Problem 5 "Car"

Dudin Maxim Lyceum 130

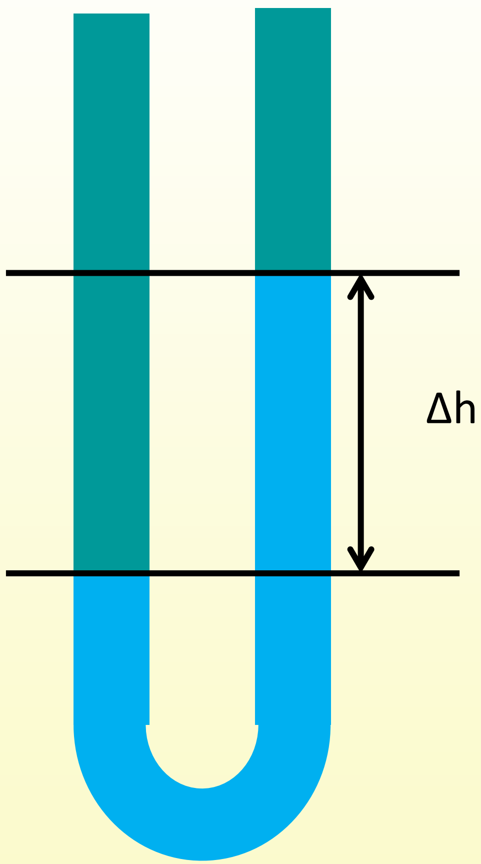
Problem

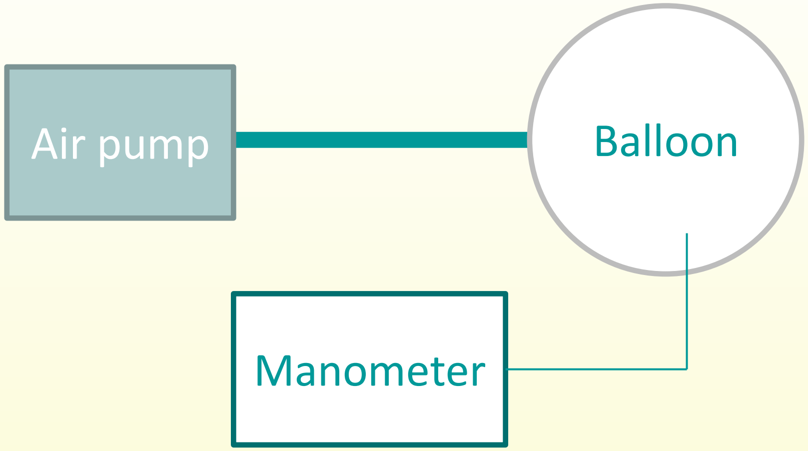
- Build a model car powered by an engine using an elastic air-filled toy-balloon as the energy source. Determine how the distance travelled by the car depends on relevant parameters and maximize the efficiency of the car.

Investigation plan

- Investigate properties of toy-balloon drive
- Analyze movement of balloon-car
- Build the car
- Investigate the influence of relevant parameters on movement of car and maximize travel path
- Rate the energy efficiency

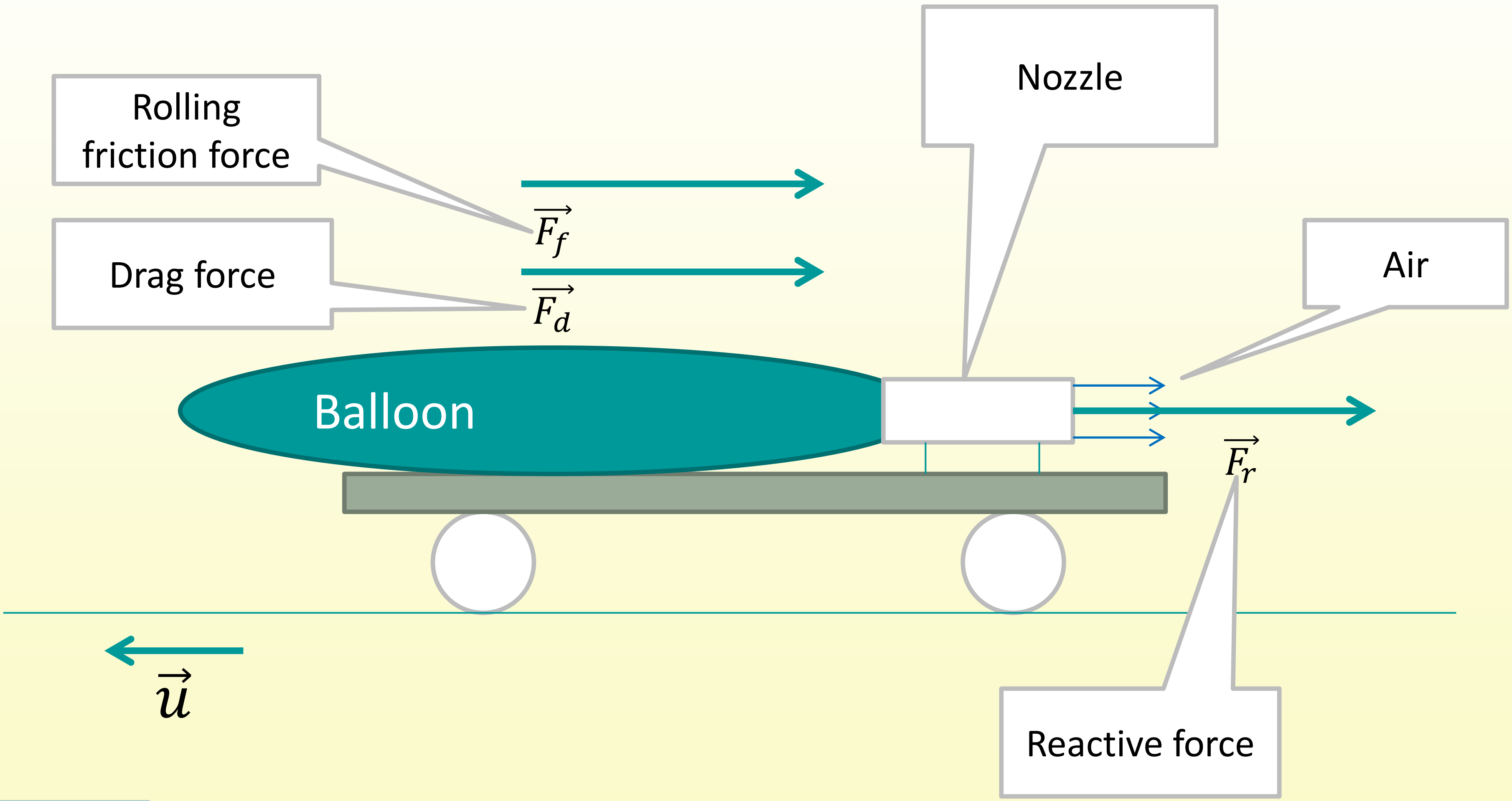
Pressure inside the balloon





Balloon usage	Pressure, Pa
1	3700
6	3500
9	3400
24	3300

Movement of the car



Efficiency

Car building

- To build the car, which will have the longest travel path we should:

- Reduce the friction → Build a car with little mass and big wheel radius

$$F = \frac{N_f b}{R}$$

- $\boldsymbol{R}$ is the **radius of wheel**
- $\boldsymbol{N_f}$ is the **normal force**
- $\boldsymbol{b}$ is the **rolling resistance coefficient**

- Reduce the drag → Build a car with little contact area between car and air

$$F = \frac{1}{2}\rho u^2 C_d A$$

- $\boldsymbol{\rho}$ is the **density of the fluid**
- $\boldsymbol{u}$ is the **velocity**
- $\boldsymbol{C_d}$ is the **drag coefficient**
- $\boldsymbol{A}$ is the **reference area**

- Use optimal nozzle
- Use optimal balloon

This parameters will be investigated after first car building

Car building

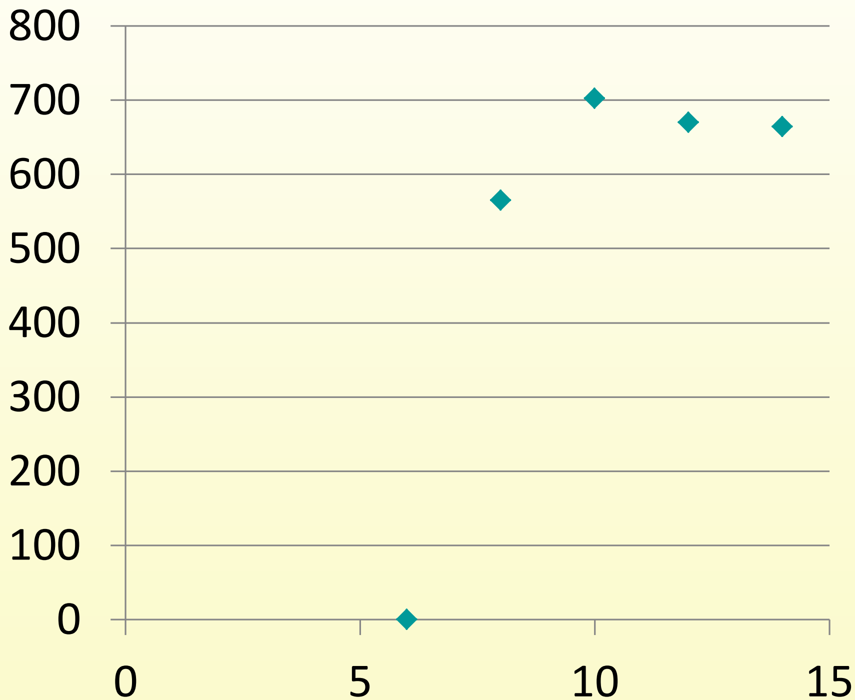
- Mass of the car is 76 gram
- Reference area (without balloon) is about 20 cm^2
- Radius of the wheel is 1.5 cm
- Smaller radius of the wheel will cause slippage

Experiment

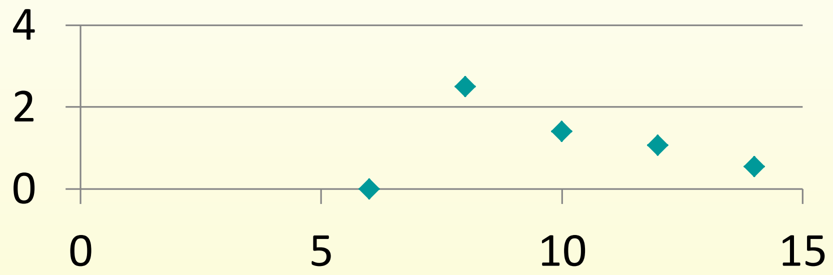
- We used:
  - Equal value of balloon – 1,4 liter
  - Finger to start the car
  - Video and movement sensor
  - 5 different nozzles

Investigation of influence of nozzle diameter

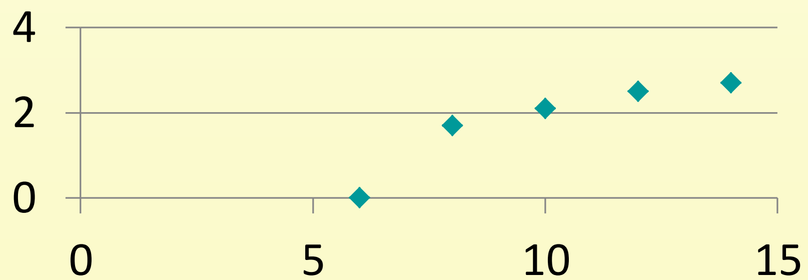
Dependence of travel path on nozzle diameter



Dependence of time of balloon working on nozzle diameter



Dependence of maximum speed on nozzle diameter



Explanation of nozzle efficiency

Small nozzle

- little middle velocity
- little drag work
- big friction between walls of nozzle and moving air

Big nozzle

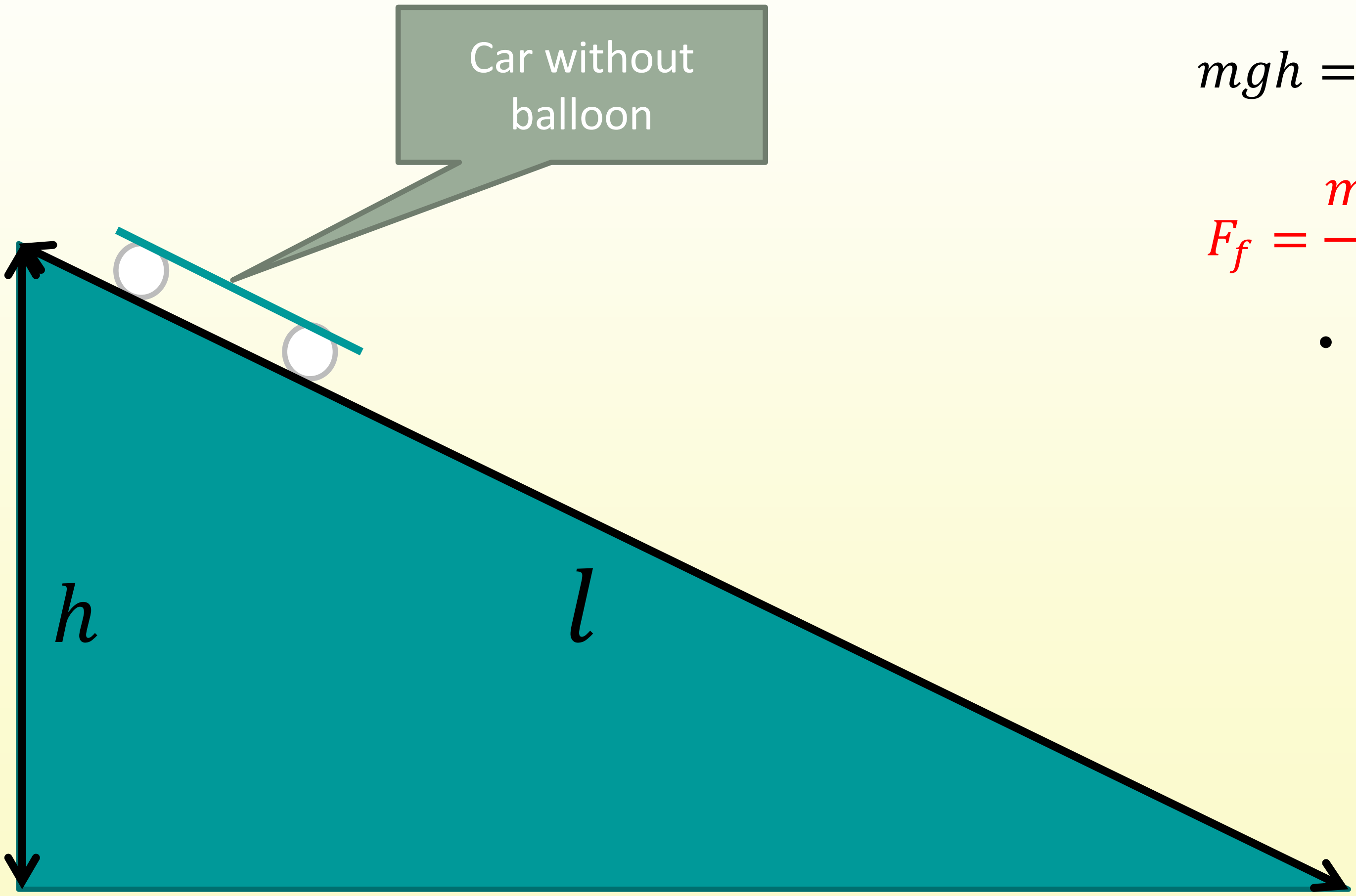
- little friction between walls of nozzle and moving air
- big drag work
- not absolutely horizontal direction of air movement

Optimal nozzle is nozzle with 10 mm diameter

Energy efficiency rate

- Energy efficiency is a ratio between sum of friction, drag and loses inside the nozzle to full balloon energy
- We should rate friction, air resistance and full energy of air inside the balloon

Experiment to rate the friction



$$mgh = W_f + \frac{mu^2}{2}$$

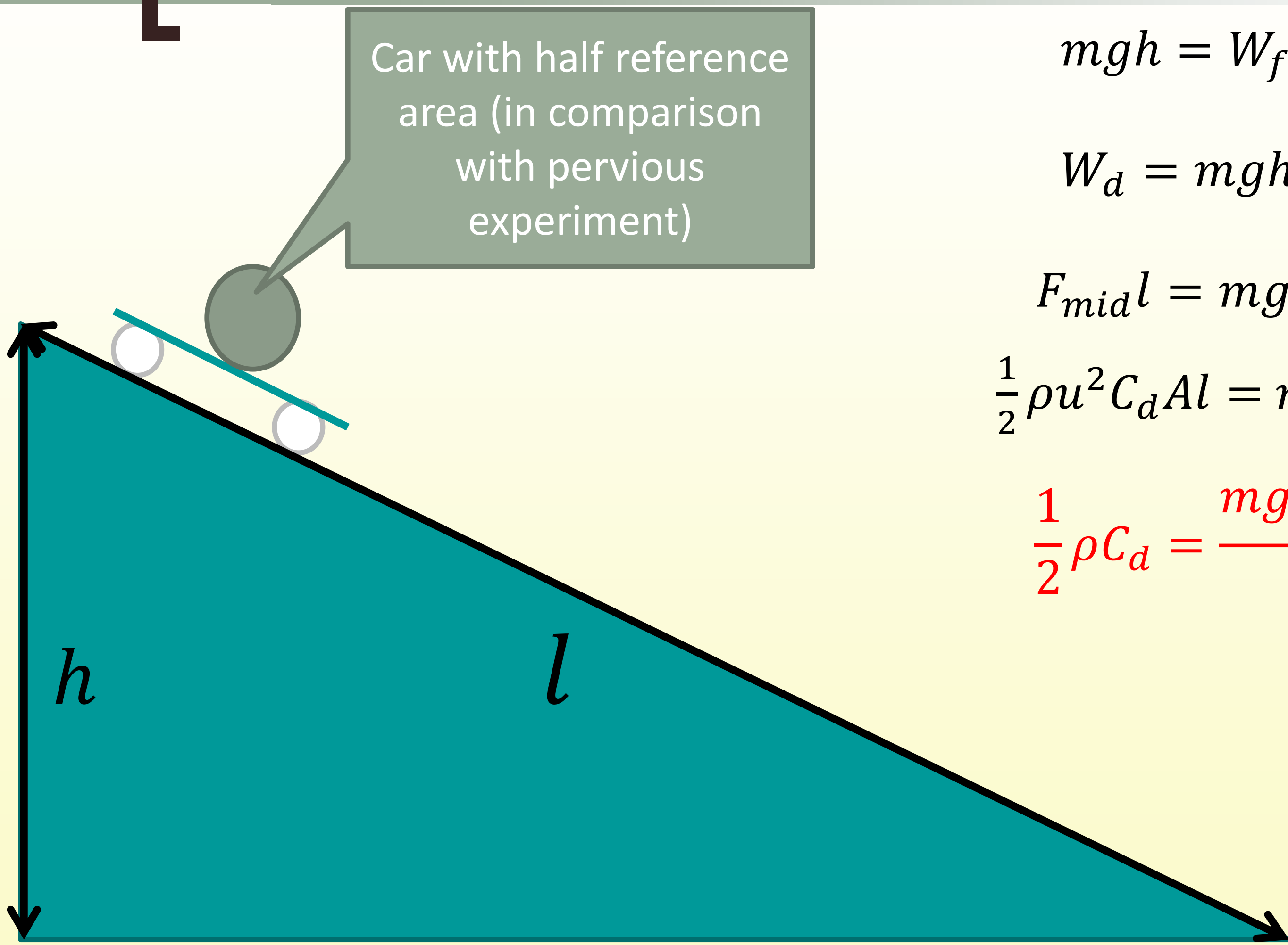
$$mgh = F_f l + \frac{mu^2}{2}$$

$$F_f = \frac{mgh - \frac{mu^2}{2}}{l}$$

- $\boldsymbol{u}$ is the velocity of car in the moment of full decent

Friction force is 0,004 N

Experiment to rate the drag



$$mgh = W_f + \frac{mu^2}{2} + W_d$$

$$W_d = mgh - W_f - \frac{mu^2}{2}$$

$$F_{mid}l = mgh - W_f - \frac{mu^2}{2}$$

$$\frac{1}{2}\rho u^2 C_d A l = mgh - W_f - \frac{mu^2}{2}$$

$$\frac{1}{2}\rho C_d = \frac{mgh - W_f - \frac{mu^2}{2}}{u^2 A l}$$

Drag and friction rate

Then we can work with results of previous experiment with car drive:

$$W_d = F_{mid} l = \frac{1}{2} \rho u_{mid}{}^2 C_d A l$$

- Blue letters were found
- Green letters is results and constants of experiments

We may find green letters from experiment with nozzles

Drag work for car with 10 mm nozzle is 0,113 J

$$W_f = Fl$$

Friction work for car with 10 mm nozzle is 0,028 J

Efficiency

- $\eta = \frac{W_{out}}{W_{in}}$

$$W_{out} = W_d + W_f = 0{,}141\ J$$

$$W_{in} = P\Delta V = 5{,}4\ \mathrm{J}$$

η=2,6%

The biggest energy efficiency is 4,5 %, for car with 14 mm nozzle

Results of the research

- 3 parameters were investigated
- Friction
- Drag
- Nozzle
- Travel path was maximized
- Efficiency was rated