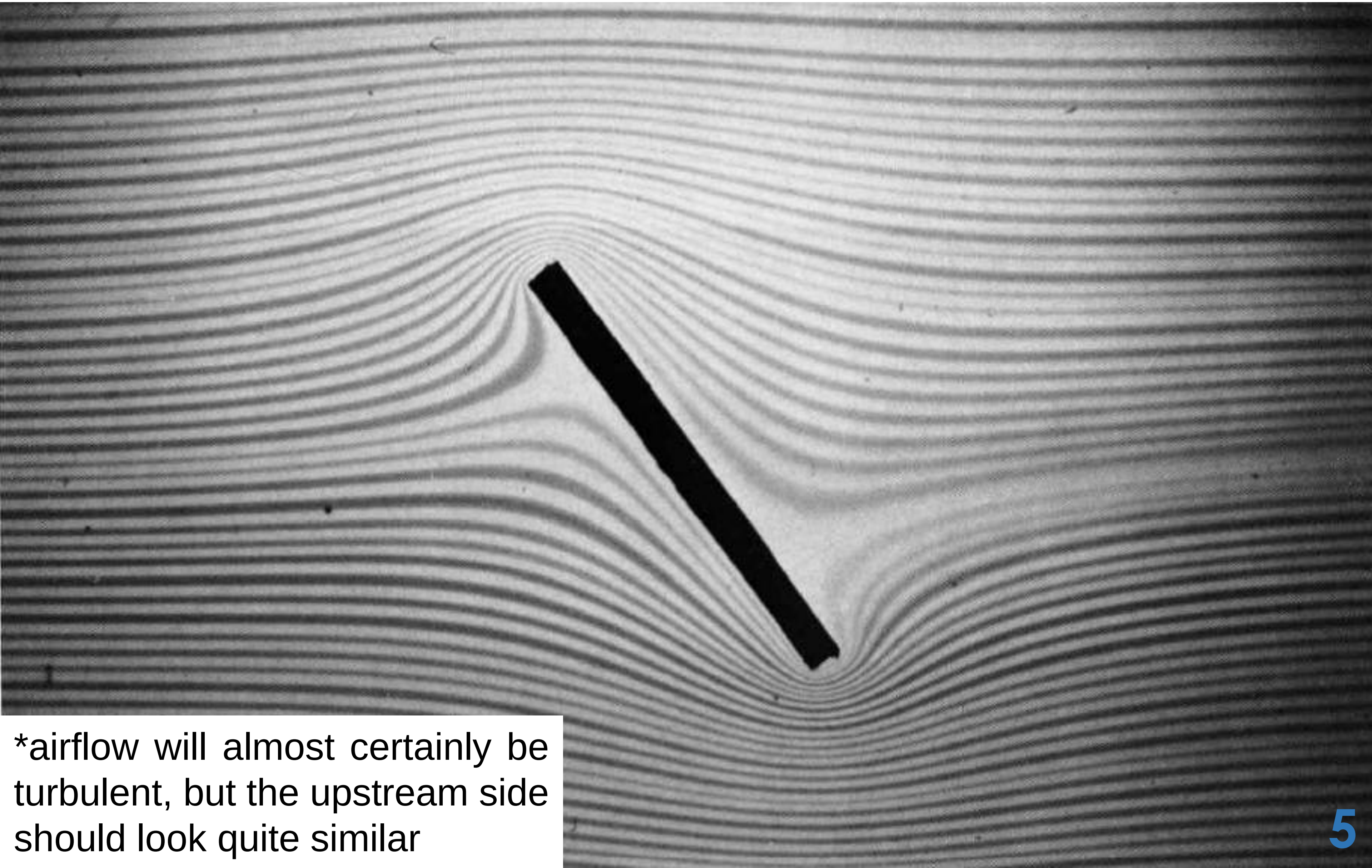
2 Rayleigh Disk

A disk suspended vertically by a thin thread is placed in an acoustic field. This device can be used to measure the intensity of sound by turning about the axis of the thread. Investigate the accuracy of such a device.

Disk zvislo zavesený na tenkej nitke vložte do akustického poľa. Takéto zariadenie je možné použiť na meranie intenzity zvuku pomocou otočenia disku okolo nitky. Preskúmajte presnosť takéhoto zariadenia.

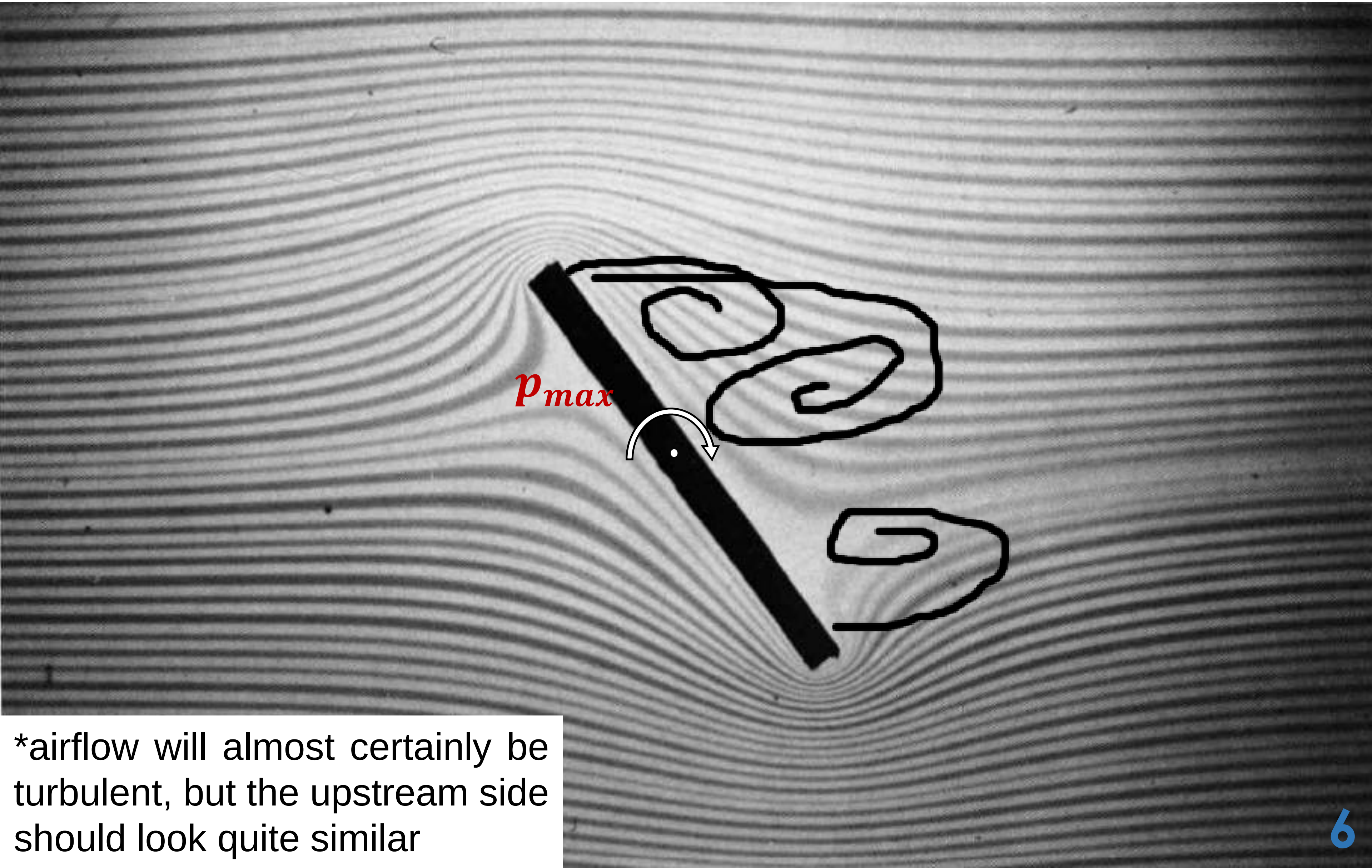
Basic explanation

Flow around an inclined plate



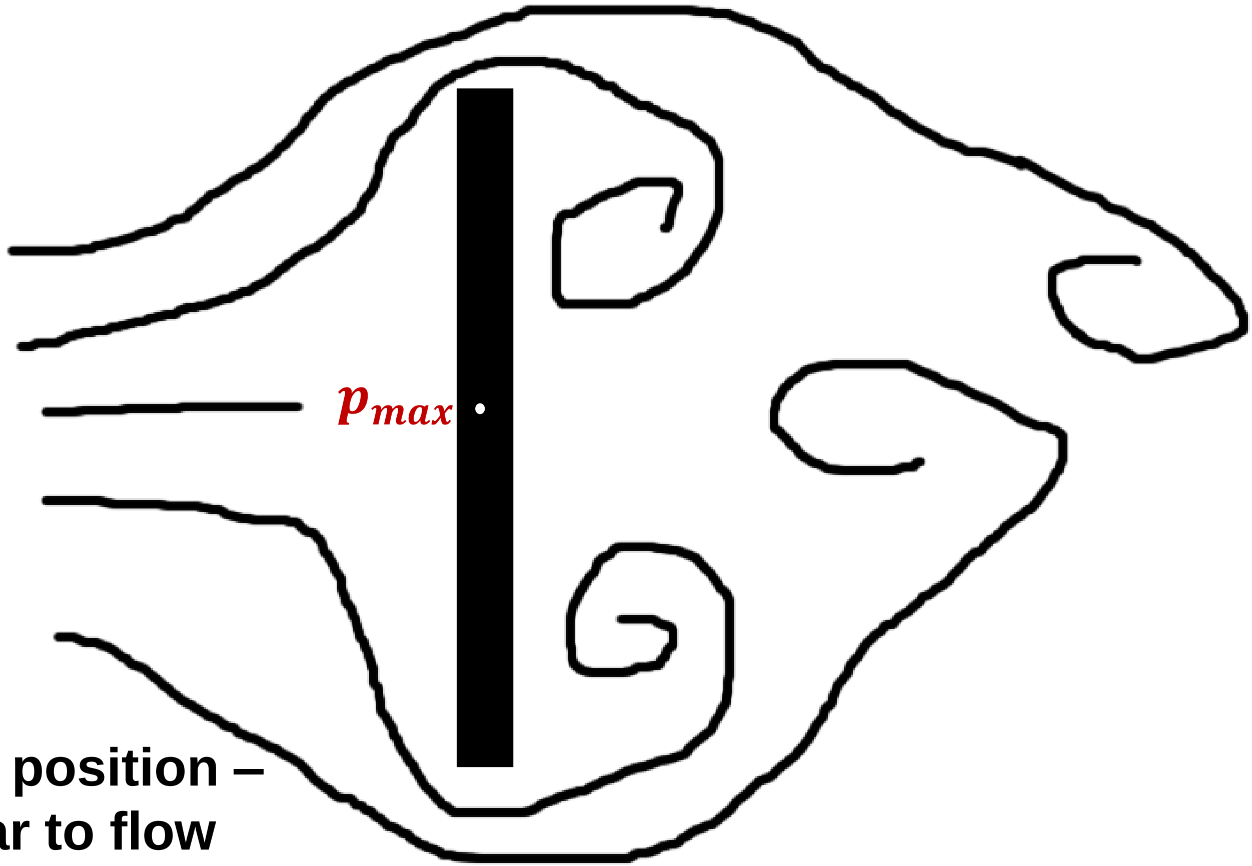
*airflow will almost certainly be turbulent, but the upstream side should look quite similar

Flow around an inclined plate



*airflow will almost certainly be turbulent, but the upstream side should look quite similar

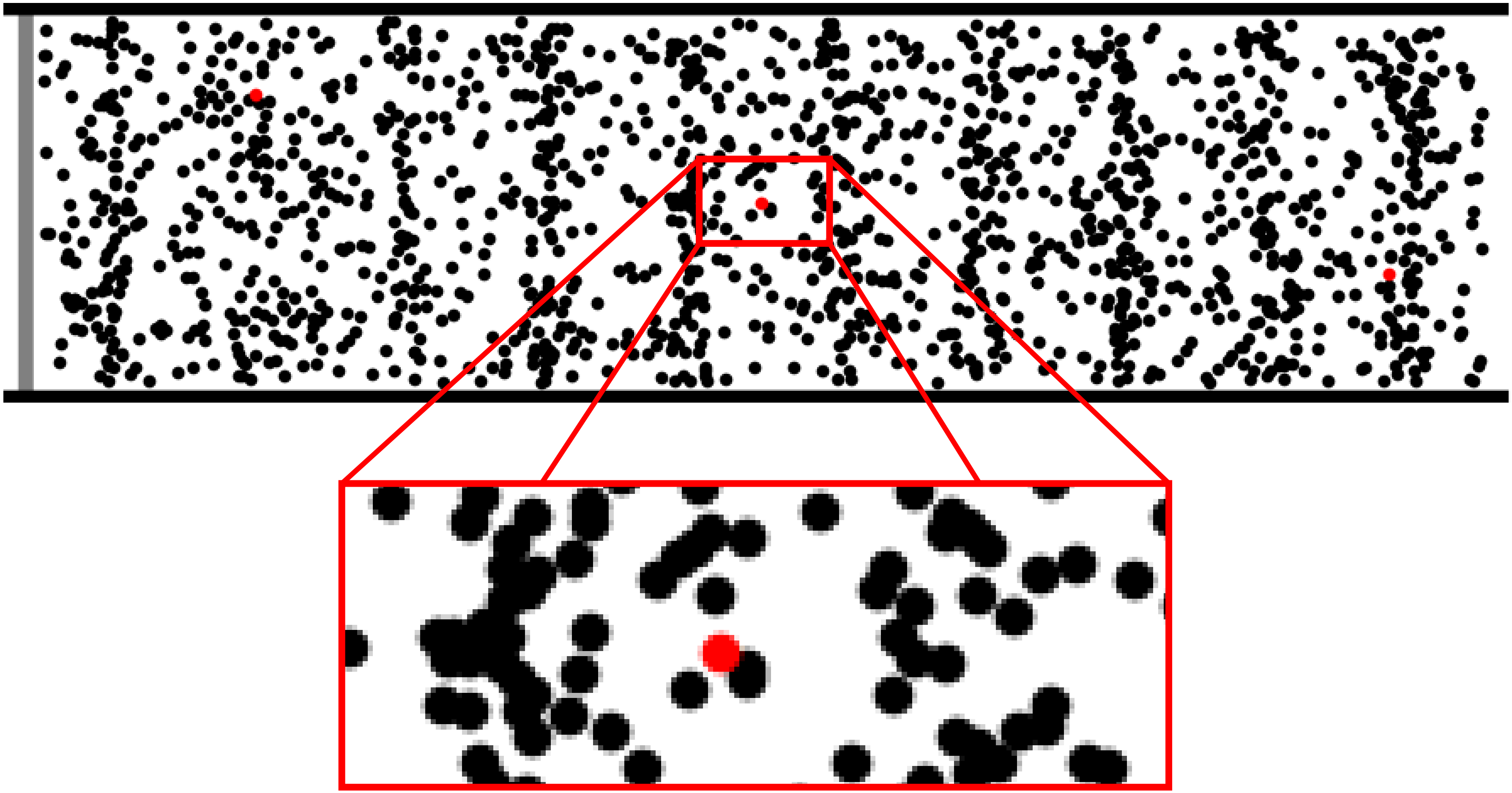
Flow around a plate



stable equlibrium position – disk perpendicular to flow

note that the same would apply for flow in the opposite direction

Sound wave



Flow with alternating direction

equlibrium position of disk perpendicular to wave propagation

Effect of thread

Torque acting to the initial position (due to torsional stiffness of the thread)

-> equilibrium positon shifted by some angle

Some theory

Sound intensity

- power carried by sound waves per unit area [W/m^2]
- defined as

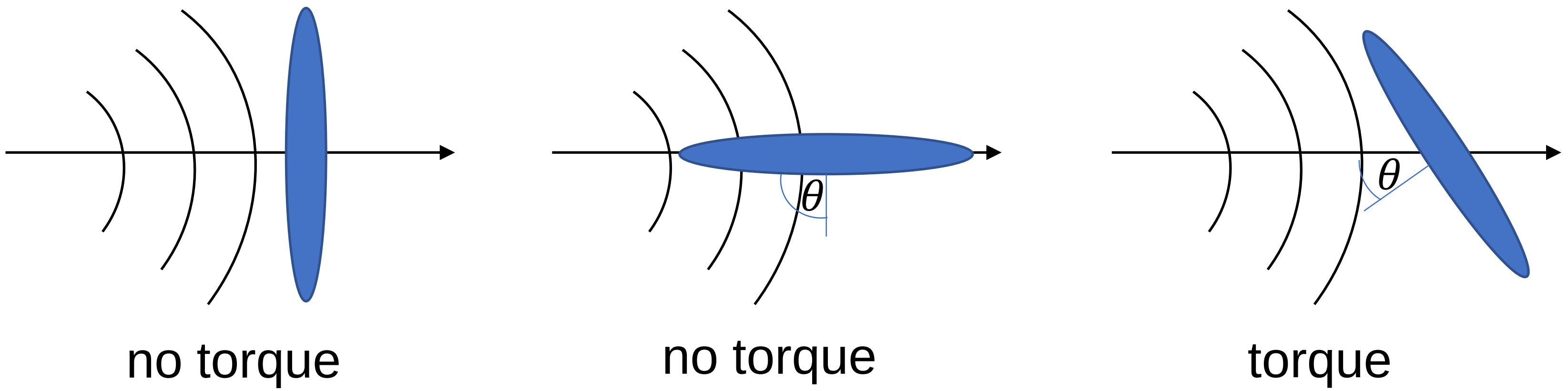
$$\boldsymbol{I} = p\boldsymbol{v}$$

- time averaged sound intensity

$$\langle I \rangle = \frac{1}{T}\int_0^T p(t)v(t)dt = \varrho c\langle v^2 \rangle$$

p – acoustic pressure (local pressure deviation from the ambient)
v – particle velocity (speed of a small part of fluid as it moves back and forth in the sound wave)
c – speed of sound
ϱ – air density

Sound induced torque



$\boldsymbol{\tau \sim \sin 2\theta}$

other parameters: fluid density, fluid velocity, disk size

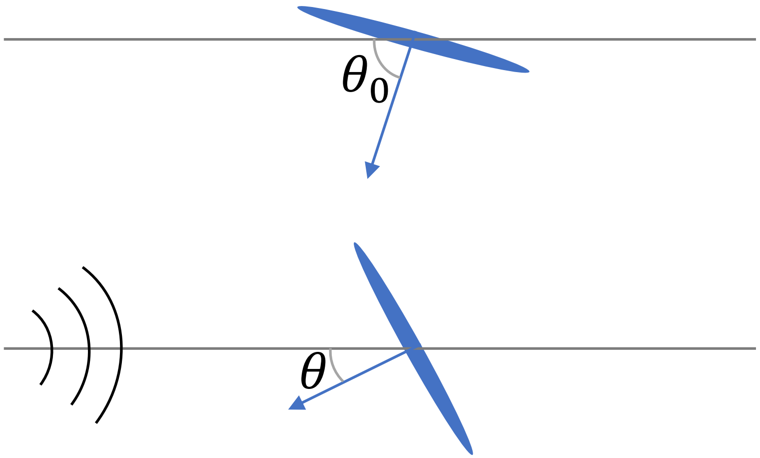
$\tau \sim \varrho^a v^b r^c \qquad kg \cdot m^2 \cdot s^{-2} = (kg \cdot m^{-3})^a \cdot (m \cdot s^{-1})^b \cdot m^c$

$\boldsymbol{\tau \sim \varrho v^2 r^3}$

$$\tau = \frac{4}{3} \varrho r^3 \langle v^2 \rangle \sin 2\theta$$

*proper derivation of the equation in refence [1]

Torque from the thread



$$\tau = -k\Delta\theta = -k(\theta - \theta_0)$$

k – torsional stiffness of the thread

Intensity vs angle

Intensity & velocity relation:

$$\langle I \rangle = \varrho c \langle v^2 \rangle$$

Flow induced torque:

$$\tau = \frac{4}{3} \varrho r^3 \langle v^2 \rangle \sin 2\theta$$

$$\Rightarrow \quad \langle I \rangle = \frac{3ck(\theta_0 - \theta)}{4 \varrho r^3 \sin 2\theta}$$

Torque from the thread:

$$\tau = -k(\theta - \theta_0)$$

Doesn't take into account:

- diffraction of the sound by the disk
- finite inertia of the disk
- finite thickness of the disk

Articles providing corrections – e.g. reference [2]

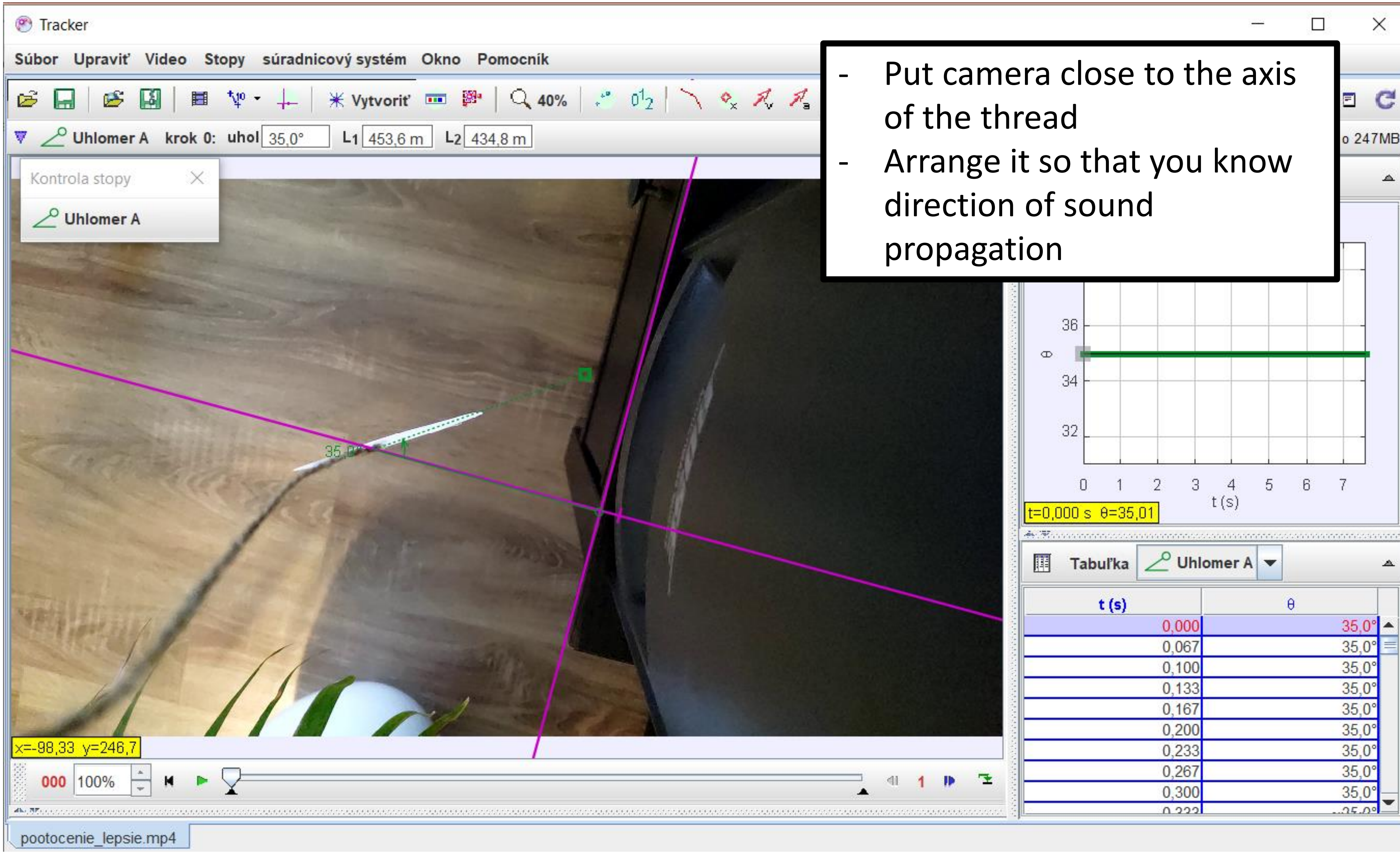
Will it hold for wavelengths smaller than the disk diameter?

Think it through, try it

Tips for experiments

Too big intensity gradient -> disk may get pulled in

Angle measurement



- Put camera close to the axis of the thread
- Arrange it so that you know direction of sound propagation

Sound intensity measurement

option 1

Your school might have one of these

Can measure sound intensity level L [dB]

$$L = 10\log_{10}\left(\frac{I}{I_0}\right)$$

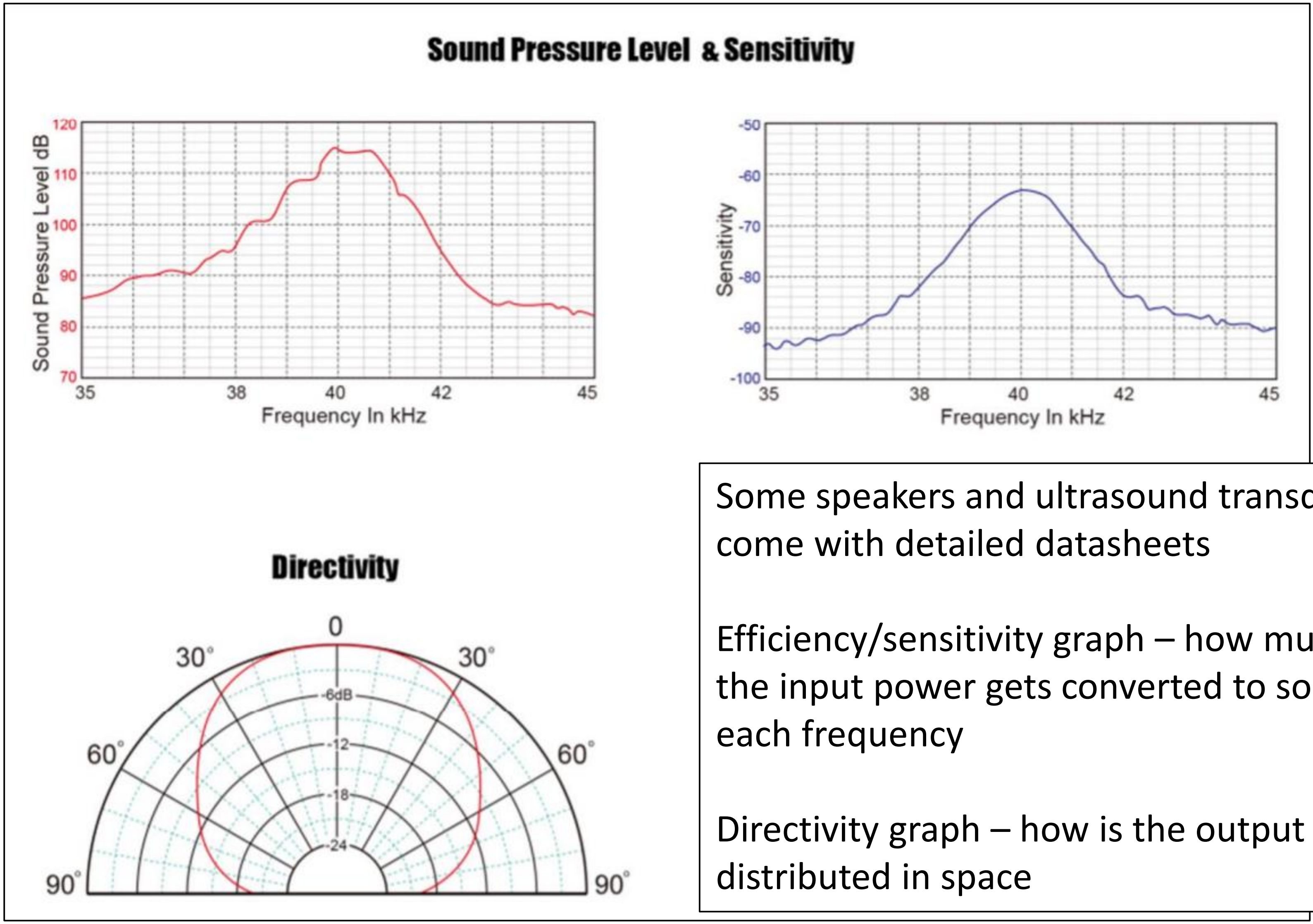
$$I = I_0 10^{L/10}$$

where

$$I_0 = 10^{-12} W/m^2$$

Sound intensity measurement

option 2



Some speakers and ultrasound transducer come with detailed datasheets

Efficiency/sensitivity graph – how much of the input power gets converted to sound at each frequency

Directivity graph – how is the output power distributed in space

Sound intensity measurement

option 3

Relative intensity

Can't get a good intensity measurement -> use multiples of a reference intensity in graphs

$I \sim P$ (P-speaker input power) within reasonable power range

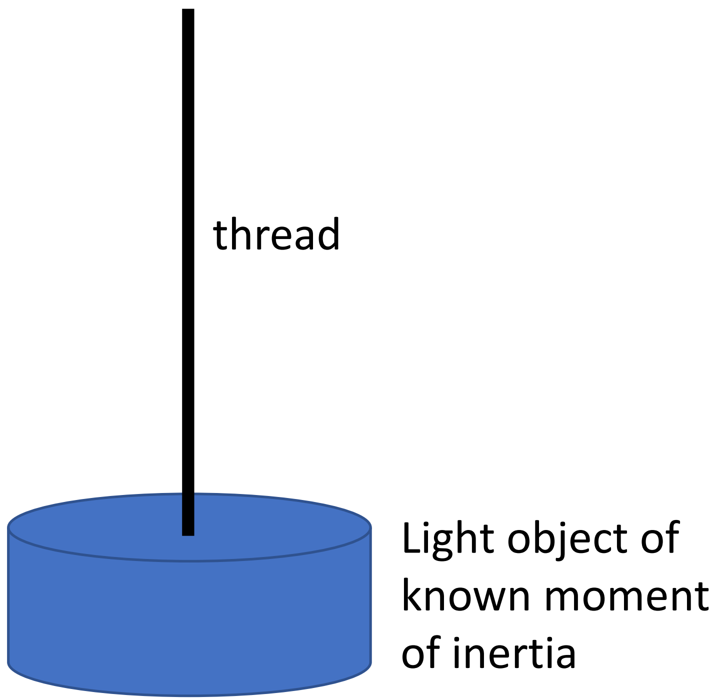
$I \sim \frac{1}{R^2}$ (R-distance from speaker) ! only for spherical wave – won't be accurate for most speakers

Torsional stiffness of the thread

Torsional pendulum

$$T = 2\pi\sqrt{\frac{J}{k}}$$

T – period of oscilations
k – torsional stiffness
J – moment of inertia
for cylinder: $J = \frac{1}{2}mr^2$



Make sure that:
- Object is centered and its axis of symmetry is coincident with the tread
- Oscillations don't die out too quickly
- Object isn't putting too much tension to the thread

To do

To do

Minimum

- Give a basic explanation
- Build a setup
- Measure angle vs intensity (at least relative) for a few θ_0
- Draw some qualitative conclusions about accuracy/precision and how they depend on θ_0 and I

Some more

- Try changing other parameters
- Make quantitative comparison between measured and theoretical I vs θ
- Quantify the accuracy/precision
- If I give you a sound can you give me $I = value \pm uncertainty$?

If the else is done

- Try wavelengths smaller than disk, is the behaviour frequency dependent?
- Read articles and apply necessary corrections to the theory, if there are still discrepancies analyse them

THANK YOU