11th IYPT '98
solution to the problem no. 2
presented by the team of Austria

Popping body

A body is submerged in water. After release it will pop out of the water.
How does the height of the pop above the water surface depend on the initial conditions (depth and other parameters)?

Abstract

As the initial conditions we considered mass, volume, depth and the shape and surface of the ball. The main forces in our first approach were gravity, buoyancy and flow resistance. After measuring we found out that this approach is only valid in shallow depth. We observed the decrease of maximum height with increasing depth. So we assumed that the reaching of the water surface should be a critical moment. Before reaching the surface the body reaches its maximum speed. When it goes through the surface, the buoyancy decreases, and the lower pressure at the bottom of the body has a negative impact on th velocity. This led us to our second approach: "Potentional flow". We ignored friction, turbulences etc. and considered the energy which is needed to accelerate water masses. This we called "virtual mass". To achive a solution we created a numerical algorithm, which corresponded more or less to our observations.

Overview

- Initial conditions
- Forces
- First approach
- Expected heights versus measured heights
- Second approach: Potential flow
- Algorithm
- Problems
- Experiments

1 Initial conditions

- Mass m
- Volume V
- Depth
- Shape, surface

2 Forces

- Gravity mg
- Buoyancy $\rho g V$
- Flow resistance

3 First approach

$$ma = \rho g V - gm - \frac{1}{2} c_W A \rho v^2$$

4 Expected heights versus measured heights

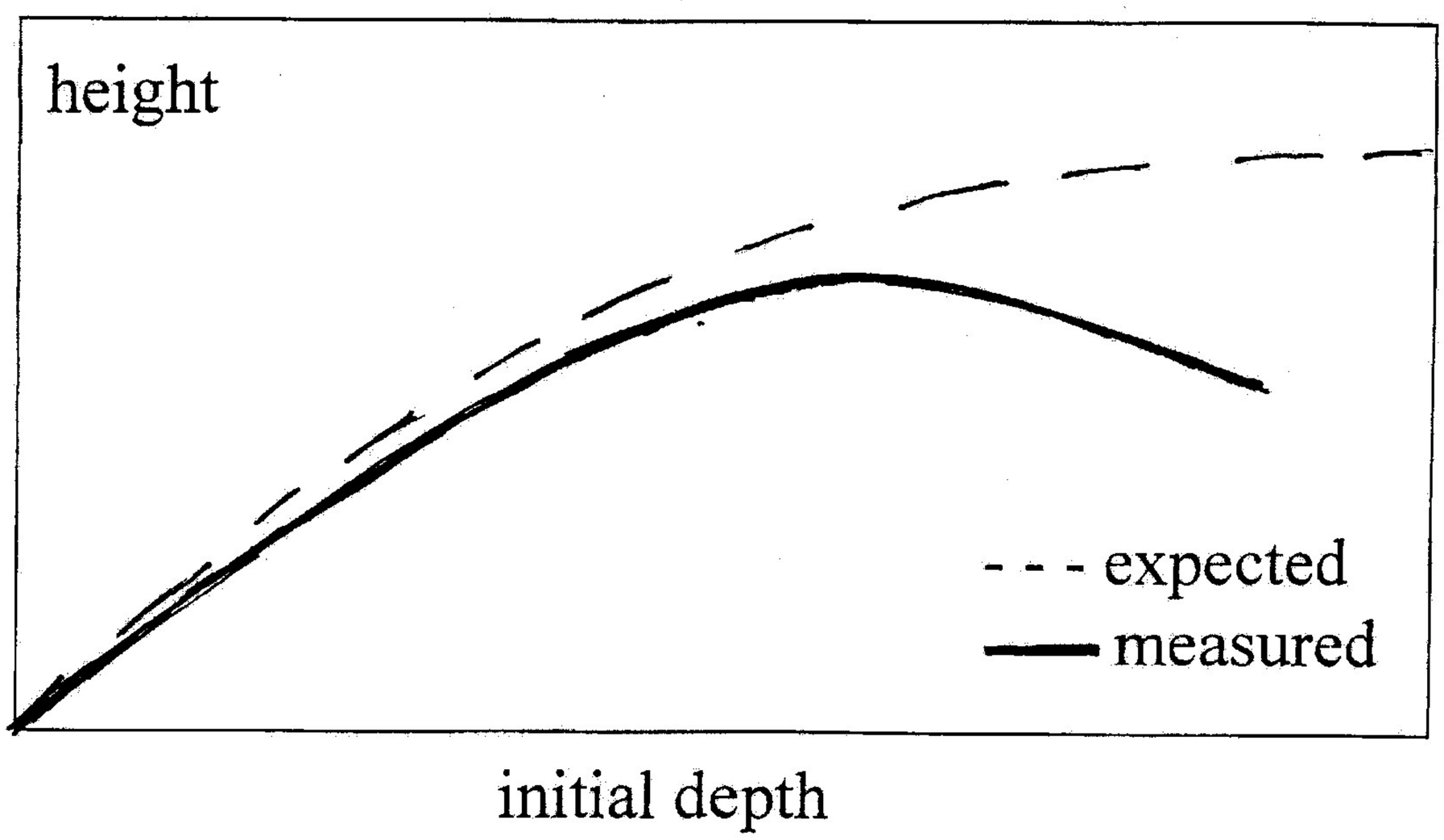


Figure 1: Expected heights versus measured heights

5 Second approach: Potential flow

- Ignoring friction, turbulences etc.
- Energy is needed to accelerate water masses ("virtual mass" mv).
- Simplifications when reaching the surface.
- Numerical solution.

6 Algorithm

Loop:

$$
\begin{aligned}
t &:= t + dt \\
a &:= \frac{F}{m + mv} \qquad \text{inside water} \\
v &:= v + a\,dt \\
h &:= h + v\,dt
\end{aligned}
$$

Popping ball ($r = 10\,\text{cm}$) in shallow depth

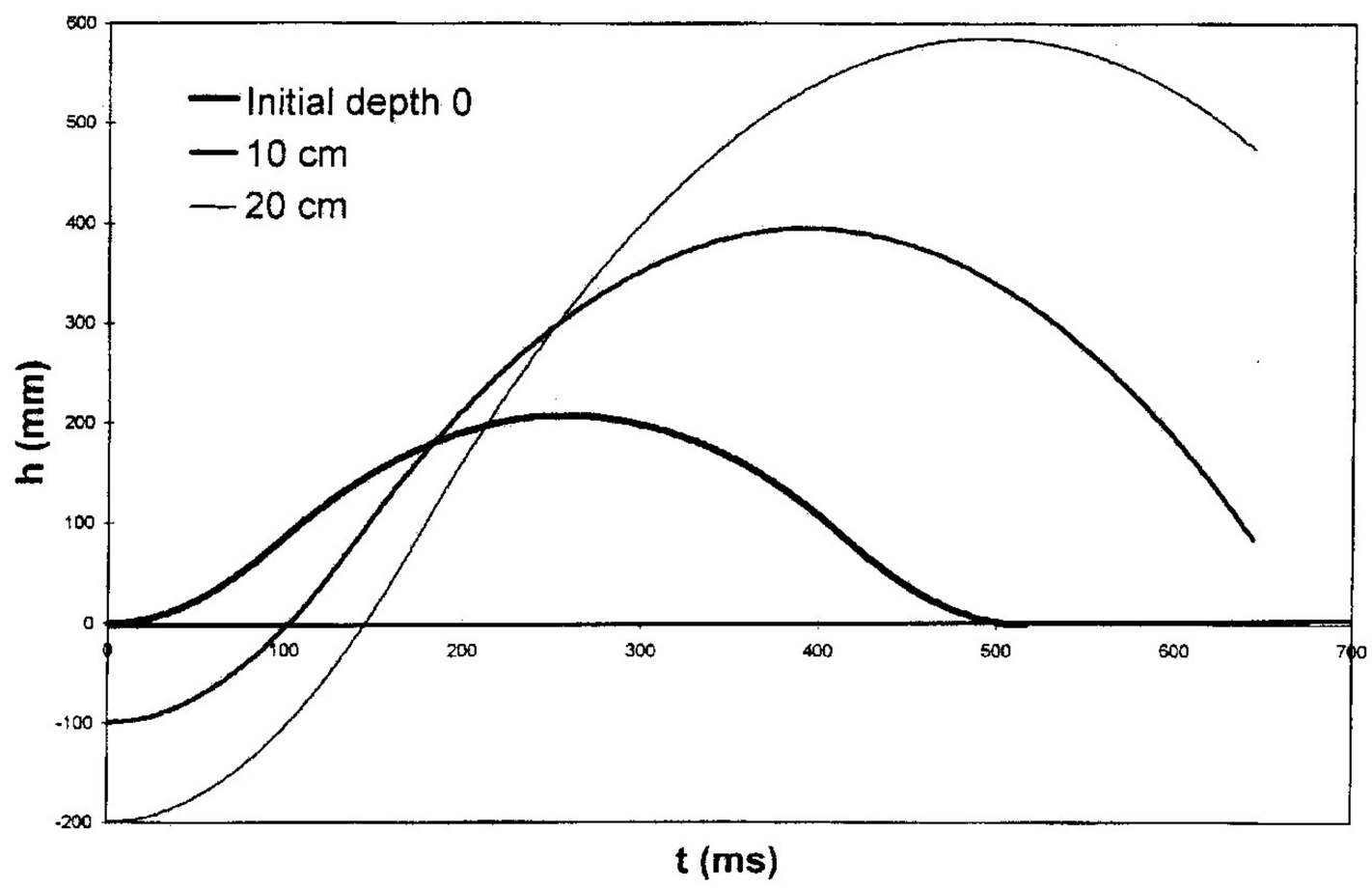
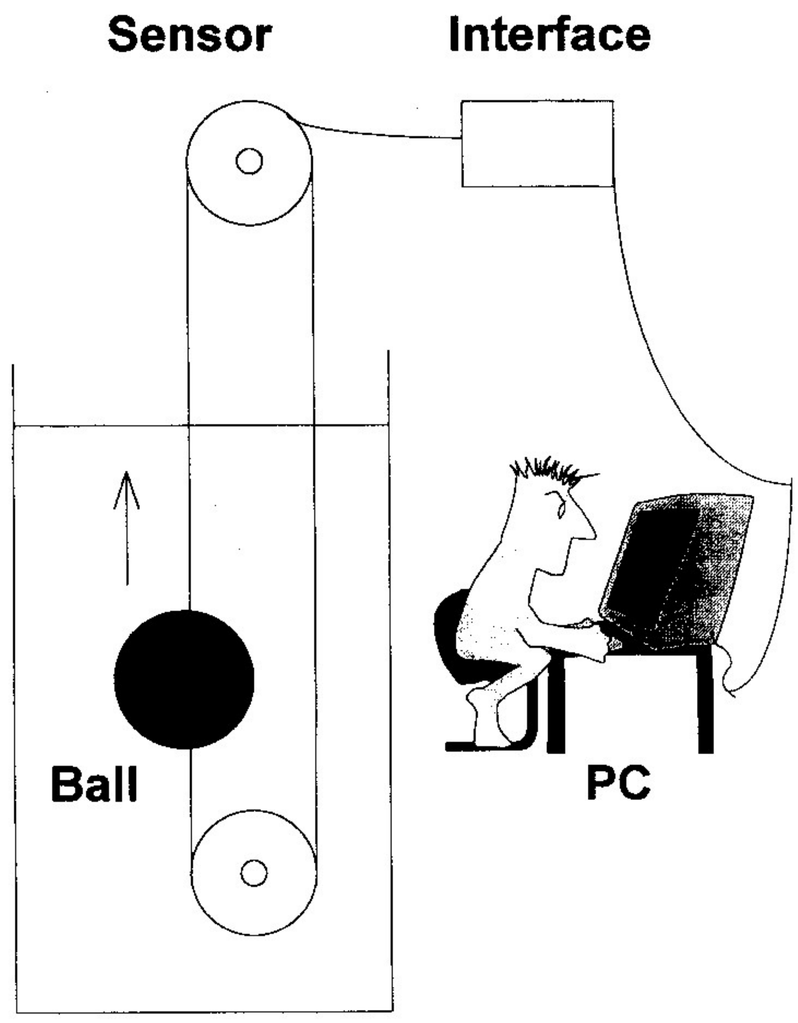


Figure 2: Shallow depth

7 Problems

- Only valid in shallow depth.
- Cannot explain the **decreasing** maximum height
  Critical moment = reaching the surface
- Development of whirls takes some time.
- Body reaches a maximum speed.
- Buoyancy decreases when reaching the surface.
- Lower pressure at the bottom of the body has a negative impact on the velocity.

8 Experiments



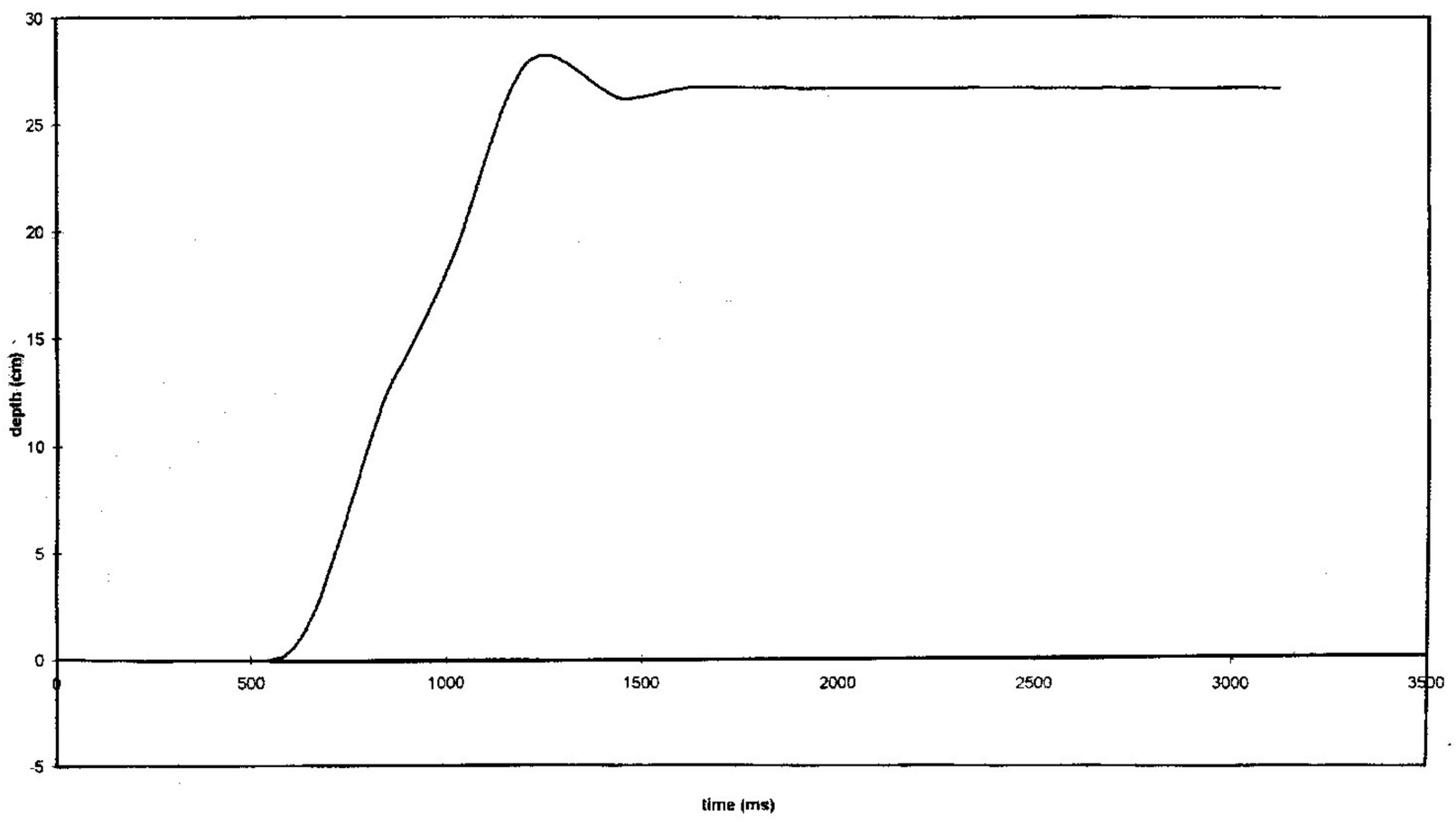


Figure 3: Experiments