ART AN AMAZING FACT IN SCIENCE

Problem No.16

Hoops

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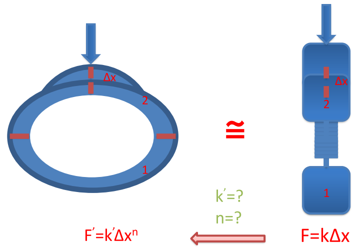
IYPT

Problem Statement

- An elastic hoop is pressed against a hard surface and then suddenly released. The hoop can jump high in the air. Investigate how the height of the jump depends on the relevant parameters.

Simple Explanation



Theoritical Study

- Initial observation
- Simple Explanation
- Spring Break-Off
- Maximum height
- Trajectory

Experiments

- Stiffness Coefficient
- Maximum height
  - Vs. Inner Radius
  - Vs. Thickness
  - Vs. Deviation
  - Vs. Felexural modulus
  - Trajectory

Discussion

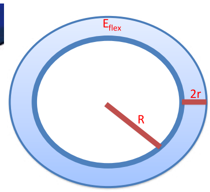
- Stiffness Coefficient
- Maximum height
  - Vs. Inner Radius
  - Vs. Thickness
  - Vs. Deviation
  - Vs. Felexural modulus
  - Trajectory

Main Approach

Conclusion

Acknowledgment

Stiffness Coefficient



$$k = f(R, r, E_{flex})$$

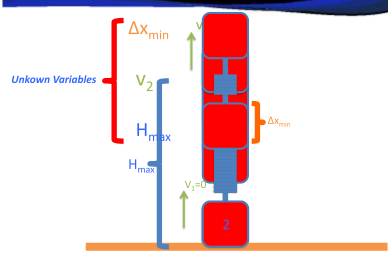
$$k \propto R^a r^b E_{flex}^c$$

$$[k] = \frac{M.L.T^{-2}}{L}$$

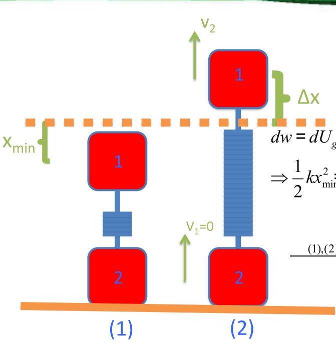
$$\Rightarrow k \propto \frac{r^3 E_{flex}}{R^2}$$

$$F = \sigma_{Exp} \frac{r^3 E_{flex}}{R^2} \Delta x^n$$

Spring Break-Off k=? f



Deriving Δx_{min}



$$k\Delta x = mg$$

$$\rightarrow \Delta x = \frac{mg}{k} \qquad (1)$$

$$dw = dU_g + dK + dU_s \qquad (2)$$

$$\Rightarrow \frac{1}{2}kx_{min}^2 = mg(x_{min} + \Delta x) + \frac{1}{2}k\Delta x^2 + \frac{1}{2}mv_2^2$$

$$\xrightarrow{(1),(2)} x_{min} = \sqrt[n]{\frac{3R\left(\frac{m}{2}\right)g}{\sigma_{Exp} r^2 E_{flex}}}$$

$$x_{min} = \frac{3mg}{k}$$

8

$$dw = dU_g + dK + dU_s$$

$$\Rightarrow \frac{1}{2}kx_{dev}^2 = mg(x_{dev} + \Delta x) + \frac{1}{2}k\Delta x^2 + \frac{1}{2}mv_2^2$$

$$v_2 = \sqrt{\frac{k}{m}(x_{dev}^2 - \Delta x^2) - 2g(x_{dev} + \Delta x)}$$

$$v_{CM} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$

$$v_{CM}(0) = \frac{v_2}{2}$$

$$H_{max} = \frac{v_{CM}^2(0)}{2g}$$

Trajectory

$$\Delta l = r'_a - r'_b - l$$

$$m r''_a = -k(r'_a - r'_b - l) - mg$$

$$m r''_b = +k(r'_a - r'_b - l) - mg$$

$$m(r''_a - r''_b) = -2k(r'_a - r'_b - l)$$

$$F = \frac{dp}{dt}$$

$$u = A\sin\omega t + B\cos\omega t$$
$$t = 0 \rightarrow u = 0 \Rightarrow B = 0,$$
$$t = 0 \rightarrow \dot u = 0 \Rightarrow A = \frac{v_0}{\omega}$$

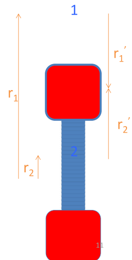
$$u = \frac{v_{(2)0}}{\omega}\sin\omega t,$$
$$\dot u = v_{(2)0}\cos\omega t,$$
$$u = v'_a - v'_b, \quad v'_b = -v'_a$$

$$\ddot u + \frac{2k}{m}u = 0 \rightarrow \omega = \sqrt{\frac{2k}{m}}$$

$$v'_a = -v'_b = \frac{1}{2}v_0\cos\omega t \rightarrow v_a = R + v'_a,\ v_b = R + v'_b$$

$$v_a = \frac{v_0}{2}(1 + \cos\omega t) - gt$$
$$v_b = \frac{v_0}{2}(1 - \cos\omega t) - gt$$

$$y_A = \frac{1}{2}\left[v_0\left(t + \frac{\sin\omega t}{\omega}\right) - gt^2\right]$$
$$y_B = \frac{1}{2}\left[v_0\left(t - \frac{\sin\omega t}{\omega}\right) - gt^2\right]$$

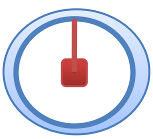


Experiments

R: 4.4 cm, 8 cm, 9.5 cm, 11.5 cm

r: 2 mm, 4 mm, 6 mm, 8 mm

E_{flex} → 2340 MPa

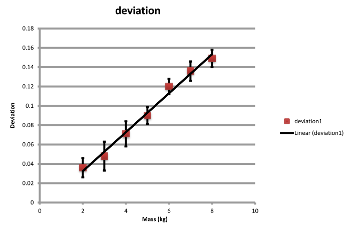


Discussion

R=0.08 m
r=0.004 m
E=2340 MPa

$F' = k'\Delta x^n$

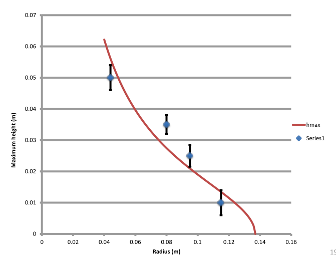
n=1



Discussion

R

r=0.004 m
X_0=0.03m
E_{flex}=2340 MPa

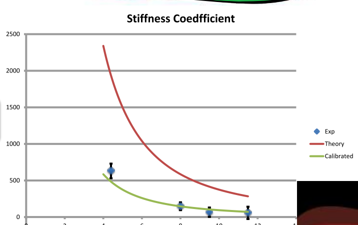


Discussion

$$k = \sigma_{Exp}\frac{r^3 E_{flex}}{R^2}$$

$$a = 2, \sigma_{exp} = 1.5625$$

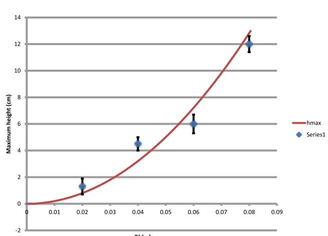
$$k = 1.5625\frac{r^3 E_{flex}}{R^2}$$



Discussion

r

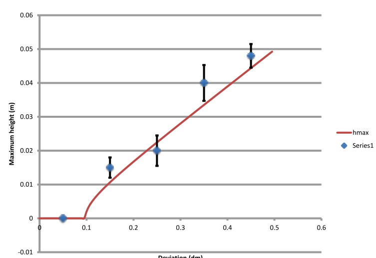
R=0.08 m
X_0=0.03 m
E_{flex}=2340 MPa



Discussion

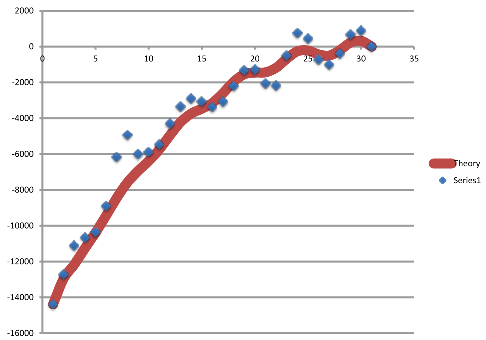
X_0

R=0.08 m
r=0.004 m
E_{flex}=2340 MPa

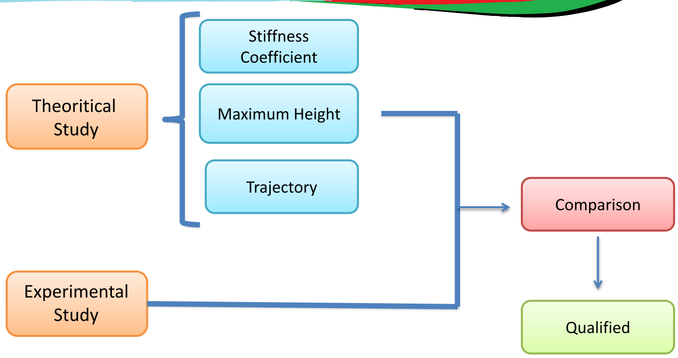


Discussion

R=0.08 m
r=0.004 m
E_{flex}=2340 MPa



Conclusion



ART AN AMAZING FACT IN SCIENCE

PROBLEM NO.2
ELASTIC SPACE

problem

The dynamics and apparent interactions of massive balls rolling on a stretched horizontal membrane are often used to illustrate gravitation. Investigate the system further. Is it possible to define and measure the apparent "gravitational constant" in such a "world"?

F.Mokhtari

introduction

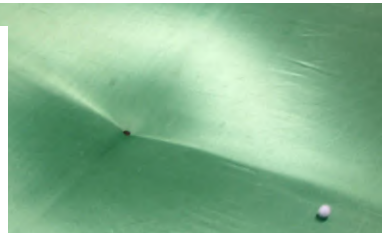
- Basic explanation
- Initial observation
- The differences between the real universe and elastic space

theory

- The surface equation in real universe
- Finding the surface equation in elastic space
- Finding the gravitational force in elastic space
- Finding the potential equation
- Finding the orbital motions
- Investigating the Kepler's laws in elastic space

experiments

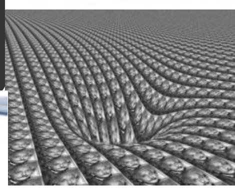
- experimental setup
- The circuit of the ball
- The orbital motion



Main approach

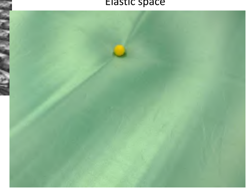
conclusion

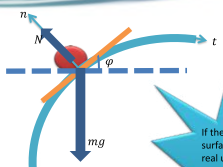
- Comparing the experiments with theory
- Summarizing



Real world

Elastic space





~~$\Sigma F_n: N = mg\cos\varphi$~~ $mg\sin\varphi = \frac{GMm}{r^2}$

$\Sigma F_t: mg\sin\varphi = ma$

If the equation of the surface is an analogy of real universe, the tangential force is equal to gravitational force.

$$\sin\varphi = \frac{GM}{gr^2}$$

$r \to 0$ ⟶ $\sin\varphi \to \infty$!

$\sin\varphi_{max} = 1 \;\to\; \varphi_{max} = 90$ ⟶ $r \geq \sqrt{\frac{GM}{g}}$

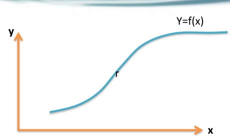
For this limitation our modeling is not responding

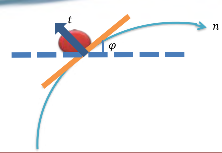
$$mg\sin\varphi = \frac{GMm}{r^2}$$

⇓

$$\tan\varphi = \frac{GM}{\sqrt{r^4g^2 - G^2M^2}}$$

$$\tan\varphi = \frac{dy}{dx}$$





$$\sqrt{1+\left(\frac{dy}{dx}\right)^2} = \frac{GM\frac{d^2y}{dx^2}}{2g\frac{dy}{dx}}\sqrt{\frac{g\frac{dy}{dx}}{GM\left(1+\left(\frac{dy}{dx}\right)^2\right)^{3/2}}}$$

$$\frac{dy}{dx} = \frac{GM}{\sqrt{r^4g^2 - G^2M^2}}$$

⟹ $$r = \sqrt{\frac{GM\sqrt{1+(\frac{dy}{dx})^2}}{\frac{dy}{dx}g}}$$

$$r = \int_a^b \sqrt{1+(\frac{dy}{dx})^2}$$

By solving this differential equation we can obtain the surface equation

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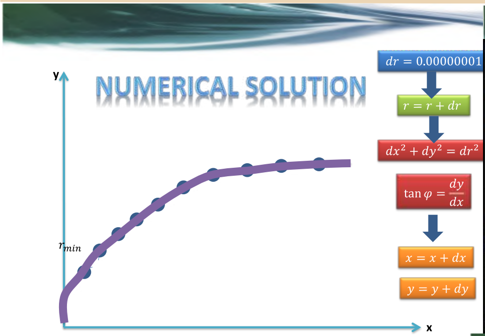

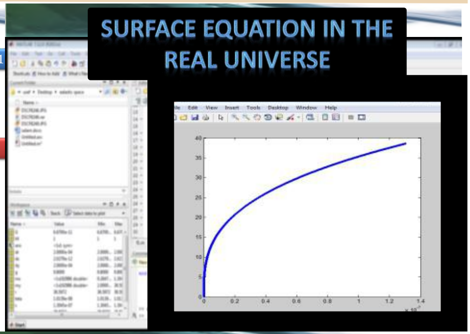

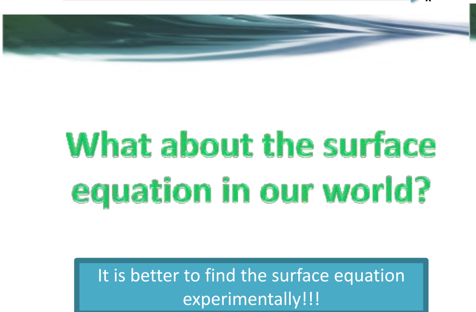

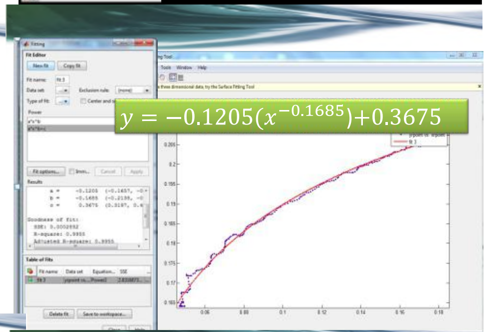

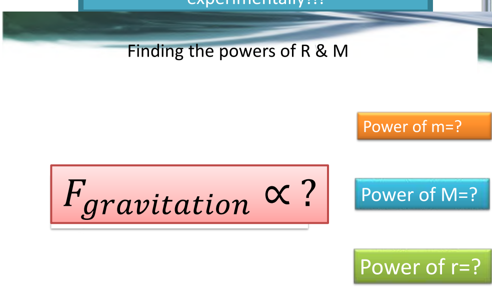

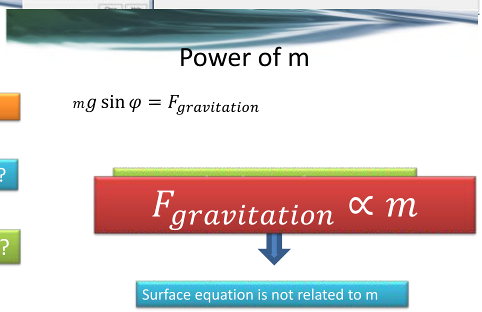

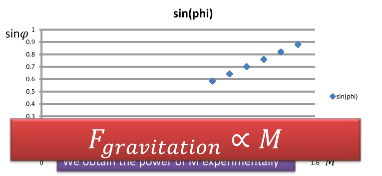

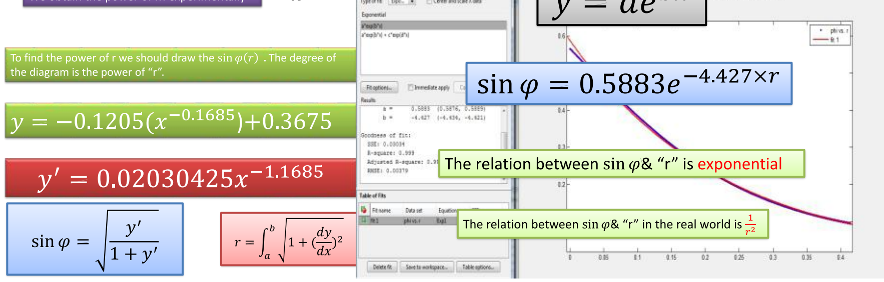

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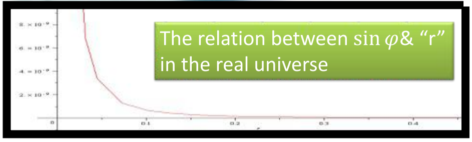
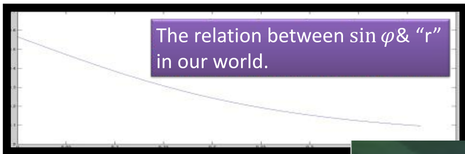




Gravitational force

REAL WORLD

$$F_g = G\frac{Mm}{r^2}$$

$$= 6.67 \times 10^{-11}$$

OUR WORLD

$$F_g = G'\frac{Mm}{(e^r)^b}$$

$$= g \times a = 5.771223$$

potential function

$$U = -\int_a^b F(r)dr = -\int_r^\infty \frac{MmG'}{e^{br}}\,dr$$

$$U(r) = -\frac{MmG'}{be^{br}}$$

potential function

REAL WORLD

$$U(r) = -G\frac{Mm}{r}$$

OUR WORLD

$$U(r) = -\frac{MmG'}{be^{br}}$$

Orbital motion

$$E = \frac{1}{2}m(\dot{r}^2 + r^2\dot{\theta}^2) + U_{(r)}$$

$$\frac{d\theta}{dt} = \frac{l}{mr^2}$$

$$\frac{dr}{dt} = \sqrt{\frac{2}{m}[E - \frac{l^2}{2mr^2} - U_{(r)}}$$

$$\frac{d\theta}{dr} = \frac{l}{mr^2\sqrt{(\frac{2}{m})(E - \frac{l^2}{2mr^2} - U_r)}}$$

$$\theta = \int_0 \frac{l}{mr^2\sqrt{(\frac{2}{m})(E - \frac{l^2}{2mr^2} - \frac{MmG'}{be^{br}})}}\,dr$$

solving this differential equation we can obtain the orbital motion of the ject in our world

Orbital period

REAL WORLD

$$T = \sqrt{kA^3}$$

OUR WORLD

$$T = \int_0^R \frac{dr}{\sqrt{\frac{2}{m}(E - \frac{l^2}{2mr^2} + \frac{MmG'}{be^{br}}}}$$

KEPLER'S LAWS IN OUR WORLD

REAL WORLD		OUR WORLD	
First law)	✔	First law)	✘
Second law)	✔	Second law)	✔
Third law)	✔	Third law)	!

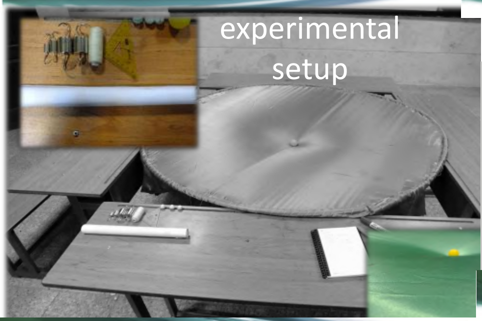
The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

Some Problems of This Modeling

A rolling ball's rotational kinetic energy has no analogue.

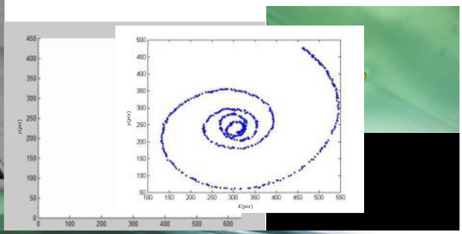
This effect can be reduced by concentrating the ball's mass near its center so that the moment of inertia is small compared to mr².

ART AN AMAZING FACT IN SCIENCE

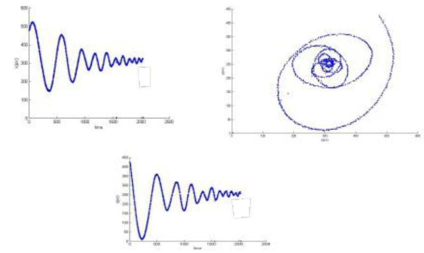


First experiment

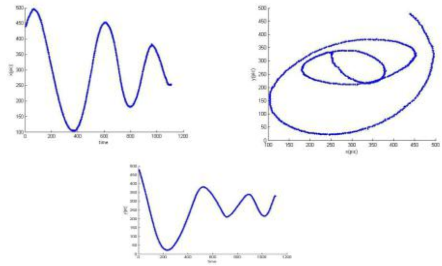
objects weights: 0.7 kg

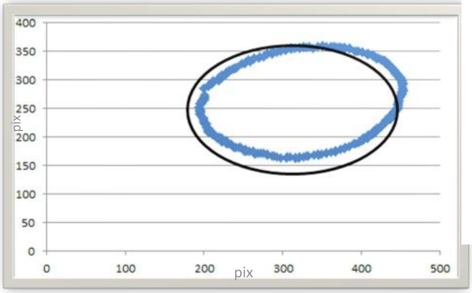


Mass weights: 1.2 kg



objects weights: 1 kg





review

1)We find the surface equation in the real universe

2) We find the surface equation in our space(Elastic space) by experimental ways.

3)We find the relation of the gravitation force with M , m , r & we find the gravitation force in elastic space.

4)We derive the potential function in elastic space

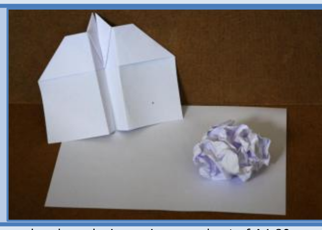
5)We investigate the orbital motions and also we explained the Kepler's laws in elastic space

6)Finally we investigate the orbital motions in elastic space , experimentally and they were in best agreement with our theory.

24th International Young Physicists' Tournament

POLAND

15. Slow Descent



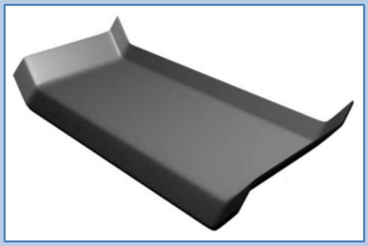
Design and make a device, using one sheet of A4 80gram per m^2 paper that will take the longest possible time to fall to the ground through a vertical distance of 2.5m. A small amount of glue can be used. Investigate the influence of the relevant parameters.

Interpretation of the task

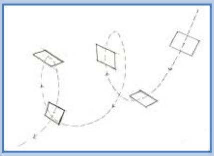
- No initial velocity
- Single device
- Whole sheet

No confetti

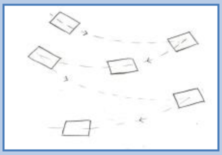
The presentation of the final device



Types of card's motion



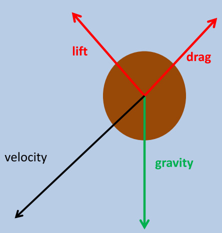
Tumbling



Fluttering

We will study and use autorotation as the source of lift force

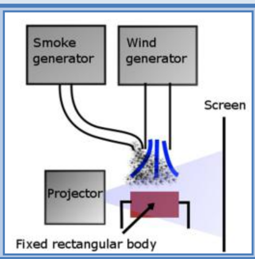
Forces on a body moving in fluid medium



Lift and drag will be studied separately

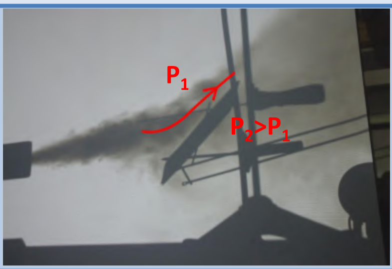
Image on the screen – front edge

Experimental setup



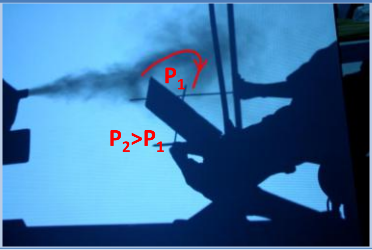
We studied images appearing on the screen in order to find out how the air flows around the strip

Image on the screen – front edge



The air would accelerate along the front edge, which indicates pressur reduction along the front edge

Image on the screen – back edge



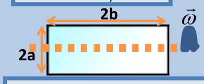
Whirlpool indicates there is an area of reduced pressure at the top of the trailing edge

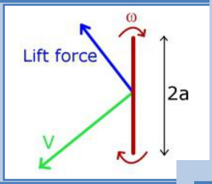
Lift force on a rectangular body

The lift force on a rotating rectangular body moving through a fluid can be found using Kutta-Joukowski theorem

$$F_{lift} = 4\pi a^2 b\omega V\rho$$

Assumptions: very long body, ideal fluid with no viscosity





How does this correspond to a real, viscous situati

Lift force experimental setup

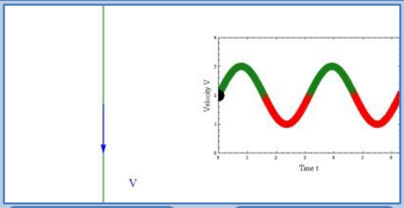
Angular velocity was found as a function of voltage by means of stroboscopic measurement

Flashing diode

The velocity of wind was found using a Venturi tube with a manometer

Image on the screen – back edge

Sustaining the rotation

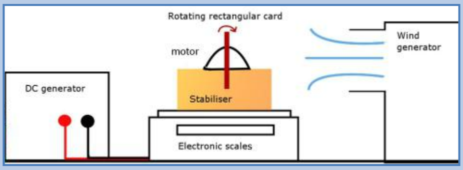


Green – described torques **increase** angular velocity

Blue – described torques **decrease** angular velocity

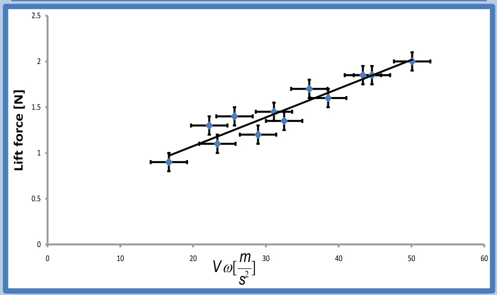
As **green** corresponds to higher velocity than **blue**, the net torque tends to **increase** the angular velocity, counter the drag and sustain stable rotation

Lift force experimental setup



Scales indication changes were measured versus the voltage and wind generator setting

Lift force measurements results



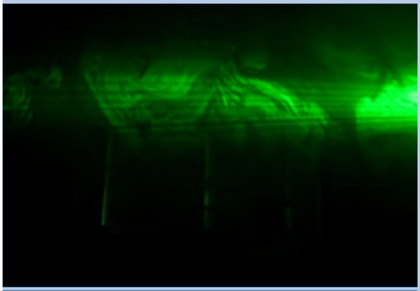
Lift force was found to be linearly dependend on $V\omega$

Flow characteristic

Reynolds number is a parameter, describing a flow in given setup.

$$\mathrm{Re} = \frac{\text{inertia force}}{\text{viscous force}}$$

Reynolds number describes the flow in given setup.

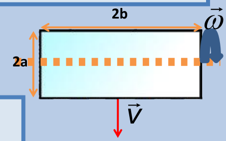


Vortexes can be seen behind the body

Flow characteristic

Reynolds number in our case is given by:

$$\mathrm{Re} = \frac{2aV}{\nu}$$



2a – side of the rectangle
V – velocity of the body
v – kinematic viscosity of the medium

Theory and experiments described in the presentation will discuss motions with **Re** of order of 10^3 to 10^4

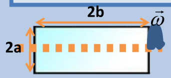
Aerodynamic drag

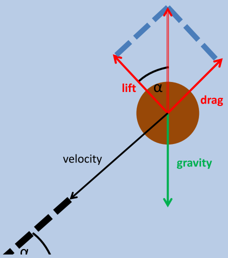
The value of aerodynamic drag for discussed motion can be approximated as (David L. Finn, "Falling paper and flying business cards"):

$$F_d = \frac{1}{2} C_d \rho A V^2$$

C_d – dimensionless drag coefficient
ρ – air density
A –area perpendicular to **V**
V – velocity of the body with respect to air

Theoretical parameters of steady motion

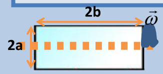




$$drag \propto abV^2$$

$$lift \propto a^2 b\omega V$$

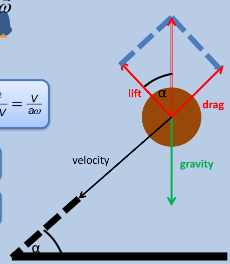
Theoretical parameters of steady motion



$$\tan\alpha = \frac{drag}{lift} \propto \frac{abV^2}{a^2 b\omega V} = \frac{V}{a\omega}$$

$$drag \propto abV^2$$

$$lift \propto a^2 b\omega V$$



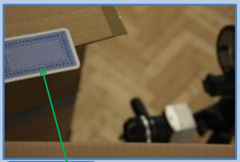
Direct measurements of tumbling bodies

Air motion protection

Distance scale

1000 W lamp

High speed camera



Studied body made of playing card

Measured parameters of motion:

- Linear velocity
- Angular Velocity
- Angle of descent

Comparison with theory

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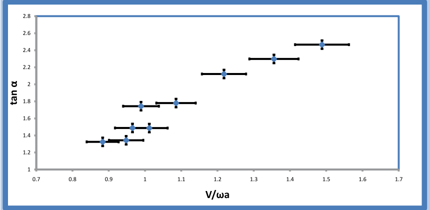
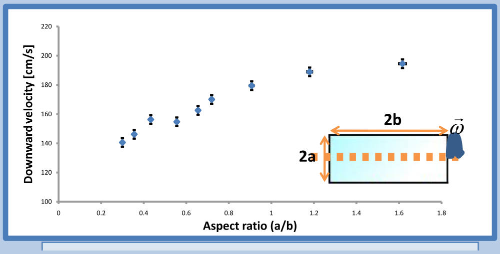
Comparison with theory



The plot is not linear but it is increasing, so a moderate agreement with the theory was achieved

Optimisation of aspect ratio



Bending of paper

Unlike playing cards, paper strips to bend during the fall

Typical bending

For 3 connected strips bending makes the motion unstable

The core of our device is two glued halves of A4 sheet.

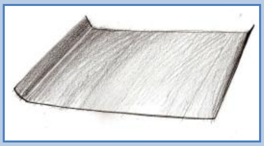
Optimisation – longer edges folded

Typical bending during tumbling of paper with a/b=1/6

With longer edges folded It has increased stiffness so that bending is rarely observable

Optimisation – shorter edges folded

The core of the device are two glued halves of A4 sheet



Instabilities (chaotic motion) occur less frequently for paper with shorter edges folded

The experiment determining the influence of winglets on falling time

The falling time of our final device

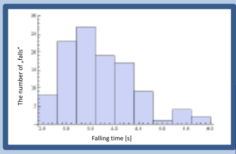
Histogram of falling times of the device without winglets – 110 falls

The mean fall time – 3.66s

Standard deviation – 0.52s

Highest fall time– 5.9s

Lowest fall time– 2.4s



The falling time of our final device

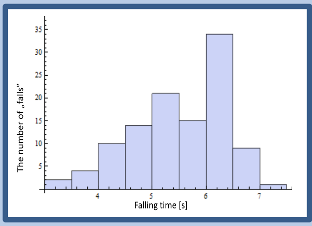
Histogram of falling times of the device with winglets – 110 falls

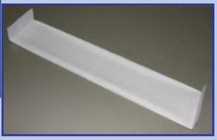
The mean fall time – 5.49s

Standard deviation – 0.69s

Highest fall time– 7s

Lowest fall time– 3.4s





The final design

Conclusions

1. During the fall of thin rectangular bodies, autorotation may arise and so lift force may be generated.
2. Simple theoretical treatement allows to qualitatively predict the parameters of motion.
3. Rigid cards with biggest aspect ratio allow slowest fall. However, aspect ratio is limited by bending.

Literature

•P. Dupleich, *Rotation in free fall of rectangular wings of elongated shape*, NACA Technical Memo No. 1201 (1941)

•J. C. Maxwell, *Scientific Papers of J. C. Maxwell* , New York, 1940, Vol. 1, p. 115.

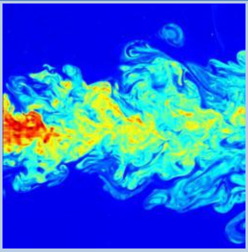
•D.L. Finn, *Falling paper and flying business cards*, SIAM News, 4, 40 (2007)

•A. Belmonte *et al.*, *From flutter to tumble: Inertial Drag and Froude Similarity in Falling Paper*, Phys. Rev. Lett. 2, 81 (1998)

•L. Mehadevan *et al.*, *Tumbling cards*, Phys. Fluids 1, 11 (1999)

Turbulent flow

In turbulent flow is characterized by the lack of stream lines.



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15.

Frustrating golf ball

Matej Badin

Problem

- It often happens that a **golf ball escapes** from the hole an instant after it has been ***putted*** into it. Explain this phenomenon and investigate the conditions under which it can be observed.

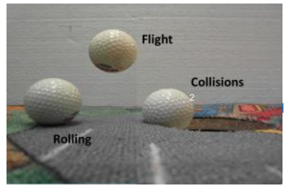
Content

- Definitions
- Analysis of the motion
  - Rolling, flight, collisions
- Simulation
- Experiment
- Conclusion

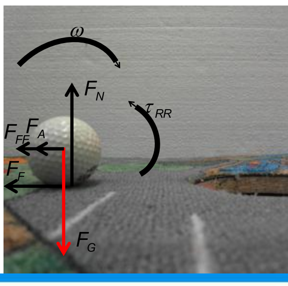
Our definitions

- Golf ball
- **USGA** norm – diameter not less than 4.267 cm
  - Our ball – d=**4.27** cm
- Hole – cylinder
  - Diameter = **10.8** cm
  - Depth = **10.2**cm

Analysis of the motion



Rolling



F_G - Gravity force

F_N - Normal force

F_F - Friction force

F_A - Air drag force

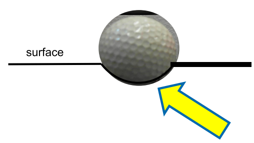
τ_{RR} - Rolling resistance torque

F_{FF} - Rolling resistance force

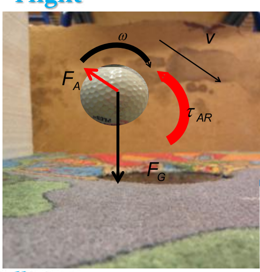
Another resistance in rolling

- Resistance **torque** to rotation around perpendicular axis to horizontal caused by **deformation of the surface or the ball**

Ball "cap" effect



Flight



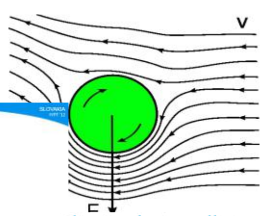
F_G - Gravity force

F_A - Drag force

τ_{AR} - Drag torque

Magnus-Robins effect

- Force caused by **pressure difference** on forward and backward moving side of spinning object.



Collision

Translation motion and rotation

Normal force and friction

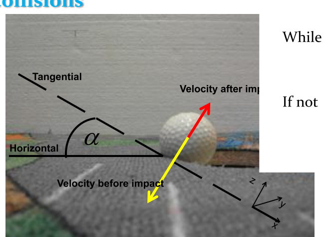
While slipping

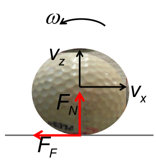
$$F_F = fF_N$$

If not

$$F_F = 0$$

Collisions

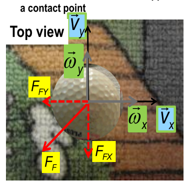




Slipping during collision

Direction of friction force is opposite to the direction of a contact point

Top view



During small time Δt

$$f^2F_N^2 = F_{FX}^2 + F_{FY}^2$$

$$\frac{F_{FX}}{F_{FY}} = \frac{V_x - \omega_y R}{V_y + \omega_x R}$$

Used trick - simulation

- Use of Newton's laws
- Simulation over small increments of the momentum Δp
- Calculation of $\Delta p_x, \Delta p_y$ from :

$$f^2 F_N^2 = F_{FX}^2 + F_{FY}^2 \Rightarrow f^2 \Delta p^2 = \Delta p_x^2 + \Delta p_y^2$$

$$\frac{F_{FX}}{F_{FY}} = \frac{v_x - \omega_y R}{v_y + \omega_x R} \Rightarrow \frac{\Delta p_x}{\Delta p_y} = \frac{v_x - \omega_y R}{v_y + \omega_x R}$$

Simulation

$v_x \Rightarrow v_x - \frac{F_{FX}}{m}\Delta t = v_x - \frac{1}{m}\Delta p_x$

$v_y \Rightarrow v_y - \frac{F_{FY}}{m}\Delta t = v_y - \frac{1}{m}\Delta p_y$

$v_z \Rightarrow v_z + \frac{\Delta p}{m}$

$\omega_x \Rightarrow \omega_x - \frac{F_{FY}}{I} R\Delta t = \omega_x - \frac{R}{I}\Delta p_y$

$\omega_y \Rightarrow \omega_y - \frac{F_{FX}}{I} R\Delta t = \omega_y - \frac{R}{I}\Delta p_x$

$\omega_z \Rightarrow \omega_z - \frac{M_{(F_N)}}{I}\Delta t$ (Ball cap effect)

Summary of effects

Rolling
- Rolling resistance
- ~~Air resistance~~
- ~~Air resistance torque~~
- Ball cap effect (deformation of ball or deformation of surface)

Fly
- ~~Magnus effect~~
- ~~Air resistance~~
- ~~Air resistance torque~~

Collisions
- Sliding
- Ball cap effect

Negligible

Summary of coefficients

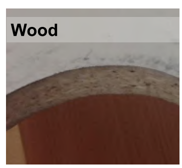
Rolling
- Rolling resistance *arm*
- Shape coefficient
- Contact area radius
- Frictions coefficients
- Moment of inertia
- Mass
- Radius

Fly
- Shape coefficients

Collisions
- Friction coefficient
- Coefficient of restitution on the edge (in dependence on angle)

Experiments

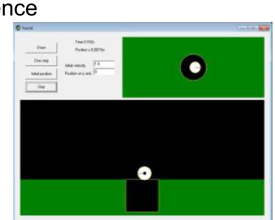
- Two surfaces



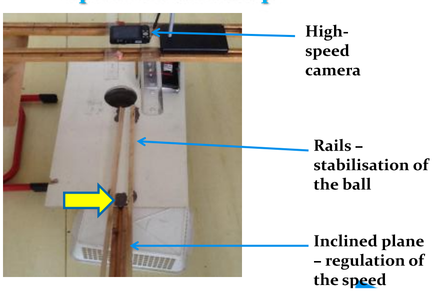
Smooth and smooth edges | Similar to grass and rough edges

Simulation

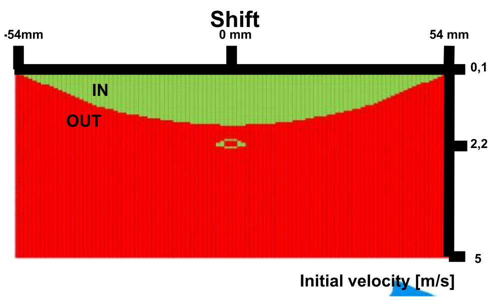
- Used described theory
- In collisions we rotated the frame of the reference

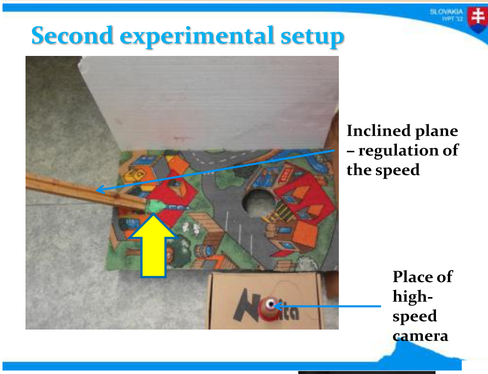


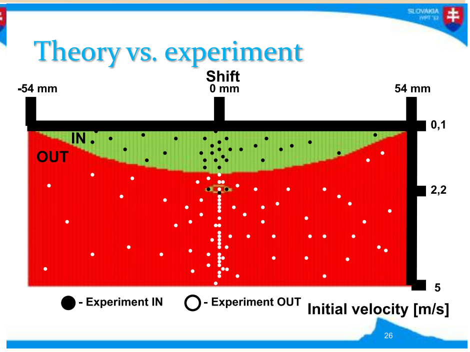
First experimental setup

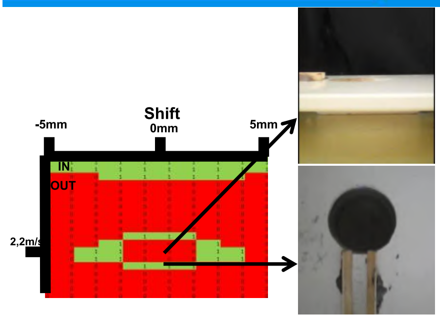


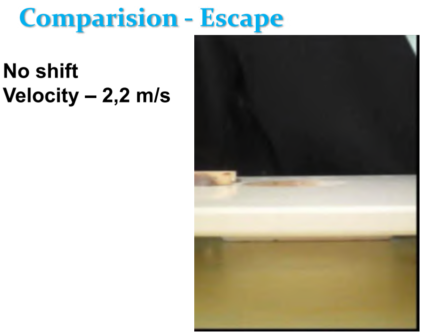
Wood simulation results

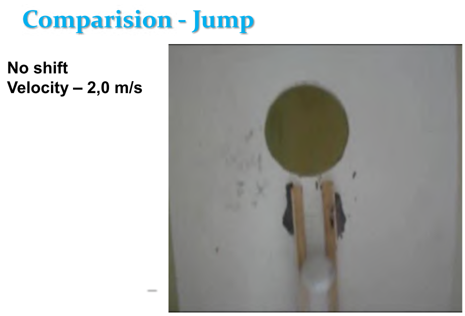


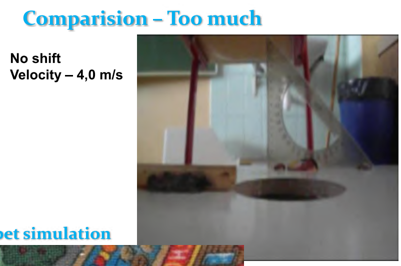

Second experimental setup
Inclined plane – regulation of the speed
Place of high-speed camera

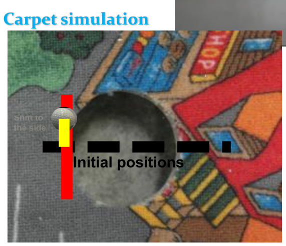

Theory vs. experiment
Shift
-54 mm
0 mm
54 mm
0,1
2,2
5
IN
OUT
- Experiment IN
- Experiment OUT
Initial velocity [m/s]

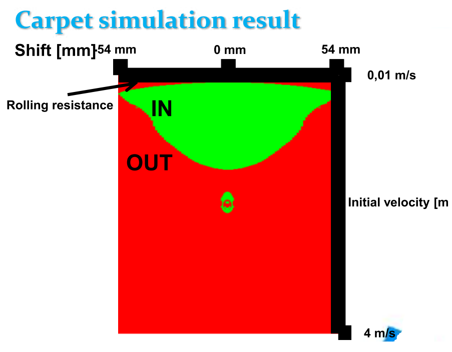

Shift
-5mm
0mm
5mm
IN
OUT
2,2m/s

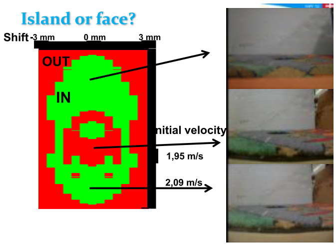

Comparision - Escape
No shift
Velocity – 2,2 m/s


Comparision - Jump
No shift
Velocity – 2,0 m/s

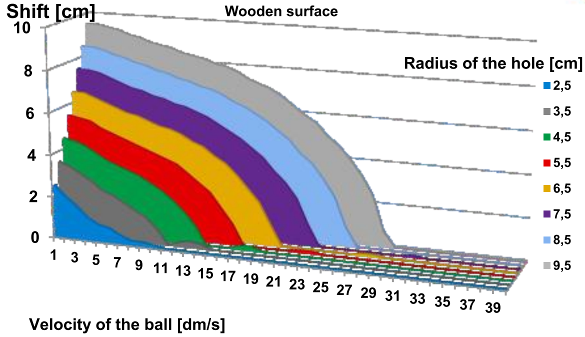

Comparision – Too much
No shift
Velocity – 4,0 m/s


Carpet simulation
Initial positions


Carpet simulation result
Shift [mm]
-54 mm
0 mm
54 mm
0,01 m/s
Rolling resistance
IN
OUT
Initial velocity [m
4 m/s


Island or face?
Shift
-3 mm
0 mm
3 mm
OUT
IN
nitial velocity
1,95 m/s
2,09 m/s

Influence of diameter of the hole



Carpet - Escape

No shift
Velocity – 1,94 m/s

Conclusion

- The most important parameters and effects
  - Rotation
  - Slipping during collision
  - Coefficient of restitution on the edge
  - Coefficient of restitution in the hole

Conclusion

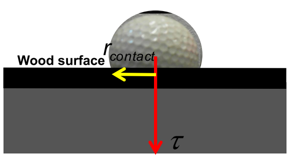
- We developed the model of the motion and collisions
- We theoretically **predicted** the path of the ball
- Prediction **correlates** with experiment
- We explained the most important parameters under which can be phenomenon observable

Deformation of the ball

We assume that normal force is evenly distributed to a contact area.
Torque acts on ball in z-axis:

$$\tau = \frac{fF_N}{\pi r_{contact}^2}\int_0^{r_{contact}} 2\pi x^2\,dx$$

$$\tau = \frac{2}{3} fF_N r_{contact}$$

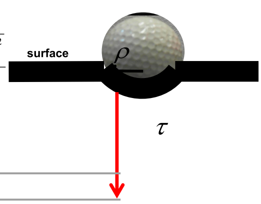


Ball cap effect

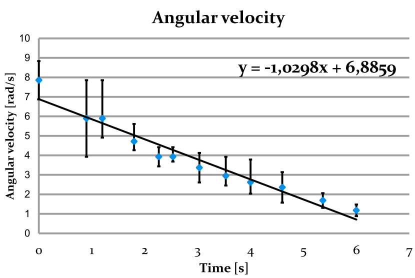
We assume that normal force is evenly distributed to a contact area.
Torque acts on ball in z-axis:

$$\tau = \frac{fF_N}{2\pi R\left(R-\sqrt{R^2-\rho^2}\right)}\int_0^{R-\sqrt{R^2-\rho^2}} 2\pi\sqrt{\left(R^2-(R-x)^2\right)}^2\,dx$$

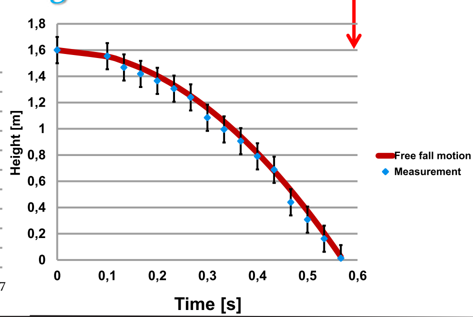
$$= fF_N\frac{\frac{2}{3}R^3-\rho^2\sqrt{R^2-\rho^2}}{R^2-R\sqrt{R^2-\rho^2}}$$



Measurement of coefficients



Drag



Summary of coefficients

Carpet

- Rolling resistance *arm - 0.0015 m*
- Shape coefficient (Air drag) – 0.1
- Coefficient of restitution Ball with
    - Carpet 0.4
    - Hole bottom 0.8
    - Hole walls, edges 0.55
- Friction coefficients - ball with
    - Carpet 0.23
    - Hole bottom 0.12
    - Hole walls 0.1
    - Hole edges 0.4
- Ball cap effect – contact radius ball on :
    Carpet - 0.0004 m
    Bottom –0.0001 m

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4.Fluid bridge

Reporter: Shiva Azizpour

IYPT 2012
BAD SAULGAU - GERMANY

IYPT 2012 Germany, National team of I. R. Iran

Main Approach

Phenomena observation
- Bridge Formation
- Unstable bridge
- Temperature increase
- Flow visualization
- Sparks

Theory
- Formation
  - Sparks
  - Droplets
  - Connection
- Stability
  - Electrical Force
  - Surface tension
  - Gravitation
- Formulation
  - Diameter vs. X
  - critical voltage
  - Reactions in the bridge

Experiments
- Setup
- oscillation
- Image Processing
  - Diameter vs. time
  - Deflection vs. time
  - Dip vs. Diameter
  - Diameter vs. X
- Voltage Reduction
  - minimum voltage vs. Length

Conclusion
- Theory vs. Experiments
  - minimum Voltage vs. Length
  - Dip vs. Diameter
  - Diameter vs. X
- Reactions in the beakers
- Stratification

Question

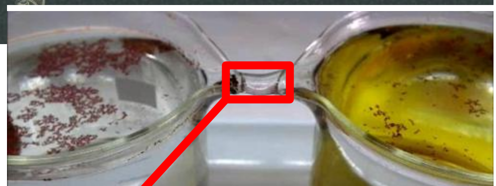
If a high voltage is applied to a fluid (e.g. deionized water) in two beakers, which are in contact, a fluid bridge may be formed. Investigate the phenomenon.

Sparks

The sparks will appear as the bridge breaks down.

Is the Bridge Always Stable?

Detecting the Water Flow



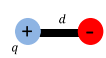
Using small colored powders we monitored the flow in two beakers

Temperature Increase

An increase in the temperature of the water passing through the bridge would change the refractive index.

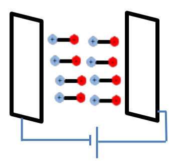
Dipole in an Electric Field

Force Application



$$P = q.d = \varepsilon_0(\varepsilon_r - 1)E$$

$$F = P.\nabla E$$

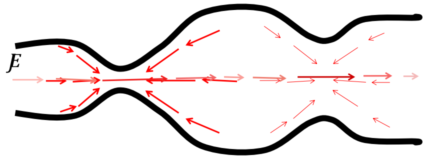


ε_0: *vacum permittivity*

ε_r: *reletive permittivity of the dielectric*

P: *dipole moment*

Electric Force



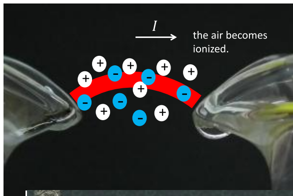
$$E = \rho\ .\ J$$

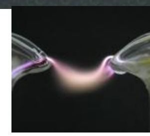
$$J = \frac{I}{A}$$

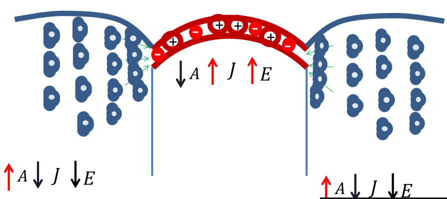
ρ: *specefic cunductance*
A: *cross sectional area*
J: *current density*

Spark

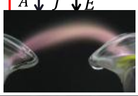
spark is formed when the electric field strength exceeds the dielectric field strength of air.



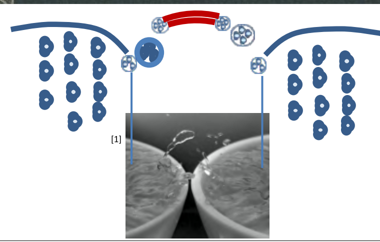




The force applied to the dipoles is in the direction of electric field's gradient.

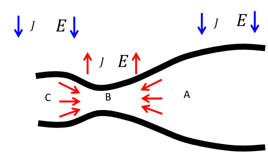


Droplet Ejection

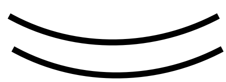


[1]http://www.ttm.tugraz.at/jw/?seite=water

Tending to the Stable Condition

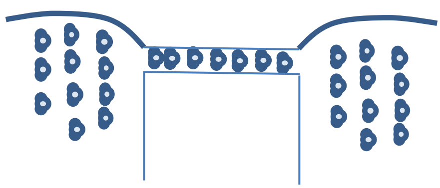


Unstable
Molecules in A and C will be attracted toward B.



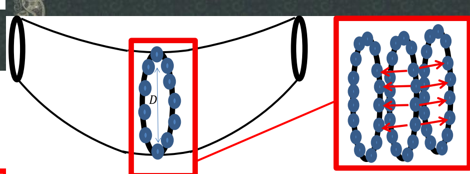
stable

Connection



Water is a stronger conductor than air → There will be a current through water rather tha air.

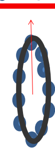
Surface Tension



$$\left.\begin{aligned} \tau &= \pi D \gamma \\ dl &= R d\theta \end{aligned}\right\}$$

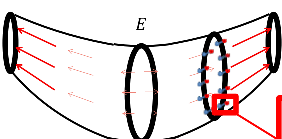
$$F_s = \frac{2\tau d\theta}{dl} = \frac{2\tau}{R}$$

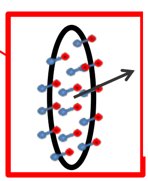
γ: *srface tension coefficient*
R: *radius of curveture*



The force applied to the surface element because of surface tension

Electric Force

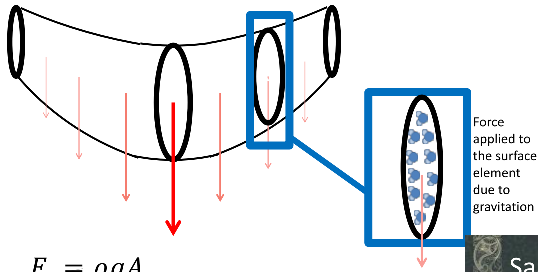




The force applied to the volume element is in the direction of electric fields gradient.

ART AN AMAZING FACT IN SCIENCE

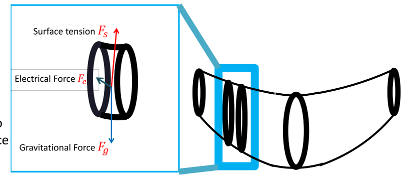
Gravitation



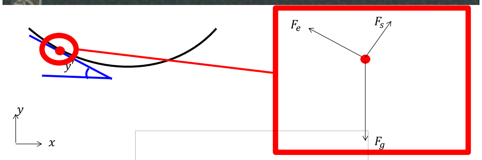
$$F_g = \rho g A$$

What is Holding the Bridge Against Gravity?

Since there is a slight sag in the bridge the main force cancelling the gravitational force is surface tension force.



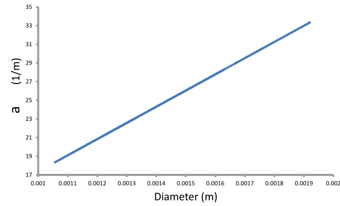
Equilibrium



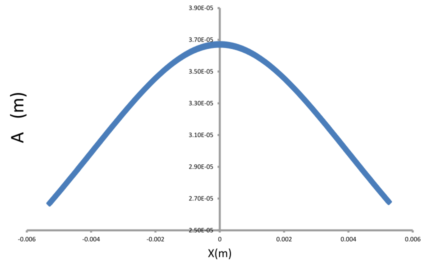
The bridge is stable So → $\sum F = 0$

Sag of the Bridge - D_0

in the center of the bridge: $F_g = F_s$ → $a = \frac{\rho g L D_0}{32\gamma}$



$A_{(I,x,A_0)}$ vs. x



Formulation

Surface tension	$F_s = \frac{2\tau}{R}$
Electrical force	$F_e = \frac{K}{D^5}\frac{\partial D}{\partial x}$
Gravitational Force	$F_g = \rho g A$

$$K = \frac{-32}{\pi^2}\varepsilon_0(\varepsilon_r - 1)\rho_s{}^2 I^2$$

Equilibrium of forces:

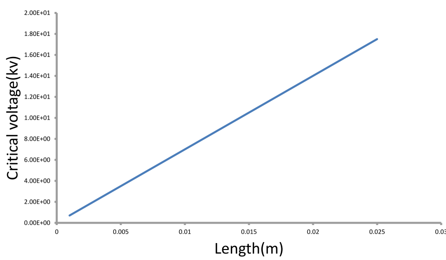
Along the bridge: $F_e + F_g sin\theta = 0$

Perpendicular to the bridge : $F_s - F_g cos\theta = 0$

$$\frac{\partial A}{\partial x} = k^2 A^3\, x$$

$$A = A_{(x)}$$

critical Voltage vs. length



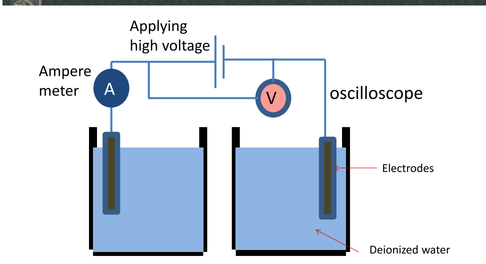
How to Reach a Limitation for Stability?

$$R = \rho_s \int_{L/2}^{-L/2} \frac{dx}{A_{(x,I,D_0)}}$$

$$V = R\,I$$

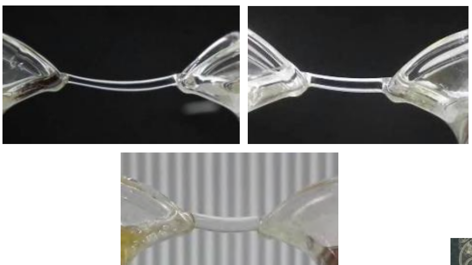
$$\lim_{I\to 0} V_{(I,L,D_0)} = V_{critical(L,D_0)}$$

Set Up
Schematic

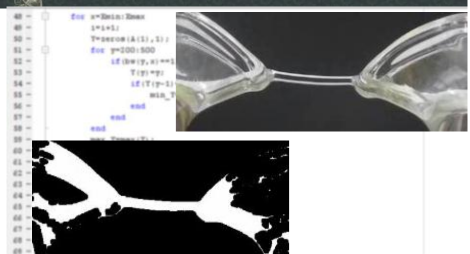


Experimental Set up

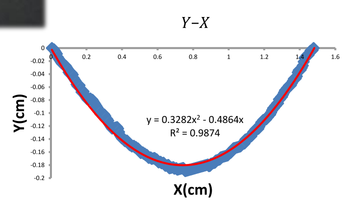
Diameter's oscillation



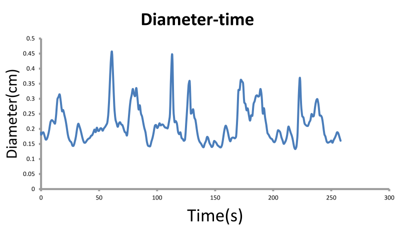
Video Processing:



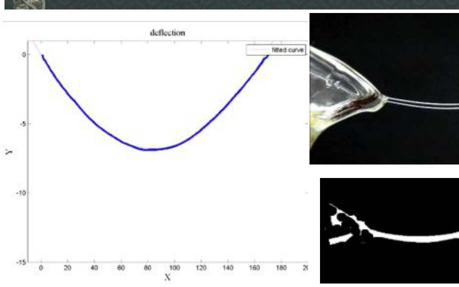
Bridge Coordinate



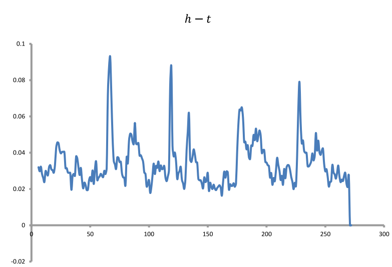
Diameter's oscillations



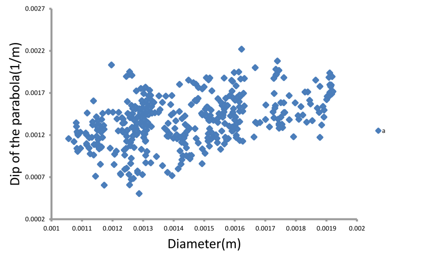
Deflection oscillation



Deflection's Oscillations

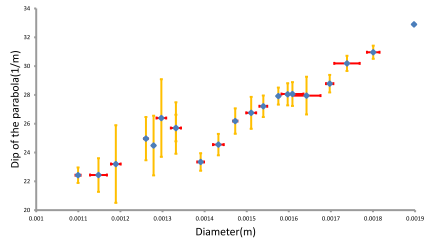


a vs. Maximum Diameter

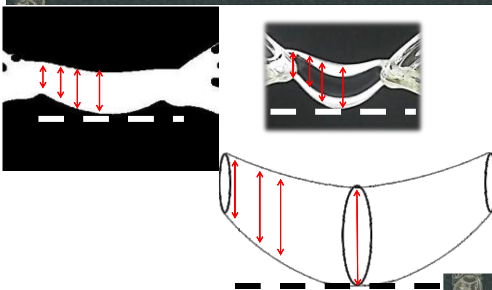


a vs. Maximum Diameter

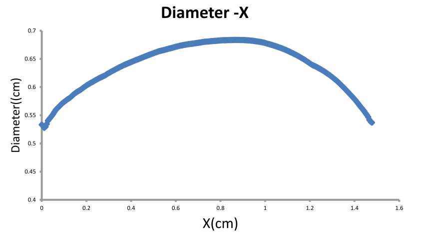
statistical operation



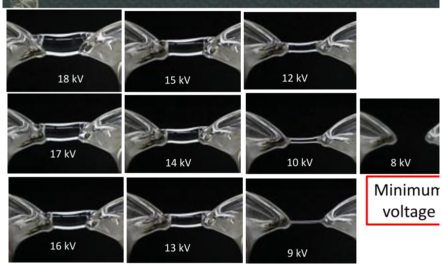
Changes of the Diameter



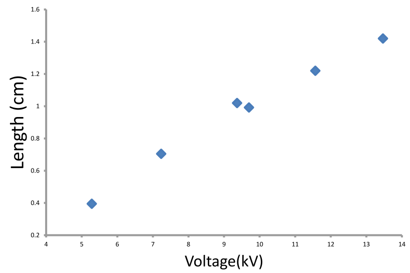
Diameter vs. X



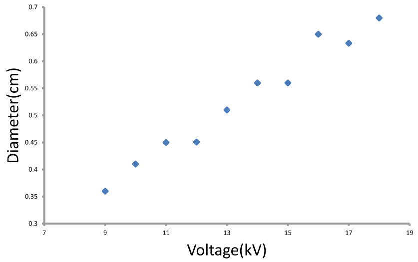
Voltage Reduction



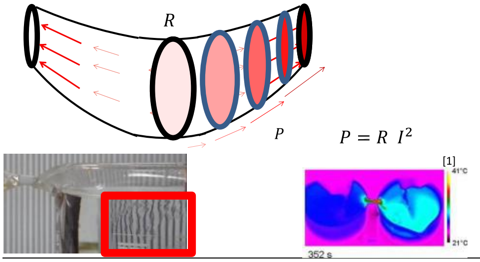
Voltage limit



Maximum Diameter vs. Voltage

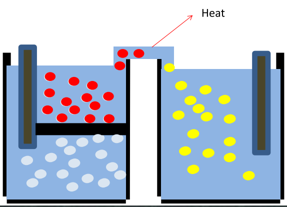


Heating

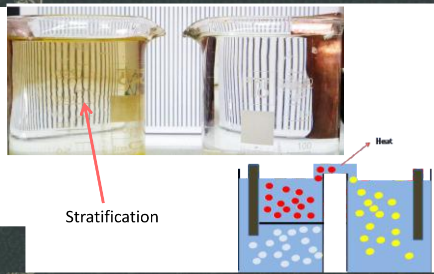


[1]Experiments in a floating water bridge. Jakob Woisetschla¨ger- Karl Gatterer -Elmar C. Fuchs

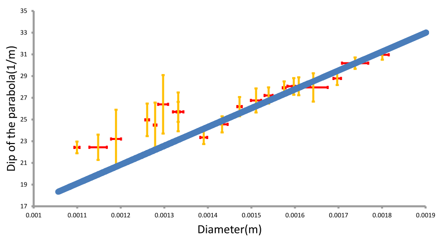
Stratification



Stratification



a vs. diameter
Theory vs. Experiment



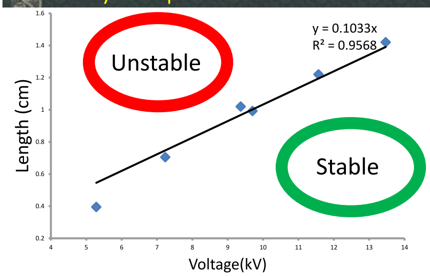
[1] Description of Spherical Aberration and Coma of a Microlens Using Vector Diffraction Theory Glen D. Gillena and Shekhar Gu

What is holding the bridge?!

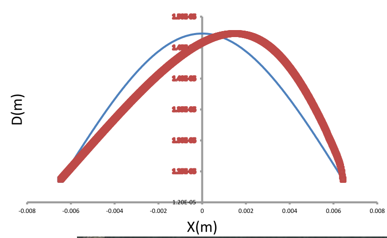
The comparison verifies our theory which stated :

The force that is holding the bridge against gravity is the **surface tension**….

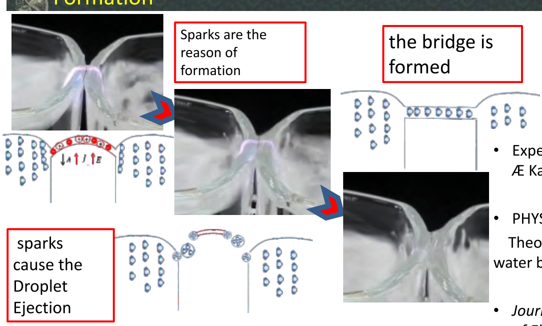
Minimum Voltage vs. Length
Theory vs. Experiment



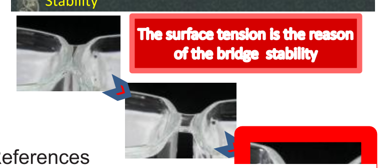
Diameter vs. X
Theory vs. Experiment



Conclusion
Formation

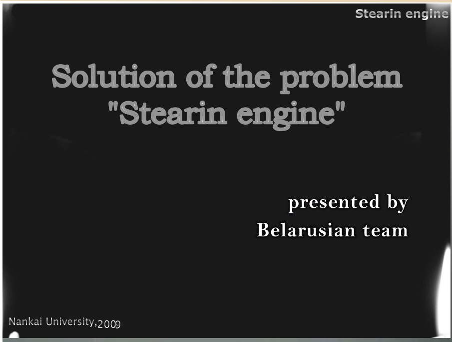


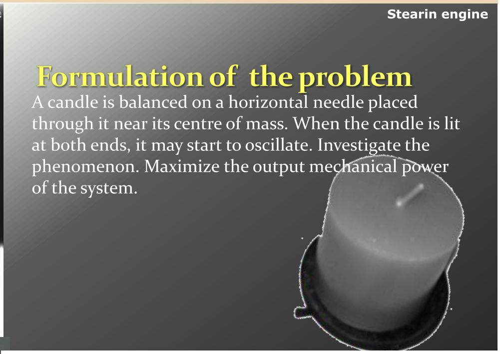
Conclusion
Stability



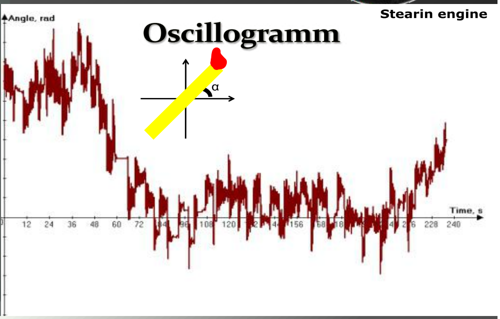
References

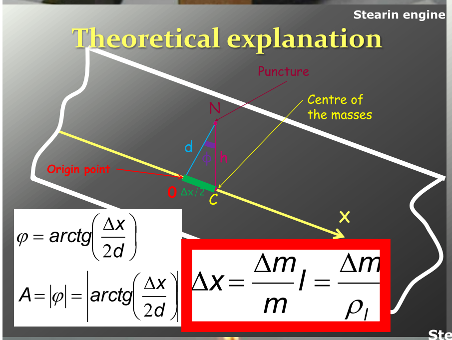
- Experiments in a floating water bridge .Jakob Woisetschla¨ger Æ Karl Gatterer Æ Elmar C. Fuchs(2010)
- PHYSICAL REVIEW E 80, 016301 2009
  Theory of the Maxwell pressure tensor and the tension in a water bridge. A. Widom, J. Swain, and J. Silverberg
- *Journal of Electrostatics,* 26 (1991) 143-156 Elsevier. *Journal of Electrostatics,* 26 (1991) 143-156 Elsevier. A. Ramos and A. Castellanos

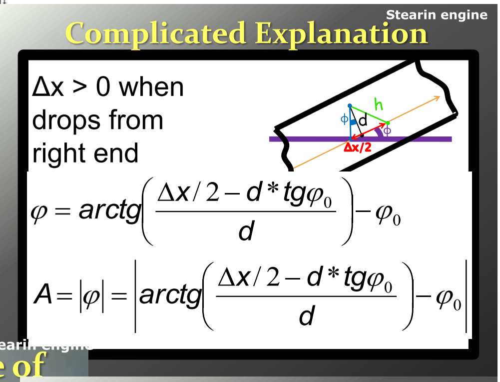

Stearin engine
Solution of the problem "Stearin engine"
presented by
Belarusian team
Nankai University,2009

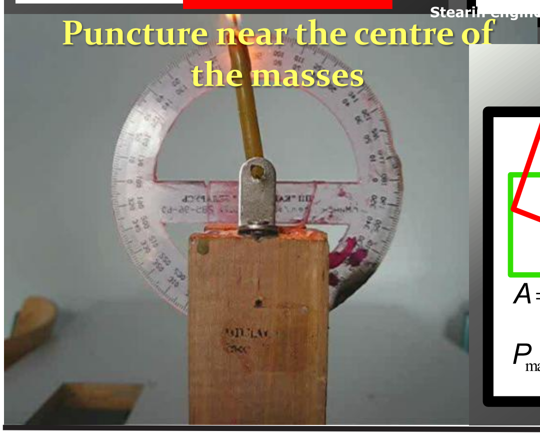

Stearin engine
Formulation of the problem
A candle is balanced on a horizontal needle placed through it near its centre of mass. When the candle is lit at both ends, it may start to oscillate. Investigate the phenomenon. Maximize the output mechanical power of the system.

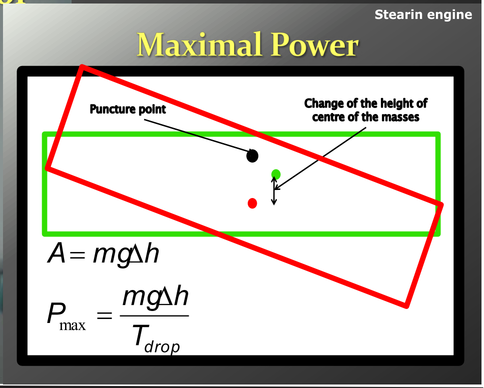

Stearin engine
Demonstration of the effect

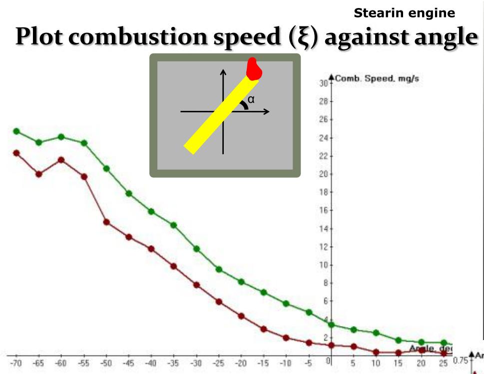

Stearin engine
Oscillogramm
Angle, rad
α
Time, s
12
24
36
48
60
72
120
156
228
240

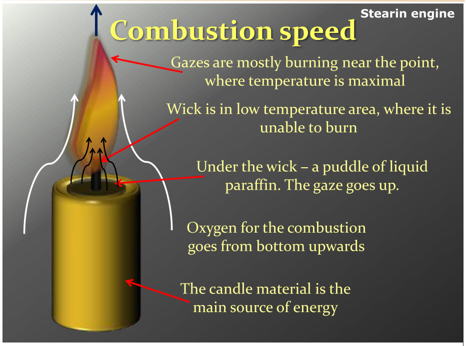

Stearin engine
Theoretical explanation
Puncture
Centre of the masses
N
d
h
Origin point
O
Δx/2
C
x
$\varphi = arctg\left(\frac{\Delta x}{2d}\right)$
$A = |\varphi| = \left|arctg\left(\frac{\Delta x}{2d}\right)\right|$
$\Delta x = \frac{\Delta m}{m} l = \frac{\Delta m}{\rho_l}$

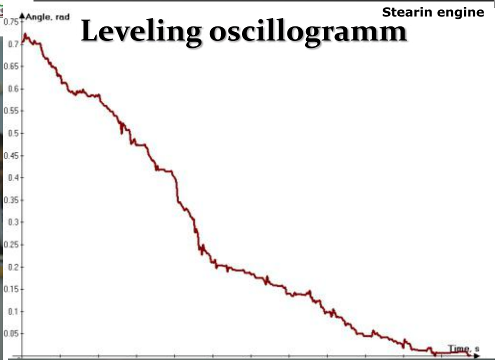

Stearin engine
Complicated Explanation
Δx > 0 when drops from right end
h
φ
d
Δx/2
$\varphi = arctg\left(\frac{\Delta x/2 - d * tg\varphi_0}{d}\right) - \varphi_0$
$A = |\varphi| = \left|arctg\left(\frac{\Delta x/2 - d * tg\varphi_0}{d}\right) - \varphi_0\right|$

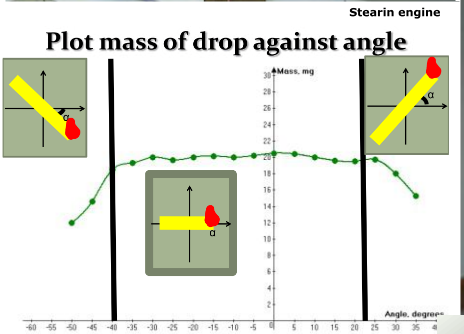

Stearin engine
Puncture near the centre of the masses

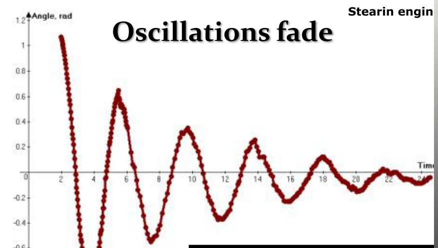

Stearin engine
Maximal Power
Puncture point
Change of the height of centre of the masses
$A = mg\Delta h$
$P_{max} = \frac{mg\Delta h}{T_{drop}}$



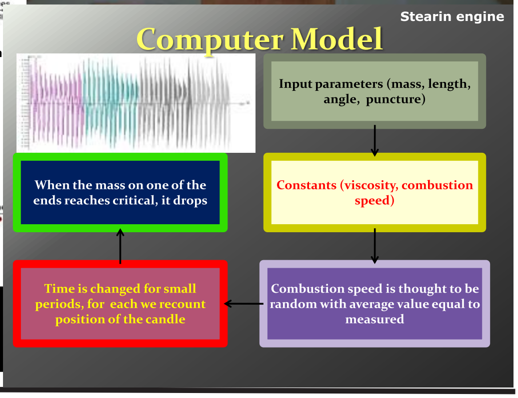


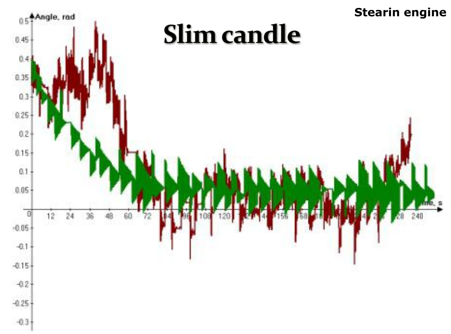


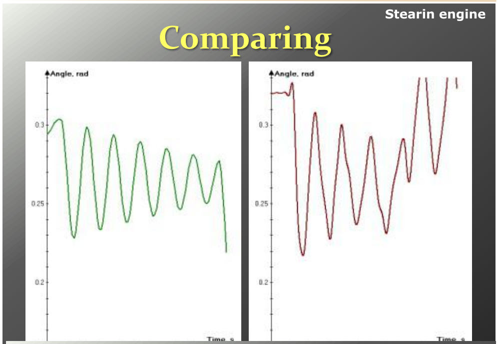


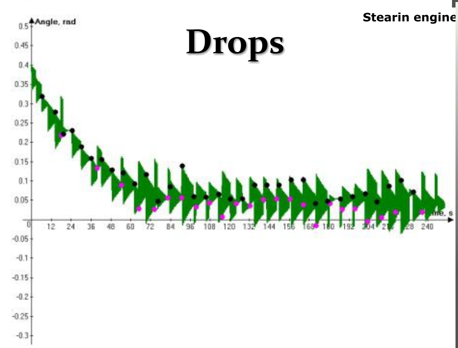


$$A_N = A_0 e^{-\beta (N*T)}$$
$$\beta = 0.17 s^{-1}$$







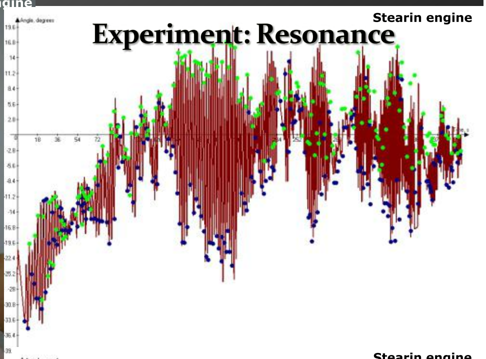


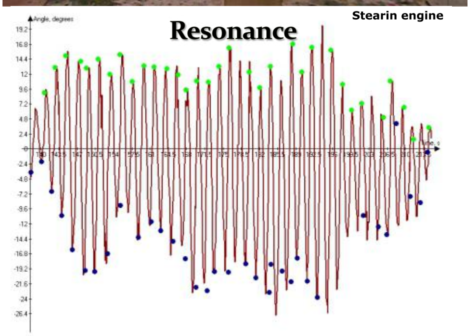
Stearin engine

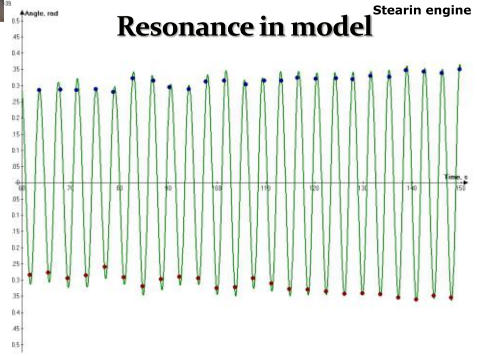
Period of oscillations

Free oscillation period of a candle:

$$T = 2\pi \sqrt{\frac{I}{mgd}} = \pi \frac{l}{\sqrt{3gd}}$$

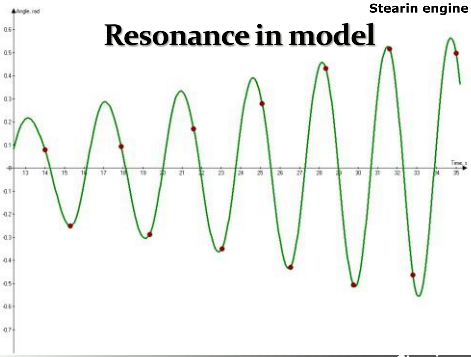






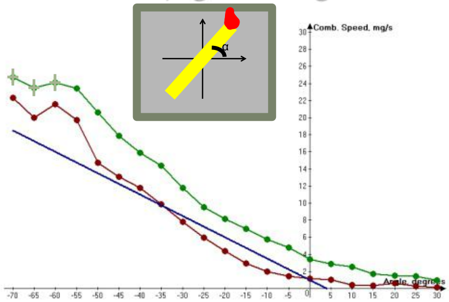
Stearin engine

Resonance in model



Stearin engine

Plot ξ against angle



Stearin engine

Resonance conditions

We'll suggest, that resonance occurs, when $T_{free} = T_{drop}$, and will find conditions, needed for the resonance. To do this, we'll find T_{drop}:

$$m_d = \int_0^{T_{drop}} \xi_i dt = \int_0^{T_{drop}} (2.85 - 0.25 A \sin(\zeta_0 + \omega t)) dt$$

Stearin engine

Resonance conditions

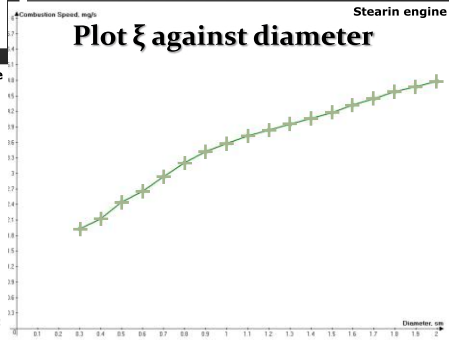
$$m_d = 2.85T + \frac{A\cos(\zeta_0 + 2\pi)}{8\pi} T;$$

$$m_d = \frac{l}{\sqrt{3gd}} \left(2.85\pi + \frac{\left| arctg\left(\frac{m_d}{2d\rho_l}\right) \right| \cos\zeta_0}{8} \right);$$

$l \approx 250 sm$ d=0.001 m R=0.003 m

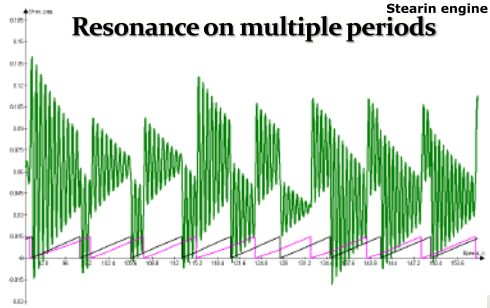
Stearin engine

Plot ξ against diameter



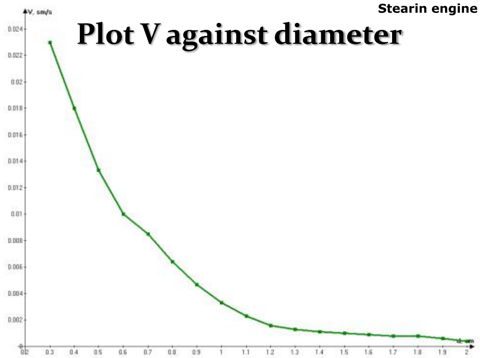
Stearin engine

Resonance on multiple periods



Stearin engine

Plot V against diameter



Stearin engine

Massive candles

We will separate a class of massive candles. Massive candles are such ones, which can't move when one drop falls. It means that the moment of the force is less than moment of frictional forces. Such candle may not oscillate in basic mode, even if punctured at the center of the masses.

Stearin engine

«Scoops»

Scoops

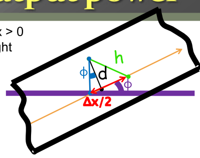
Stearin engine

Counting output power

$$A_i = m_c g(h_2 - h_1)$$

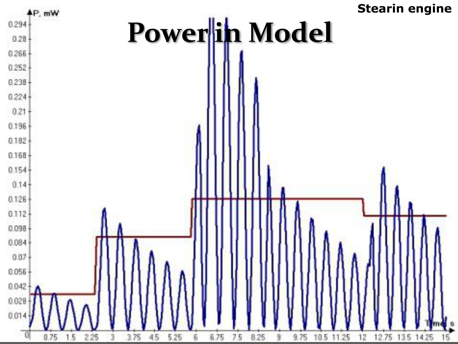
$$P_i = \frac{A_i}{T_{drop}} = \frac{A_i}{N*T} =$$

$$= \frac{mg\sqrt{d^2 + (\frac{\Delta x}{2} - d*tg\varphi)^2} - \frac{d}{\cos\varphi} + \frac{\Delta x}{2}\sin\varphi}{N*\pi l / \sqrt{3g\sqrt{d^2 + (\frac{\Delta x}{2} - d*tg\varphi)^2}}}$$



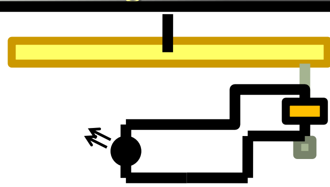
Stearin engine

Power in Model

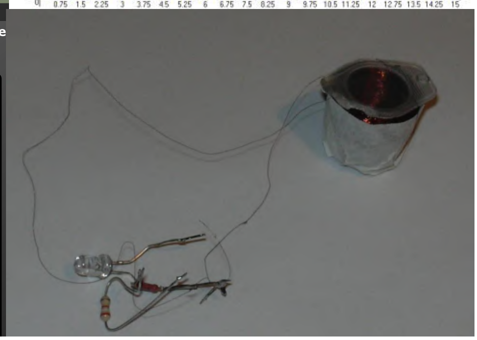


Stearin engine

Usage of Power



$$P = \frac{<\varepsilon>^2}{R}; <\varepsilon> \sim \frac{\Phi_0}{T} \sim A\omega; P \sim A^2\omega^2$$



Stearin engine

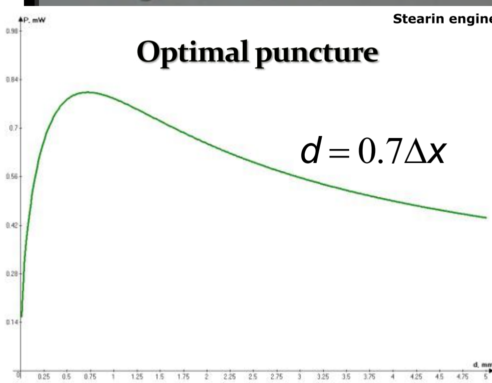
Output Power

$$P \sim A^2\omega^2 \sim \frac{arctg(\frac{\Delta x}{2d})\sqrt{d}}{l}$$

$$\Delta x = \frac{\Delta m}{\rho\pi R^2}$$

Stearin engine

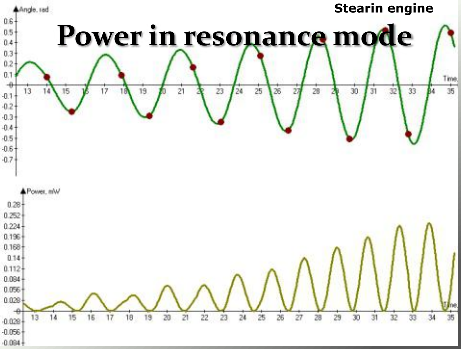
Optimal puncture



$$d = 0.7\Delta x$$

Stearin engine

Power in resonance mode



Stearin engine

Conclusions:

- Stearin engine is not a heat machine
- We need to use candles from paraffin of about 1sm wide.
- The resonance effect is the basic of getting maximal power.
- The optimal puncture is needed for the power to be maximal.
- The best way of using Stearin engine is transforming its mechanical energy into electromagnetic.

Viscosity

$$M_{res} = 2 * \int_0^{l/2} k V_l l dl = 2 \int_0^{l/2} k \omega l^2 dl = 2k\omega \frac{l^3}{3*8}$$

$$\Rightarrow \beta = \frac{kl^3}{12I} = \frac{kl^3}{ml^2} = \frac{k}{\rho_л} = \frac{k}{\rho * \pi R^2}$$

$$M_{fr} = \mu N * r = \mu mgr = \mu \rho l \pi R^2 r$$

Stearin engine

Results:

- The effect of oscillations was explained
- We created a computer model, which lets us imitate effect of the problem
- We found the parameters, which the oscillations depend on.
- We defined optimal parameters for achieving maximal output mechanical power of the system.
- We created a device, transforming the power of oscillation into electromagnetic oscillations.

How fast the candle burns

$$\xi = 50\sqrt{R * e^{- \cdot \ 0\,04}}$$

Stearin engine

Literature:

- Slobodjanuk A. I. “Advance high school physic”
- Slobodjanuk A. I. “Computer model of physical processes for high school students”
- Y. A. Smorodinsky “Temprature”

Problem No. 1

Invent yourself

Report : F.Mokhtari

The Problem

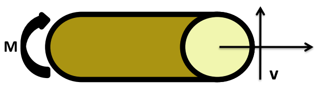
- It is more difficult to bend a paper sheet, if it is folded "accordion style" or rolled into a tube. Using a single A4 sheet and a small amount of glue, if required, construct a bridge spanning a gap of 280 mm. Introduce parameters to describe the strength of your bridge, and optimize some or all of them.

Initial information

P : axial force

V : shear force

M : momentum



σ : normal stress that is equal with axial force divided by surface ($\frac{P}{A}$)

τ : shear stress that is equal with shear force divided by surface ($\frac{V}{A}$)

} $\frac{N}{m^2}$

I : Area moment of inertia

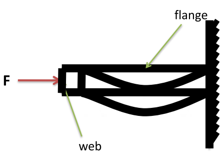
E : young's module

Q : first moment of area

Initial information

Buckling :

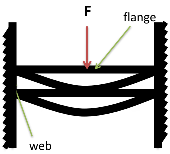
Is a deformation that happen after a magnitude of axial force, it does not have any resistance against axial force and it makes a instability in a section, different parts in a structure shall not be buckle.



Initial information

Bending :

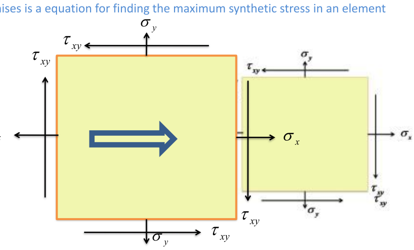
Is a deformation that happen due to resistance against transverse force (**F**) and it happen in all magnitude of transverse force (**F**), we have maximum bending , in this point section will be



Step 1 : yield or fracture criteria

Von mises is a equation for finding the maximum synthetic stress in an element

If : σ_x



$\sigma_{ultimate}$: ultimate resistance that consider to type of substance.($\sigma_{ultimate} = 50\ Kg/cm^2$)

$$\sigma_{\text{von mises}} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \times \sigma_y + 3 \times \tau_{xy}^2}$$

$$\sigma_{von\ mises} > \sigma_{ultimate}$$

collapse

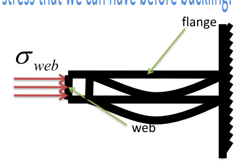
$$\sigma_{\text{von mises}} \le \sigma_{\text{ultimate}}$$

This equation shows the maximum stress that we can have before buckling.

$$\sigma_{buckling} = k \times E \times (\frac{t}{b})^2$$

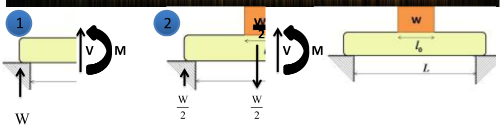
t: thickness

If : $\sigma_{web} > \sigma_{buckling}$



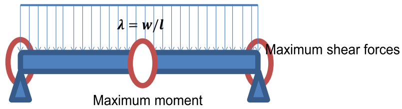
$$\sigma_{web} \le \sigma_{buckling}$$

Step 2 : internal forces



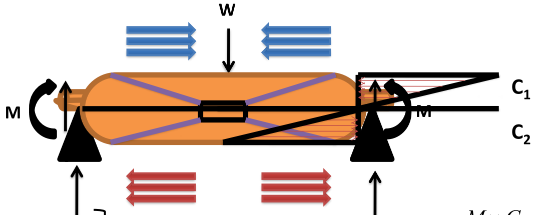
1
$$\sum F(y)=0 \longrightarrow \frac{W}{2}+V=0 \longrightarrow V=-\frac{W}{2}$$
$$\sum M=0 \longrightarrow M-\frac{W}{2}\times(\frac{L}{2}-\frac{l_0}{2})=0 \longrightarrow M=\frac{W}{2}\times(\frac{L}{2}-\frac{l_0}{2})$$

2
$$\sum F(y)=0 \longrightarrow \frac{W}{2}-\frac{W}{2}-V=0 \longrightarrow V=0$$
$$\sum M=0 \longrightarrow M-\frac{W}{2}\times(\frac{L}{2}-\frac{l_0}{4})=0 \longrightarrow M=\frac{W}{2}\times(\frac{L}{2}-\frac{l_0}{4})$$

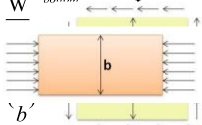


$$V=\int -\lambda dx \quad\Rightarrow\quad V=-\lambda x+\frac{w}{2}$$
$$M=\int V dx \quad\Rightarrow\quad M=-\frac{\lambda x^2}{2}+\frac{w}{2}x$$

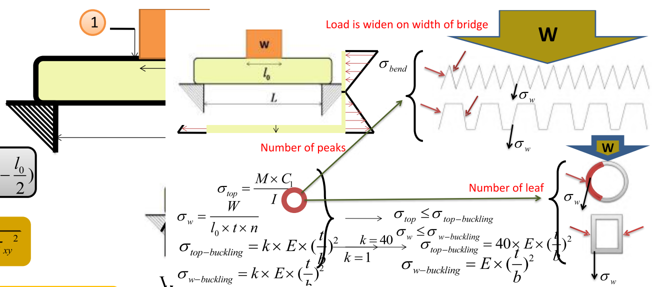
We will construct our bridge considering the maximum moment and shear forces



$$\sigma_{top}=\frac{M\times C_1}{I}$$
$$\tau_{xy}=\frac{V\times Q}{I\times t} \longrightarrow \tau_{xy}=\frac{V}{A_w}$$
$$\sigma_{top} \leq \sigma_{top-buckling}$$
$$\tau_{xy} \leq \tau_{xy-Buckling}$$
$$\sigma_{top-Buckling}=k\times E\times(\frac{t}{b})^2 \xrightarrow{k=6} \sigma_{top-buckling}=6\times E\times(\frac{t}{b})^2$$
$$\tau_{xy-Buckling}=k\times E\times(\frac{t}{b})^2 \xrightarrow{k=8} \tau_{xy-Buckling}=8\times E\times(\frac{t}{b})^2$$
$$\sigma_{bottom}=\frac{M\times C_2}{I}$$

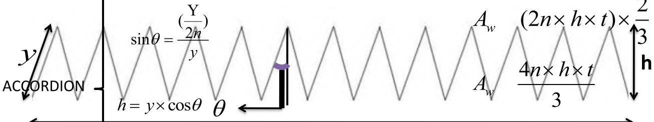


$$\tau_{xy}=\frac{V}{A_w} \qquad V=-\frac{W}{2}$$
$$\sigma_{bottom}=\frac{M\times C_2}{I} \longrightarrow M=\frac{W}{2}\times(\frac{L}{2}-\frac{l_0}{2})$$
$$\sigma_{\text{von mises}}=\sqrt{\sigma_x^{\ 2}+\sigma_y^{\ 2}-\sigma_x\times\sigma_y+3\times\tau_{xy}^{\ 2}}$$
$$\sigma_y=0 \qquad \sigma_x=\sigma_{bottom} \qquad \sigma_{\text{von mises}} \leq \sigma_{\text{ultimate}}$$



$$\sigma_{top}=\frac{M\times C_1}{I}$$
$$\sigma_w=\frac{W}{l_0\times t\times n}$$
$$\sigma_{top-buckling}=k\times E\times(\frac{t}{b})^2 \xrightarrow{k=40} \sigma_{top} \leq \sigma_{top-buckling}=40\times E\times(\frac{t}{b})^2$$
$$\sigma_{w-buckling}=k\times E\times(\frac{t}{b})^2 \xrightarrow{k=1} \sigma_w \leq \sigma_{w-buckling}=E\times(\frac{t}{b})^2$$

ACCORDION



$$y=\frac{21}{2n}=\frac{10.5}{n}$$
$$\sin\theta=\frac{(\frac{Y}{2n})}{y}$$
$$h=y\times\cos\theta$$
$$A_w=(2n\times h\times t)\times\frac{2}{3}$$
$$A_w=\frac{4n\times h\times t}{3}$$
$$I_0=\frac{y\times t\times h^2}{12} \longrightarrow I=n\times I_0 \longrightarrow I=\frac{21\times t\times h^2}{12}$$

TRAPEZOID

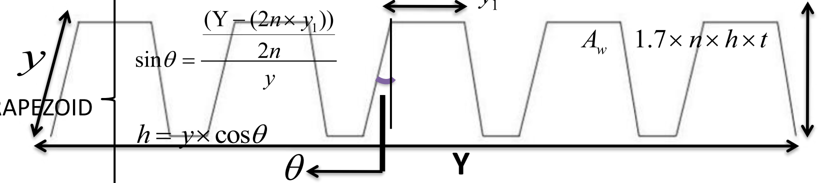
$$y = \frac{21}{2n} - 1.$$

$$\sin\theta = \frac{\frac{(Y-(2n\times y_1))}{2n}}{y}$$

$$h = y\times\cos\theta$$

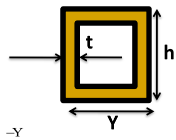
$$A_w \quad (2n\times h\times t)\times 0.85$$

$$A_w \quad 1.7\times n\times h\times t$$



$$I_0 = \frac{2y\times t\times h^2}{12} + \frac{2y_1\times t\times h^2}{4} \longrightarrow I_{total} = n\times I_0 = \frac{n\times t\times h^2}{2}\times\left(y_1+\frac{y}{3}\right)$$

BOX



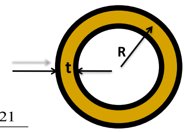
BOX

$$h = \frac{21}{2n} - Y$$

$$A_w \quad (2n\times h\times t)\times 0.85$$

$$A_w \quad 1.7\times n\times h\times t$$

$$I_0 = 2\times(Y\times t)\times\left(\frac{h}{2}\right)^2 + \frac{2\times h^3\times t}{12} \longrightarrow I_{total} = n\times I_0$$



BOX

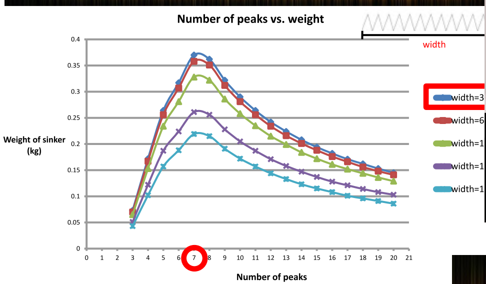
$$R = \frac{21}{2n\times\pi}$$

$$A_w \quad n\times\pi\times R\times t$$

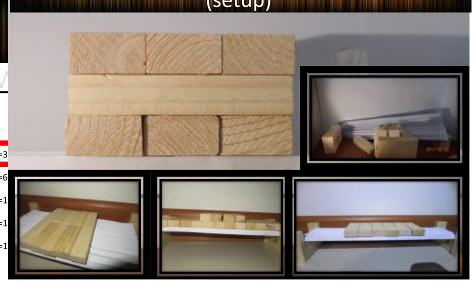
$$A_w \quad n\times\pi\times R\times t$$

$$I_0 = \pi\times R^3\times t \longrightarrow I_{total} = n\times I_0 = n\times\pi\times R\times t$$

ACCORDION



Experiment
(setup)



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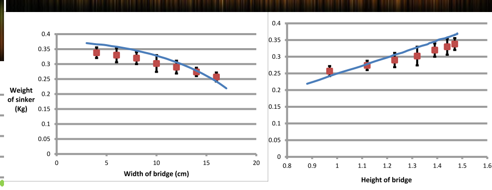

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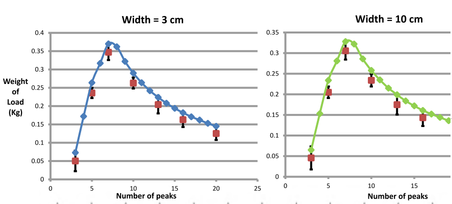
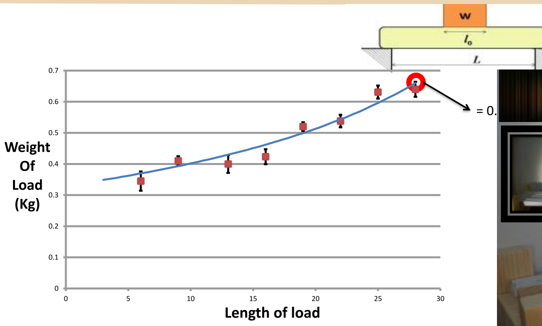
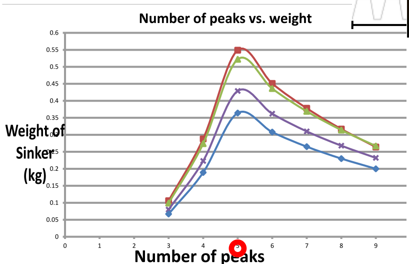


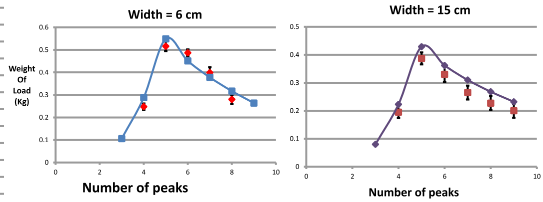


Experiment
(setup)

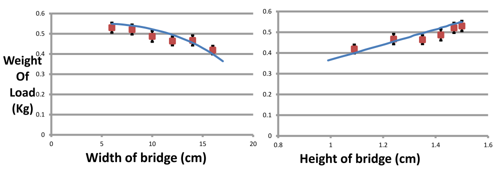
TRAPEZOID (THEORY RESULTS)

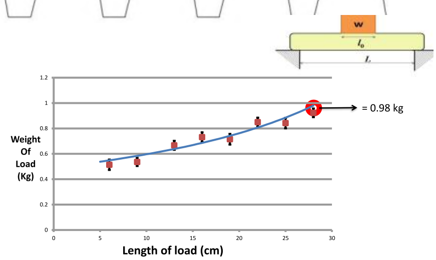


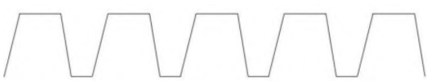
TRAPEZOID

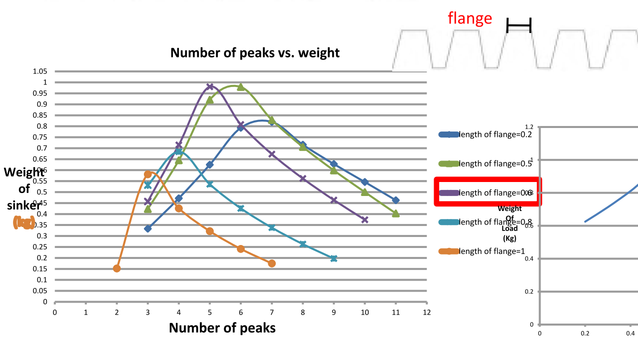


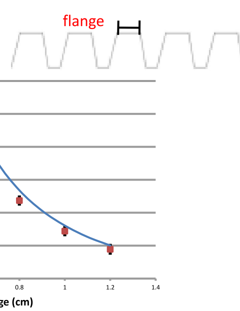
TRAPEZOID

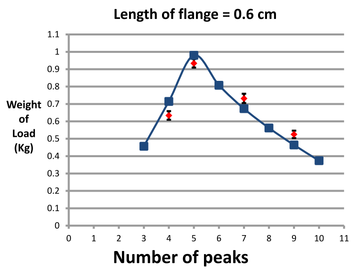


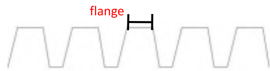


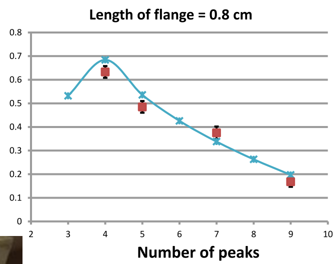


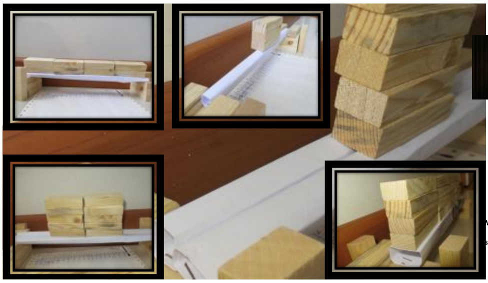




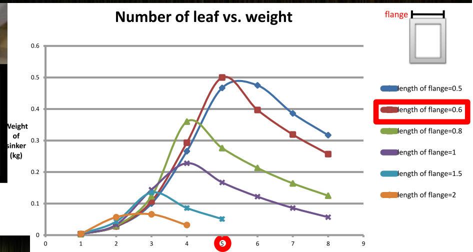




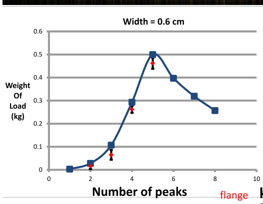


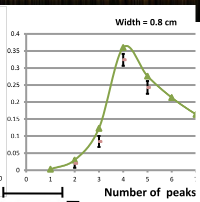


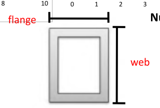
BOX (THEORY RESULTS)



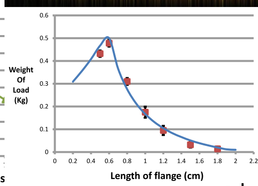
BOX

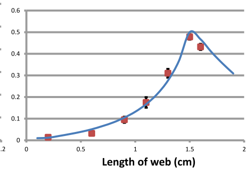


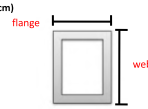


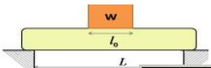


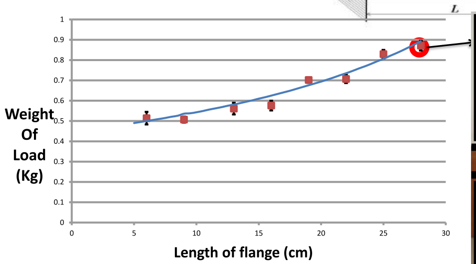
BOX



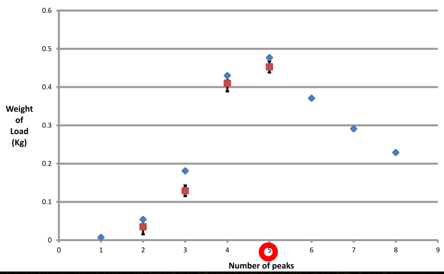








TUBE



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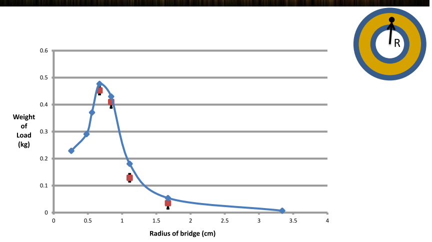
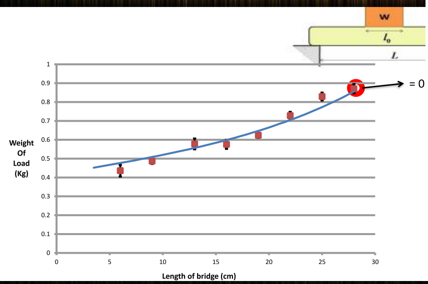
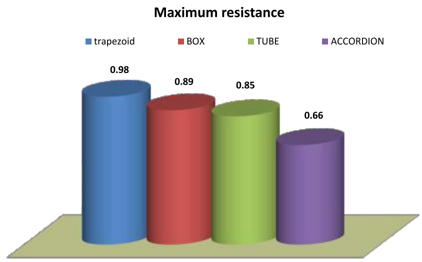


TUBE





Review

In this research we find the best shape that have maximum resistance against weight and we calculate all the stresses and forces and we compares this parameters.

Reference

- Plastic analysis of plates and shapes _ professor Tomasz Wierzbicki
- Mechanics of materials _ Ferdinand P.Beer, E.Russel Johnston
- Mechanics of materials _ Egor P. Popov
- The stability of beams with buckled compression flanges _ Cherrys
- Handbook of structure stability _ Gerard G , Becker H
- Theory of plates and shells _ Stephan p. Timoshenko

ART AN AMAZING FACT IN SCIENCE

Hovercraft

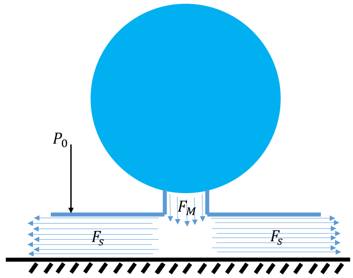
Amirhossein Ebadi

Problem

A simple model hovercraft can be built using a CD and a balloon filled with air attached via a tube. Exiting air can lift the device making it float over a surface with low friction. Investigate how the relevant parameters influence the time of the 'low friction' state.

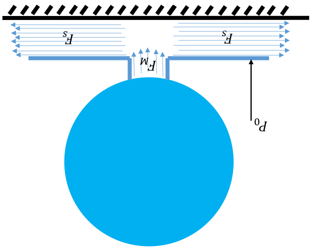
Observation

First idea



$F_S + F_M > P_0 a + W$

Second idea



$F_S + W < P_0 + F_M$

Inconsistency

$F_S + F_M > P_0 + W$ ✗

$F_S + W < P_0 + F_M$ → $F_S + W < P_0 + F_M$

The pressure under the CD is less than the pressure of air

Adiabatic

$$p \cdot v^{\gamma} = constant$$

$$p_1 \cdot {v_1}^{\gamma} = p_2 \cdot {v_2}^{\gamma} \Rightarrow p = \frac{cons}{v^{\gamma}}$$

$(\gamma \ is \ \frac{c_p}{c_v})$

P: pressure

V:volume

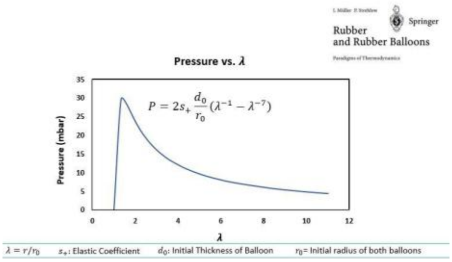
Criticizing the Navier-Stocks

Navier-Stokes momentum equation (compressible fluid)

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = -\nabla p + \mu\nabla^2\mathbf{u} + \tfrac{1}{3}\mu\nabla(\nabla\cdot\mathbf{u}) + \rho\mathbf{g},$$ [1]

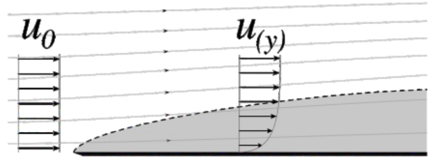
$\frac{\partial u}{\partial t} = 0$ ✗ Unsteady

P-V Chart

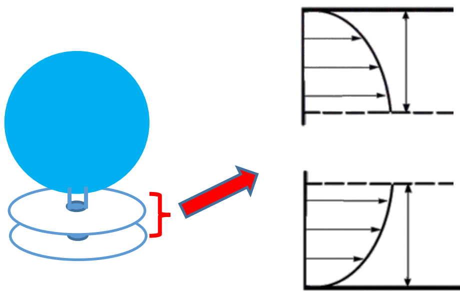


Flow under the hovercraft

Boundary layer:

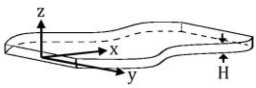


Flow under the CD



Hele-Shaw

$$u = \nabla p \frac{z^2 - H^2}{2\mu}$$



u=velocity of flow

P(x,y,t)=Local pressure

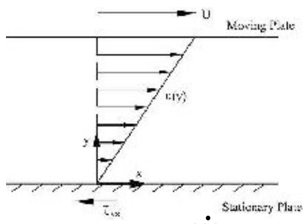
$z = \pm H$

μ= Flow's viscosity

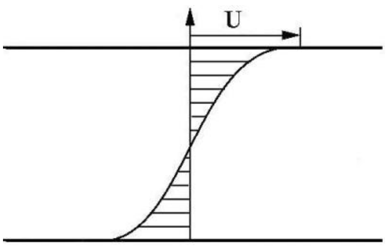
Flow under the CD (Couette flow)

$v_{CD} < v_{flow}$

$v_{CD} = v_{flow}$



$v_{CD} > v_{flow}$



$\dot{m}$

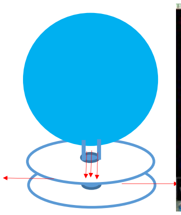
$$\dot{m} = \lim_{\Delta t \to \infty} \frac{\Delta m}{\Delta t} = \frac{dm}{dt}$$

$$\dot{m} = \rho \cdot v \cdot A$$

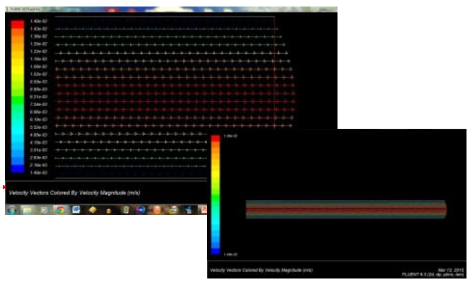
ρ = pressure

V = volume

A = Area



Simulation

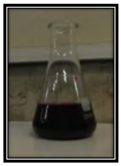


$$\dot{m} = \lim_{\Delta t \to \infty} \frac{\Delta m}{\Delta t} = 0.14\ \frac{g}{s}$$

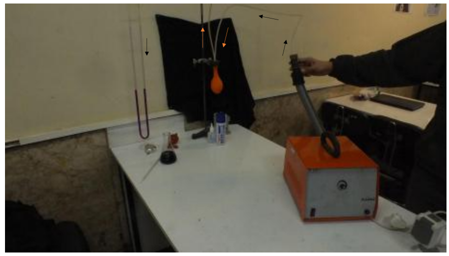
P-V Chart

Barometer

Blower

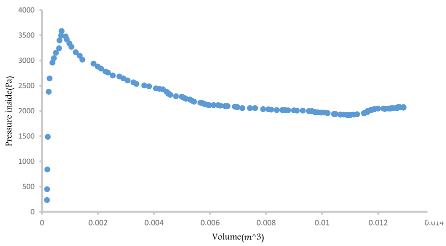


Potassium permanganate ($KMnO_4$)



Processing

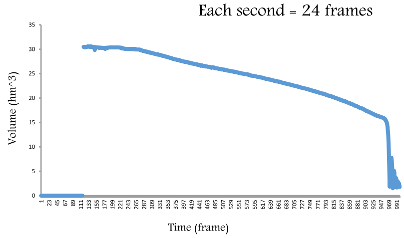
Outcome



The pressure inside the balloon isn't stable

V-t chart

Each second = 24 frames



Reynolds number

$$Re = \frac{INERTIAL\ FORCES}{VISCOUS\ FORCES} = \frac{\rho \cdot V \cdot L}{\mu}$$

V=VELOCITY OF FLOW (m/s)

ρ=DENISITY (kg/m^3)

μ=DYNAMIC VISCOSITY (N·s/m^2)

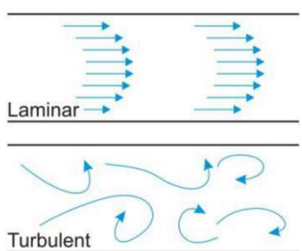
L=is a characteristic linear dimension(m)

$$Re = \frac{1.225 \times 0.647 \times 0.0012}{0.00018} = 79$$

Laminar/Turbulent

$Re < 2000$ laminar

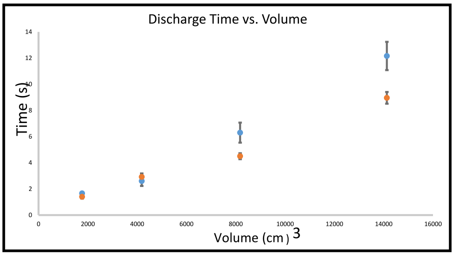
$Re > 4000$ turbulent



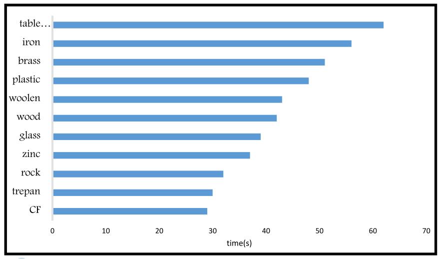
Effective parameters

- Air pressure inside the balloon
- Hovercraft's weight
- Volume of air in the balloon
- Density of air inside the balloon
- Diameter of the CD
- Area of the nozzle
- Surface of the ground
- Height of the CD from the ground

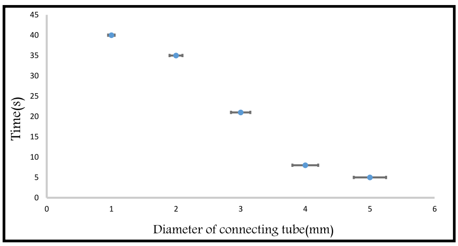
Volume



The surface effect



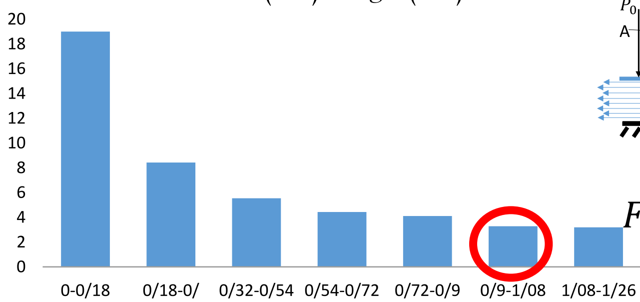
Diameter of connecting tube

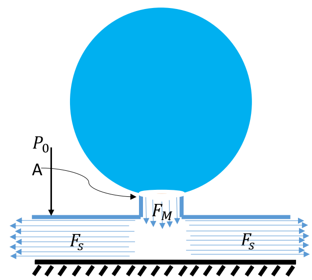


Measuring the FM

Initial height of the hovercraft

Time (min)– Height (mm)

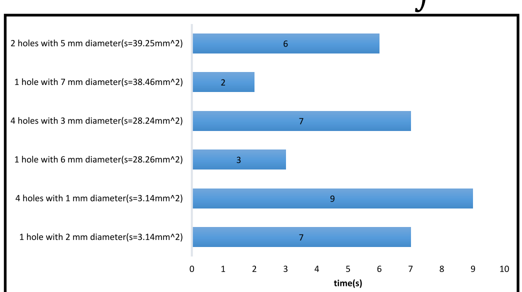




$$F_M = \frac{\dot{m}\dot{V}}{A} + m\frac{\ddot{V}}{A}$$

$$m = \int \dot{m}\, dt$$

Diameter of holes on valve



17th International Young Physicists' Tournament

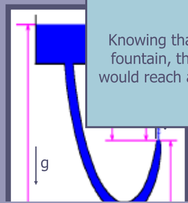
POLAND
Stanisław Staszic
Secondary School in Warsa

14. Fountain

Construct a fountain with a 1m "head of water". Optimise the other parameters of the fountain to gain the maximum jet height by varying the parameters of the tube and by using different water solutions.

General theory

To calculate what height will the ideal liquid's stream reach with given variables, we may use Bernoulli's equation:



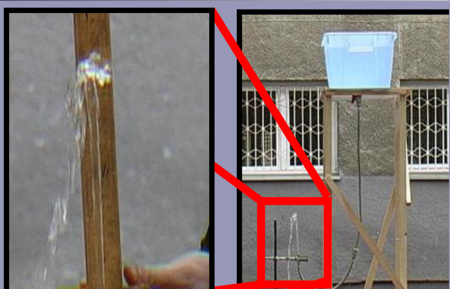
Knowing that, we have constructed a fountain, thinking that the jet height would reach a little less than one meter.

cons

$h = 1m$

Which is an answer to our problem for ideal conditions.

Our first fountain



Why is that theory wrong?

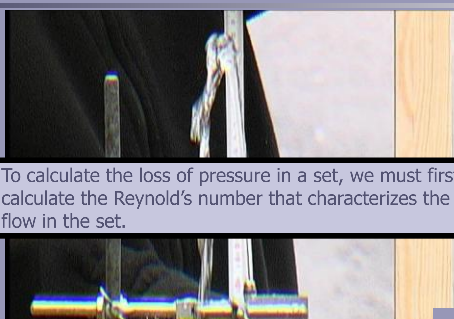
If the liquid in the fountan was ideal, and the resistances equal zero, the speed on the jet would be equal to:

$$V_{\max} \approx 4,4\frac{m}{s} \approx 15,9\frac{km}{h}$$

Those factors have influence on this velocity:

- Linear resitance of flow
- Local resistances of flow
- Air resistance
- Liquids viscosity
- Air's density and pressure
- Jet type
- Type of the flow of water
- Material, that the pipes are made of

Pressure losses



To calculate the loss of pressure in a set, we must firs calculate the Reynold's number that characterizes the flow in the set.

Reynold's number

Reynold's number specifies whether the flow is laminar or turbulent.

Reynold's number depends on viscosity coefficient ν, diameter of the flow and liquid's average velocity in the conduit;

$$\mathrm{Re} = \frac{V \cdot l}{\nu} = \frac{\rho \cdot V \cdot l}{\mu}$$

For each fountain the Reynold's number must be calculated separately. It's magnitude should be the smallest possible, because the energy lost by turbulences in the flow is the lowest.

Absolute roughness

Here is a list of the absolute roughness coefficient value for some common materials:

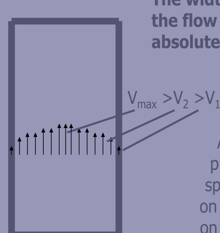
glass	0,0015-0,01
aluminium	0,015-0,06
Steel	0,02-0,10
Corroded steel	0,40
Cast iron	0,25-1,0

$$\varepsilon = \frac{k}{D}$$

***Where epsilon* is the relative roughness, *k* is absolute roughness and D is the flow's diameter**

Relative roughness

The width of the zone in which the flow is slowed depends on the absolute roughness k.



On this picture, the influence of viscosity is omitted.

At some distance from the pipe's surface the flow has a speed which does not depend on the absolute roughness (but on viscosity only). The width of this zone is inversely proportional to relative roughness.

Linear flow resistance

It is the proportion between loss of pressure in the pipe and the specific gravity weight. It is calculated with equation:

$$h_L = \frac{p_1 - p_2}{\gamma} = \lambda \frac{L}{D}\frac{v^2}{2g}$$

where λ is the linear resistance coefficient

Local resistances

Local resistances are calculated from formula:

$$h_{lost} = \zeta \frac{V^2}{2g}$$

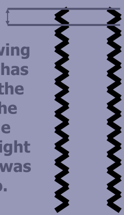
Where ζ is the local resistances coefficient, and V is an average velocity in the cross-section after the obstacle

Even smallest increase or decrease of flow's diameter, each valve, bend, etc cause some loss of pressure.

Local resistances

The influence of local resistances is effectively visualized by the height that the stream from one of the fountains we have constructed reached:

Each narrowing in this pipe has decreased the speed of the water. The stream's height in this case was near zero.



What pipe will be the best?

As said before, linear flow resistance are described by equation:

$$h_l = \lambda \frac{L}{D}\frac{V^2}{2g}$$

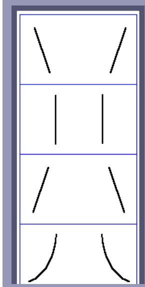
To minimize velocity losses in the flow, we must design such fountain, that length L of the flow would be the smallest, and the diameter D the biggest possible.

$$\frac{L}{D} \approx 1$$

Choosing pipes with lowest roughness, having sizes as above and for low Reynolds numbers, we may calculate:

$\lambda \approx 0.0006$ **so** $h_l \approx 0.0006 \approx 6 \cdot 10^{-4}$

Resitances at waterspout



Conic widening mouthpiece: **turned out to be less effective. Water splashed heavily.**

Cylindric mouthpiece: **It gave various effects, depending on the fountain.**

Conic narrowing mouthpiece: **gave very good results.**

Curved mouthpiece (Weisbach's jet) **results nearly identical to those from conic narrowing mouthpiece.**

Water solutions

Liquid properties:

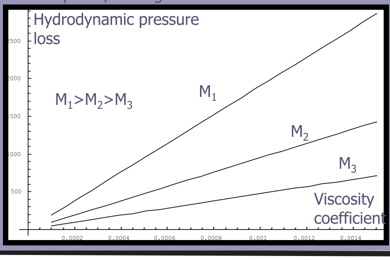
- **density**
- **viscosity**
- **specific heat**
- **compressibility**
- **temperature**
- **surface tension**

We must now find out which of these properties have influence on the height of the liquid's stream.

Viscosity and, indirectly, tempereature, seem to have the biggest influence on the height of the stream.

Liquid's viscosity

From the value of the kinematic viscosity coefficient depends the velocity od the flow lost due to local resistances. The more viscous the liquid is, the higher the resitances are:



The best water solution

To choose the best water solution, we must consider how will it change the water viscosity. Basing on the information from literature, we were able to divide substances into those that:

Lower the viscosity	Increase the viscosity
• soap • ethyl alcohol • fenol	• sugar • salt

To maximize the stream's height, we must minimalize the linear resitances, so the soution's viscosity must be lowest possible.

Our experiments

We have tried out three different solutions: water with soap, salt and sugar. Then, we've compared the gathered data with the results for clean water (experiment was carried out on a 0,75 cm diameter conic narrowing mouthpiece)

Clean water	87 cm
Salt solution [1%]	85 cm
Sugar solution [3%]	84 cm
Soap solution	88 cm

The results vary, however, very slightly - they are on the verge of measurement error. However, they seem to confirm our presumptions.

Our experiments

Sugar solution [15%]

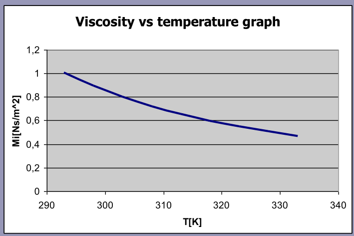
Our experiments

Sugar solution [20%]

Liquid's temperature influence

As the temperature increases, liquid's viscosity decreases:

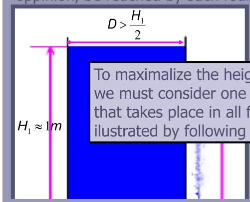
$$\mu = Ae^{\frac{E}{RT}}$$



Our experiments confirmed this theory: hot (ok. 60ºC) water

Optimal fountain

The highest stream height will, in our oppinion, be reached by such fountain:



• Reynolds number for the flo...

...izes linear

...exst only a... the mouthpiece – everywhere else they are ommitable.

• hotest possible soap water

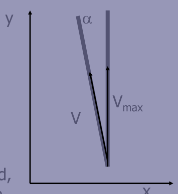
To maximalize the height of the stream, we must consider one more phenomenon that takes place in all fountains. It is illustrated by following photos.

„Falling water"

While designing the optimal fountain it is worthy to consider deviating the stream from perpendicularity with gravity field to minimize this effect.

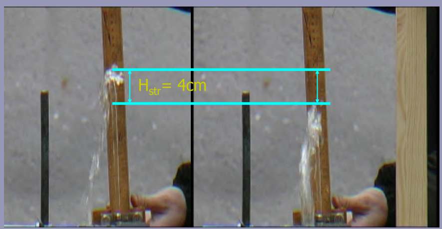
However, it is connected with decreasing the maximal reached height, because the speed of water on vertical axis will be:

$$V = V_{max} \cos\alpha$$



It needs to be empirically checked, whether it is better to deviate the mouthpiece or not.

„Falling water"



The height lost in this way may reach even 25% maximal height. What can be done to bypass this effect?

Our fountain

Having analyzed the theory, we began constructing our own „optimal" fountain.

We have built a fountain for which the biggest pressure losses are those on mouthpiece, and for which linear and local losses are much smaller, nearly ommitable.

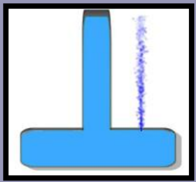
We have used a conic narrowing mouthpiece (Weisbach's jet was too hard to make in school conditions).

We have also decided to deviate the stream from perpendicular of about 4 degrees.

Calculations for our fountain

$\mathrm{Re} < 10$ (for the flow in the tank)

$$V \approx 4{,}15 \frac{m}{s} \approx \frac{95}{100} V_{\max}$$



Our best result

Conclusion

Our fountain's efficiency reached more than 90%

(92 cm exactly).

There is one more thing to mention: with the problem formuilated this way, it was possible to obtain a height of a stream much greater than one meter by, for example, creating a pressure difference between „head of water" and mouthpiece or by constructing so-called Hero's fountain.

However, we decided not to consider those matters, l focus on strictly hydrodynamic problems.

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- ***Mechanika płynów w inżynierii środowiska*** **– Z. Orzechowski, J. Prywer, R. Zarzycki**
- ***Hydraulika i hydrologia*** **– B. Jaworowska, A. Szuster, B. Utrysko**
- ***Tablice i wykresy do obliczeń z mechaniki płynów*** **- W. Stefański, K. Wyszkowski**

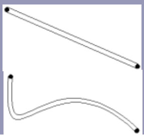
Local resistances

Examplary local resistance coefficients:

Nazwa przeszkody	Współczynnik oporów miejscowych ζ
Wlot z przewodu do zbiornika	$\zeta = 1$
Nagłe zwiększenie przekroju z D_1 do D_2 (tylko dla Re > 3500)	$\zeta = [(\frac{D_1}{D_2})^2 - 1]^2$
Nagłe zmniejszenie przekroju z D_2 do D_1	$\zeta = \frac{1}{2}[1 - (\frac{D_2}{D_1})^2]$
Wodomierz tłoczkowy	$\zeta = 12$
Wodomierz skrętowy	$\zeta = 6$
Kompensator dławikowy	$\zeta \cong 0{,}2$

Pipe's shape

Any pipe may connest two holes. The be connection, from the hydrodynamic poin is such, that the pipe is ideally straight, l the pressure losses are minimal.



In such pipe only resistance influen flow.

In such pipe, eacl narrowing, bend, a loss of pressure flow.

Ideal fountain's general assumptions

We aim at a set, in which the influence of all earlier mentioned factors will be optimised for depreciating the flow's resistance and to increase the discharge coefficient:

- smallest possible pipe's length, large diameter and possibly smallest roughness: linear flow resistance → 0;
- lack of narrowings, bends and any other obstacles on water's way: local flow resistances → 0;
- Weiscbach's jet instead of usual round hole → discharge coefficient → 1;
- Low viscosity liquid: flow resistances → 0

Resitances at waterspout

Type of hole and mouthpiece	Coefficients			
	throttling φ	Velocity α	discharge μ	Local resitance ξ
Round hole	0,64	0,97	0,62	0,6
Conic widening mouthpiece	1,0	0,45-0,50	0,45-0,50	3-4
Cylindric internal mouthpiece	1,0	0,707	0,707	1,0
Cylindric external mouthpiece	1,0	0,82	0,82	0,5
Conic narrowing mouthpiece	0,98	0,96	0,94	0,09
Curved mouthpiece	1,0	0,98	0,98	0,04

Taken from: *Tablice i wykresy do obliczeń z mechaniki płynów* - W. Stefański, K. Wyszkowski

Pipe types

Each pipe is characterized by few parameters:

- length – L
- internal diameter – D
- material of which it is made and, connected with i absolute roughness –

This pipe is, inside, made of rubber

Crimping, plastic pipe – extremely large roughness

1. Gaussian Cannon

Reporter : S. M. Ali Modarressi

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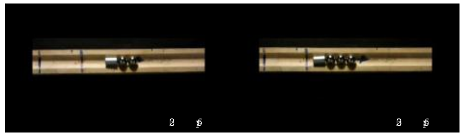
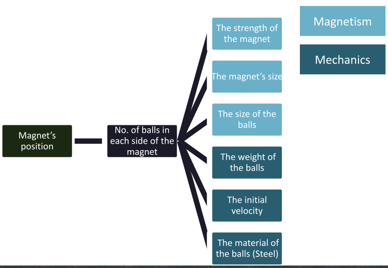
Initial Observations



- A high velocity ejection

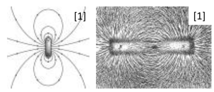
$$E_1 ? E_2$$

Effective parameters

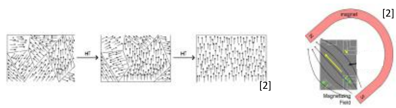


Theory Background

- Magnetism
  - Magnetic field



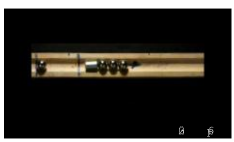
  - Magnetization (M) and magnetic moment (m)



[1] : en.wikipedia.org/wiki/Magnetic field
[2] : en.wikipedia.org/wiki/Magnetic_domains

Theory Base The Phenomenon

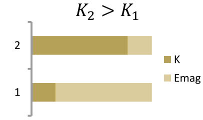
1 The main reason



$$K_1 + E_{mag1} = E_{mag2} + K_2$$

$$E_{mag1} > E_{mag2}$$

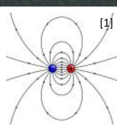
$$K_2 > K_1$$



$$E_1 = E_2$$

Theory Background

- Magnetic dipoles

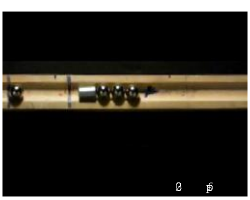


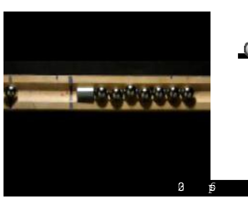
- Mechanics
  - Coefficient of restitution
  - $C_R = \frac{\Delta v_2}{\Delta v_1}$ [5]

[1] : en.wikipedia.org/wiki/Magnetic_field
[2] : en.wikipedia.org/wiki/Coefficient_of_restitution

Theory Base The Phenomenon

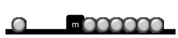
2 The energy loss





Theory Base The Phenomenon

2 The energy loss



$$E_1 \times \left(\left(\frac{1 + C_r}{2}\right)^2\right)^5 = E_2$$

$$E_1 \times \left(\left(\frac{1 + C_r}{2}\right)^2\right)^N = E_2$$

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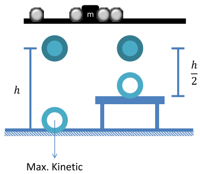
Theory Base The Phenomenon

3 The left side of the magnet

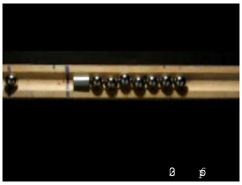


$\Longrightarrow$ *0 Balls on the Other side of the magn*

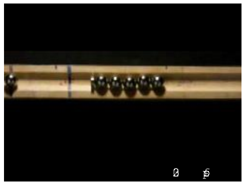
Theory Base The Phenomenon

4 Multi ball ejection

Very strong magnet



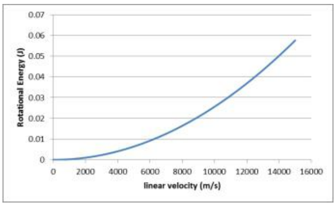
Normal magnet



Note: The Initial velocity are the same

Theory Base The Phenomenon

5 The rotational energy



$\Longrightarrow$ *The rotational energy is negligible*

Theory Governing equation

1 The theory formulation

We mesh the whole model
In each point we have:

$$B = \frac{\mu_0}{4\pi}\left[\frac{3n(n\cdot m) - m}{|x|^3}\right]^{[1]}$$

$$\sum B = B_0$$

$$M = \left(\frac{3}{\mu_0}\right)\left(\frac{\mu - \mu_0}{\mu + 2\mu_0}\right)B_0^{[2]}$$

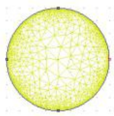
And the magnetic moment is determined by:

$$MV = m^{[3]}$$

And the magnetic energy is calculated by

$$U = -m \cdot B^{[4]}$$

Note: the magnet has a multi-dipole modeling

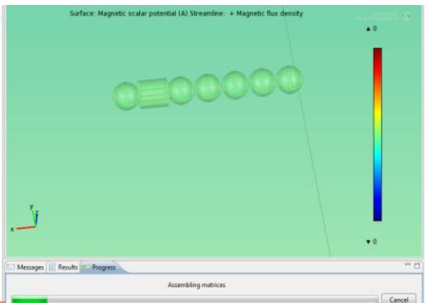


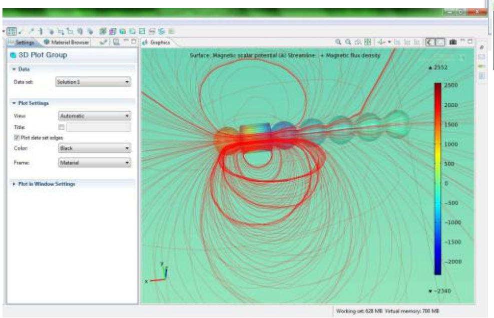
Theory Governing equation

2 Simulation

- Making the geometry
- Meshing the model
- Materializing the model
- Inserting initial values (M)
- Simulating...
- Plotting graphs
- Measuring the parameters (m, F, B, H, ...)

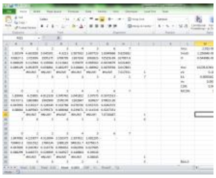
2 Simulation





Theory Governing equation

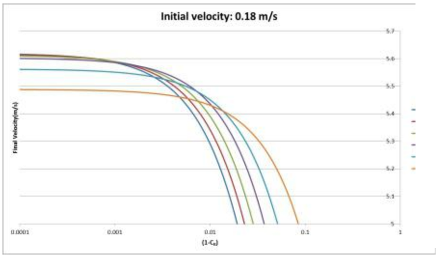
3 Modeling the cannon



- simulation
- Magnetic field of each ball is obtained
- Magnetization of each ball is calculated
- Magnetic moment of each ball is calculated
- The potential energy of each ball is calculated
- $(U_1 + K_1) \times \left(\left(\frac{1+C_r}{2}\right)^2\right)^N - U_2 = K_2$
- Final velocity is obtained

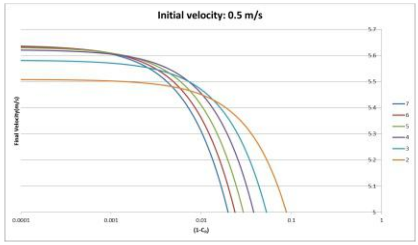
Theory Results

1 The effects of the coefficient of restitution



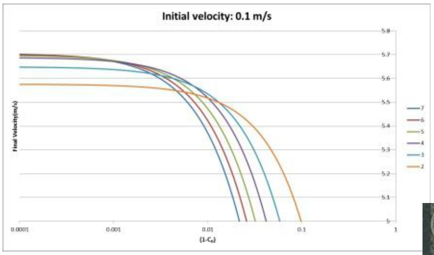
Theory Results

1 The effects of the coefficient of restitution



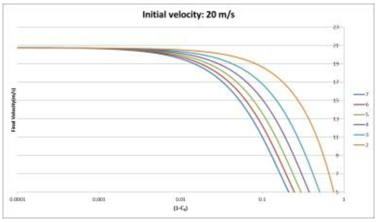
Theory Results

1 The effects of the coefficient of restitution



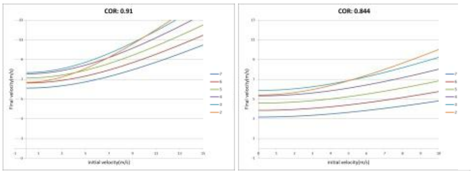
Theory Results

1 The effects of the coefficient of restitution



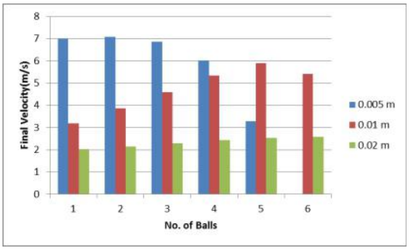
Theory Results

2 The effects of the initial velocity



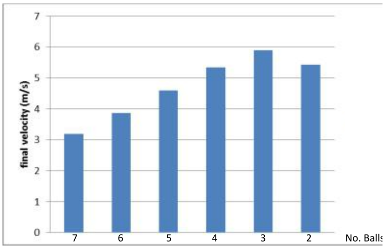
Theory Results

3 The effects of the size of the ball



Theory Results

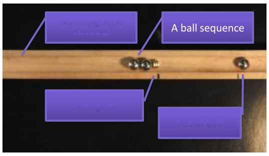
4 The theory results by the reality's properties



Experiment Setup

1 The main structure

- Our Variables:
  - The No. Balls
- Our Setup



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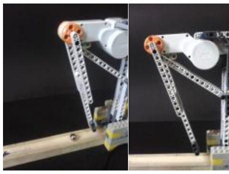
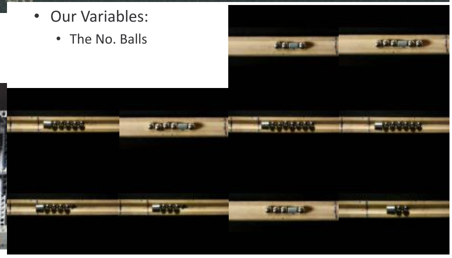
Experiment Setup

1 The Shooter

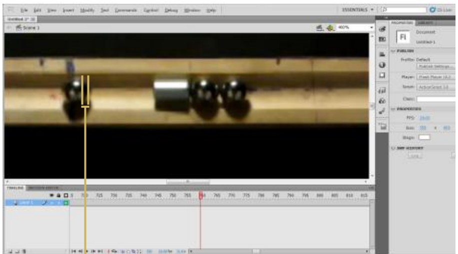


Experiment Setup

- Our Variables:
  - The No. Balls



Experiment Speed Measurement



Displacement 4 pixels

Experiment Speed Measurement

$$\Delta x = 4\, pixels \rightarrow \times \frac{0.01}{20} \rightarrow \Delta x = 0.002\, m$$

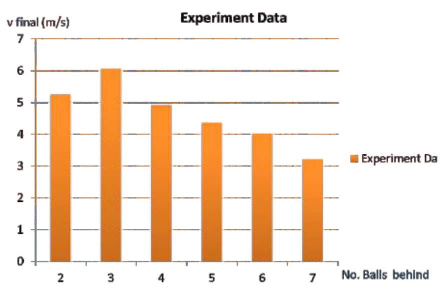
$$\Delta t = 4\, frames \rightarrow \times \frac{1}{320} \rightarrow \Delta t = 0.0125\, s$$

$$\frac{\Delta x}{\Delta t} = velocity = \frac{0.002}{0.0125} = 0.16 \frac{m}{s}$$

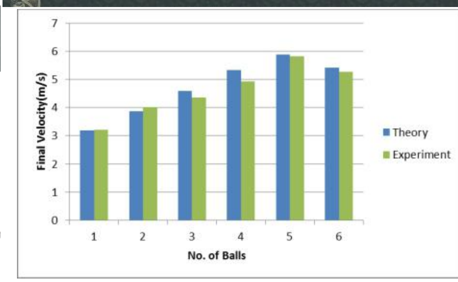
Global Function

$$v = \frac{displacement(pixels)}{frame_2 - frame_1} \times 0.16$$

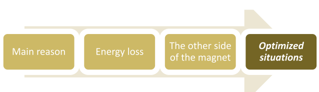
Experiment Results



Theory vs. Experiment



Conclusion



The phenomenon occurs due to the difference of the attractions of the first an

Situation	Optimum position
Our experiments	***3 balls***
Increasing the initial velocity	***Decreases the number of balls***
Increasing the COR	***Increases the number of balls***
Increasing the size of the ball	***Decreases the number of balls***

References

- [1] : Jackson, John David (1999). Classical electrodynamics (3 rd ed.). New York, [NY.]: Wiley. ISBN 0-471-30932-X p. 186
- [2] : Jackson, John David (1999). Classical electrodynamics (3 rd ed.). New York, [NY.]: Wiley. ISBN 0-471-30932-X p. 200
- [3] : Kazimierczuk, Marian K. (2009). High-Frequency Magnetic Components, 1st edition Wiley . ISBN 0-470-71453-0 p. 55
- [4] : Jackson, John David (1999). Classical electrodynamics (3 rd ed.). New York, [NY.]: Wiley. ISBN 0-471-30932-X p. 190
- [5] : Cross, Rod (2006). The bounce of a ball. Physics Department, University of Sydney, Australia. Retrieved 2008-01-16 p. 1, l. 24

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Problem No. 12

Lanterns

Kamran.K.Hedayat

IYPT 2012
BAD SAULGAU - GERMANY

Problem

Paper lanterns float using a candle. Design and make a lantern powered by a single tea-light that takes the shortest time (from lighting the candle) to float up a vertical height of 2.5 m. Investigate the influence of the relevant parameters.

Background
- What is Lantern?
- Why does it rise?
- Designs
- Parameters
- Theoretical Approach

Theory
- Governing equations
- Stages of rising
- Stage 1
- Stage 2
- Simulations

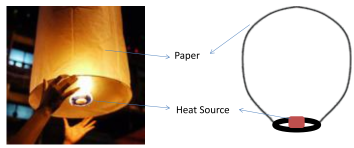
Experiments
- Objectives
- Setup
- Measurements
- Cases & Results

Main Approach

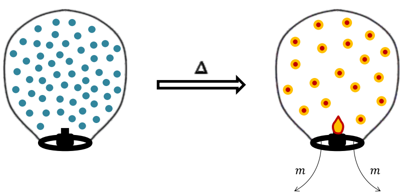
Conclusion & Discussion
- Tea Light or Not?
- Theory Vs. Experiments
- Optimization

Background - Lanterns

- Lanterns are constructed using paper and a flammable wax as a heat source.

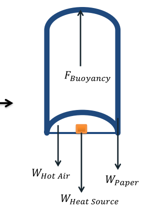


Background - Flying Mechanism



Background – Lantern's Free Body Diagram

Due to pressure difference we have the buoyancy force.



Background - Theoretical Approach

F_B & W_{hs} & W_p $cte.$

W_{ha} $Variable$ $\rightarrow$ $W_{ha} = m_{ha} g = V_{ha} \cdot \rho_{ha} \cdot g$

$\rho \propto T$ → $Min\{Energy\ loss\}$ → E_l c

Therefore the ideal shape is the one were the ratio between Volume & Surface is large.

Background - Finding the best Design

- So the best "shape" for the lantern is spherical.

$\frac{Volume}{Surface} = MAX$

$Dissipation = MIN$

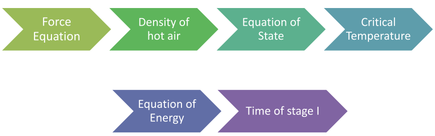
Theory – Governing Equations

$$Force : \sum F = ma$$

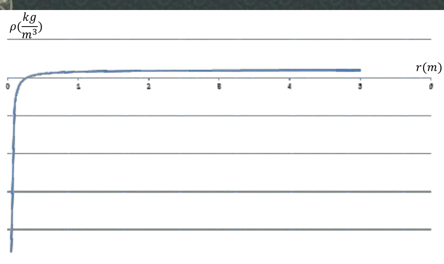
$$Energy : q_{in} - q_{out} = q_s$$

$$State : PV = nRT$$

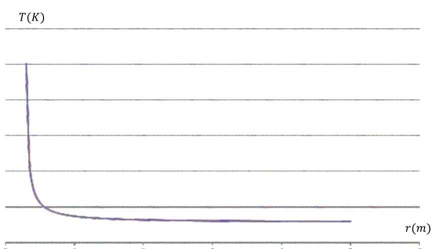
Theory – First stage theoretical Approach



Theory – Stage I (Finding the critical Density)

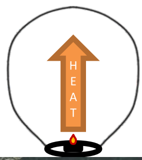


Theory – Stage I (Finding the critical Temperature)



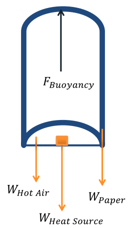
Theory – Stages of Rising

II. Rising the distance of 2.5(m).



I. Reaching the moment of flying.

Theory – Stage I (Finding the critical Density)



At the moment of flying : $\sum F = 0$

$$-m_{ha}g - m_{hs}g - m_p g + \rho_a V g = 0$$

The hot air density should reach the amount below :

$$\rho_{ha} = \frac{\rho_{hs}V_{hs} + \rho_p A - \rho_a V}{V_{ha}}$$

Theory – Stage I (Finding the critical Temperature)

Using the equation of state : $PV = nRT$

$$T = \frac{M.P}{\rho_{cr}.R}$$

ρ_{cr} : *Hot air Density measured using Force equation*
P : *Atmospheric Pressure*
M : *Molecular Mass*
R : *Gas Constant*

Theory – Stage I (Finding the time)

$$Energy : q_{in} - q_{out} = q_{stg}$$

$$q_{in} - q_{out} = mc\frac{dT}{dt}$$

$$q_{in} - \frac{T_{in} - T_{out}}{R} = mc\frac{dT}{dt}$$

By solving the differential equation the Temperature in terms of time can be measured.

Theory – Second stage theoretical Approach

Equation of Energy → Temperature in terms of time → Equation of State → Density in terms of time

Force Equation → Force in terms of time → Time of Rising

Theory – Stage II (Finding the temperature in terms of time)

$$Energy: \; q_{in} - q_{out} = q_{stg}$$

$$q_{in} - q_{out} = mc\frac{dT}{dt}$$

$$q_{in} - \frac{T_{in} - T_{out}}{R} = mc\frac{dT}{dt}$$

By solving the differential equation the Temperature in terms of time can be measured.

Theory – Stage II (Finding the density in terms of t

Using the equation of state : $PV = nRT$

$$\rho = \frac{MP}{RT}$$

ρ_{cr} : *Hot air Density measured using Force equation*
P : *Atmospheric Pressure*
M : *Molecular Mass*
R : *Gas Constant*

Theory – Stage II (Finding the displacement in terms of time)

$$\sum F = ma \longrightarrow \rho_a g V - \rho_p A g - \rho_{ha} V g - m_{hs} g = m_T a$$

Acceleration is a function of the parameters above where Volume , Surface & density are variable.

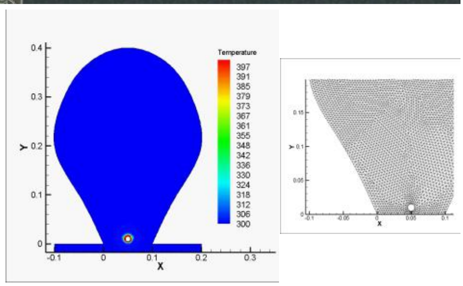
$a(t)$ *could be found.*

$$x(t) = \iint a \, . dt$$

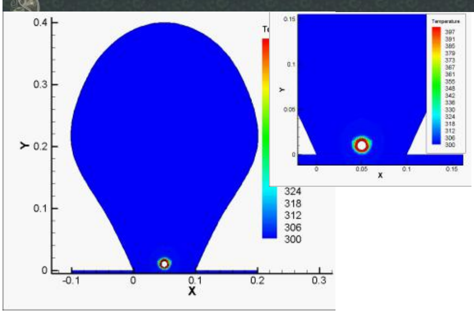
Theory - Simulation

Using Flow dynamics equation solver "Fluent" → Geometry & Mesh → Governing Equations → Initial Conditions & Boundary Condition

Theory - Simulation



Theory - Simulation

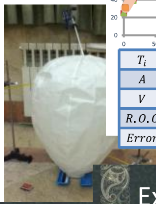


Experiments – Objectives & Set up

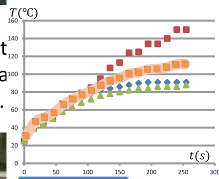
- Finding the temperature in terms of time.
- Finding the force in terms of time.
- Finding the displacement in terms of time.


Experiments – Temperature - Time

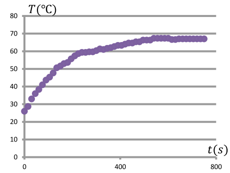
- To calculate the average temperature of the lant several thermometers were used in different pla of the lantern using tea light as the heat source.



Experiments – Temperature - Time

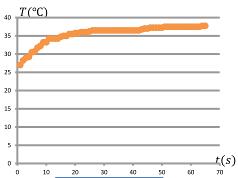


T_i	22°C
A	$0.554\ m^2$
V	$0.038\ m^3$
$R.O.C$	$68\ j/s$
$Error$	±1°C



T_i	26°C
A	$2.526\ m^2$
V	$0.375\ m^3$
$R.O.C$	$68\ j/s$
$Error$	±1°C

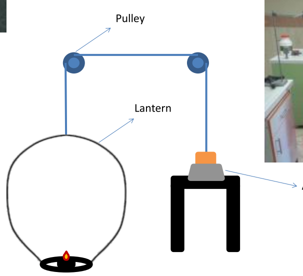
Experiments – Temperature - Time



T_i	25°C
A	$6.686\ m^2$
V	$2.365\ m^3$
$R.O.C$	$68\ j/s$
$Error$	±1°C

Using Tea light as the heat source.

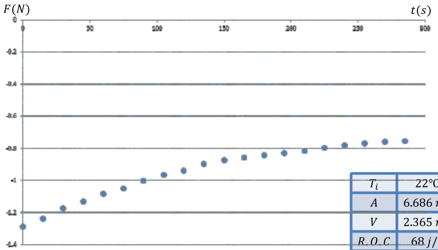
Experiments – Force (Setup)



Experiments – A problem called tea light!!

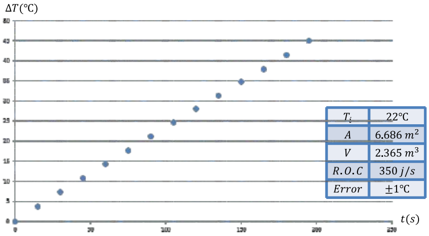
- It was seen in the experiments that a tea light can not produce the energy needed for a lantern to go up. So another heat source was used.

Experiments – Force - Time



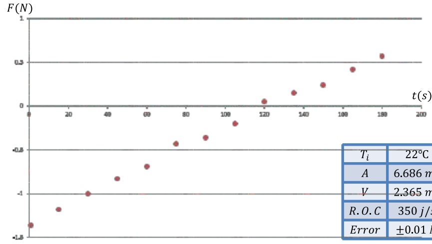
T_i	22°C
A	$6.686\ m^2$
V	$2.365\ m^3$
$R.O.C$	$68\ j/s$
	1 N

Experiments – Temperature - Time



T_i	22°C
A	$6.686\ m^2$
V	$2.365\ m^3$
$R.O.C$	$350\ j/s$
$Error$	±1°C

Experiments – Force - Time

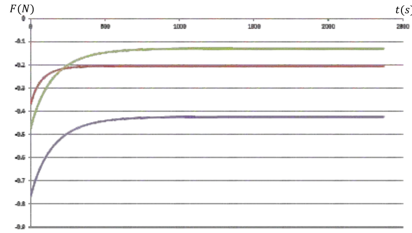


T_i	22°C
A	$6.686\ m^2$
V	$2.365\ m^3$
$R.O.C$	$350\ j/s$
$Error$	±0.01 N

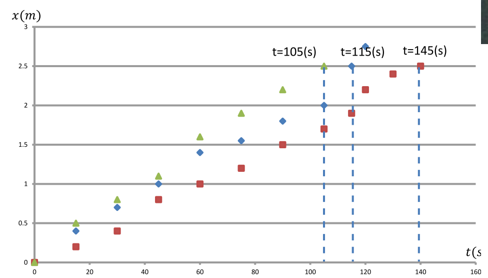
Experiments - Explanation

- It was seen that the lantern rise using this heat source so we continued the experiments to find best lantern.
- The lantern which rises the 2.5 meter height in the least time is the optimized model.

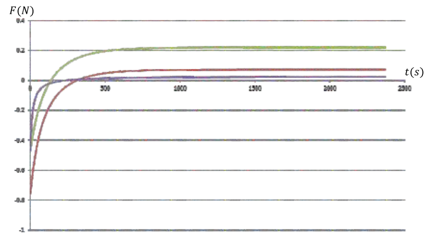
Discussion – Tea light or not??



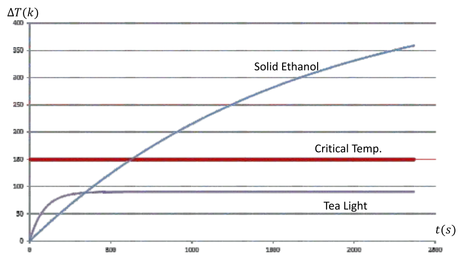
Experiments – Displacement - Time



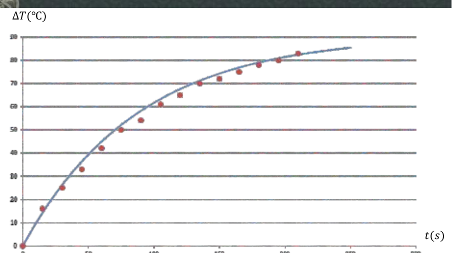
Discussion – Tea light or not??



Discussion – Tea light or not??

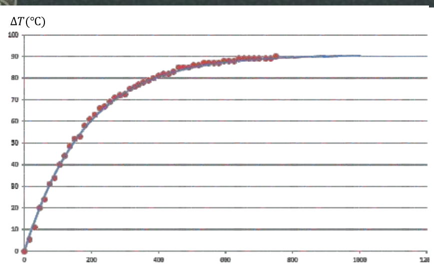


Discussion – Theory Vs. Experiments



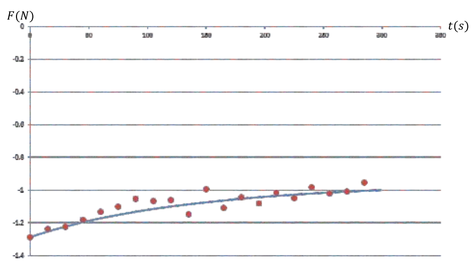
Calibrating the theory to match the experiments

Discussion – Theory Vs. Experiments

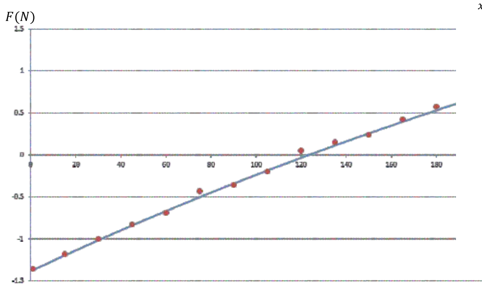


Using the same calibrated constant we verified our calibration

Discussion – Theory Vs. Experiments

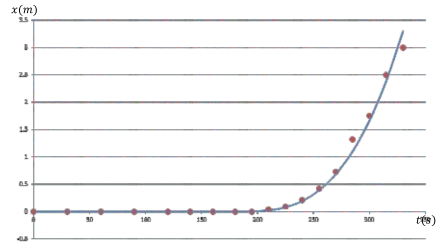


Discussion – Theory Vs. Experiments

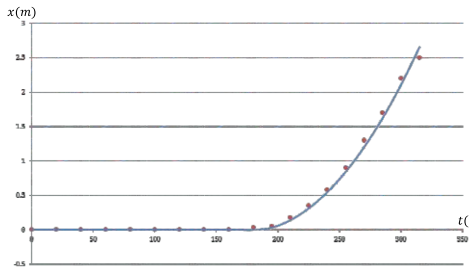


Using the same calibrated constant we verified our calibration

Discussion – Theory Vs. Experiments



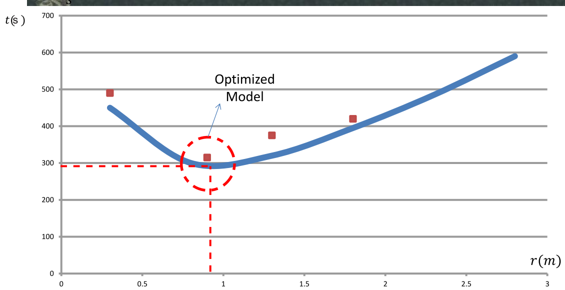
Discussion – Theory Vs. Experiments



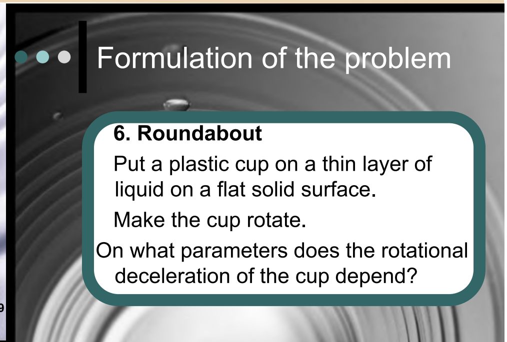
Conclusion – Heat source

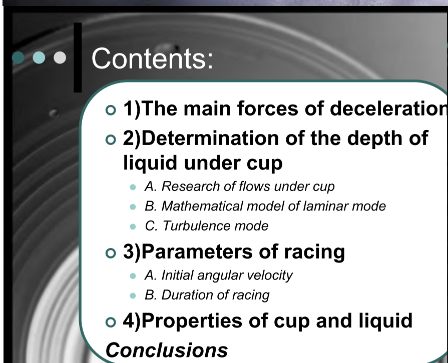
- Tea light can not produce the heat needed for a lantern to rise.
- Using another heat source the time of rising has been optimized.

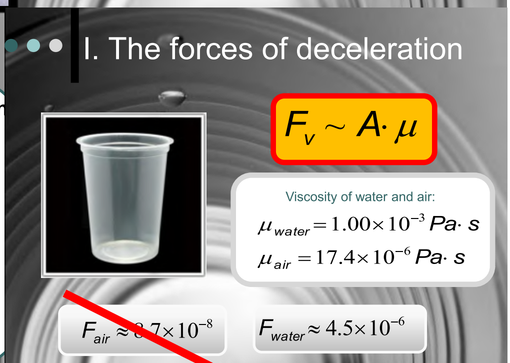
Optimization



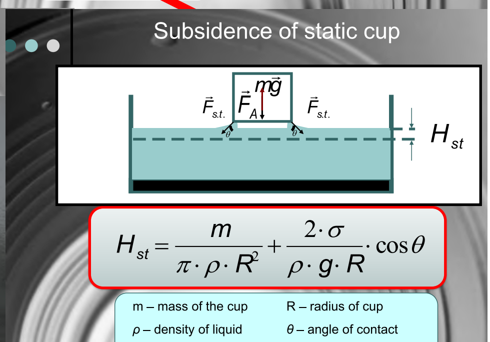

BELARUSIAN TEAM
PRESENTS
Roundabout
Reporter: Alexandr Mamoiko
Tianjin, China 2009

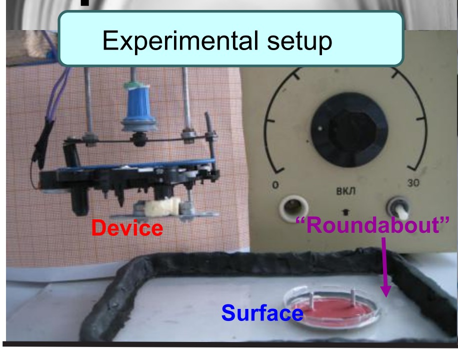

Formulation of the problem
6. Roundabout
Put a plastic cup on a thin layer of liquid on a flat solid surface.
Make the cup rotate.
On what parameters does the rotational deceleration of the cup depend?

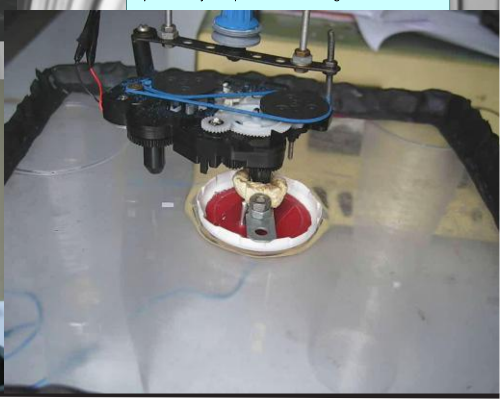

Contents:
1)The main forces of deceleration
2)Determination of the depth of liquid under cup
A. Research of flows under cup
B. Mathematical model of laminar mode
C. Turbulence mode
3)Parameters of racing
A. Initial angular velocity
B. Duration of racing
4)Properties of cup and liquid
Conclusions

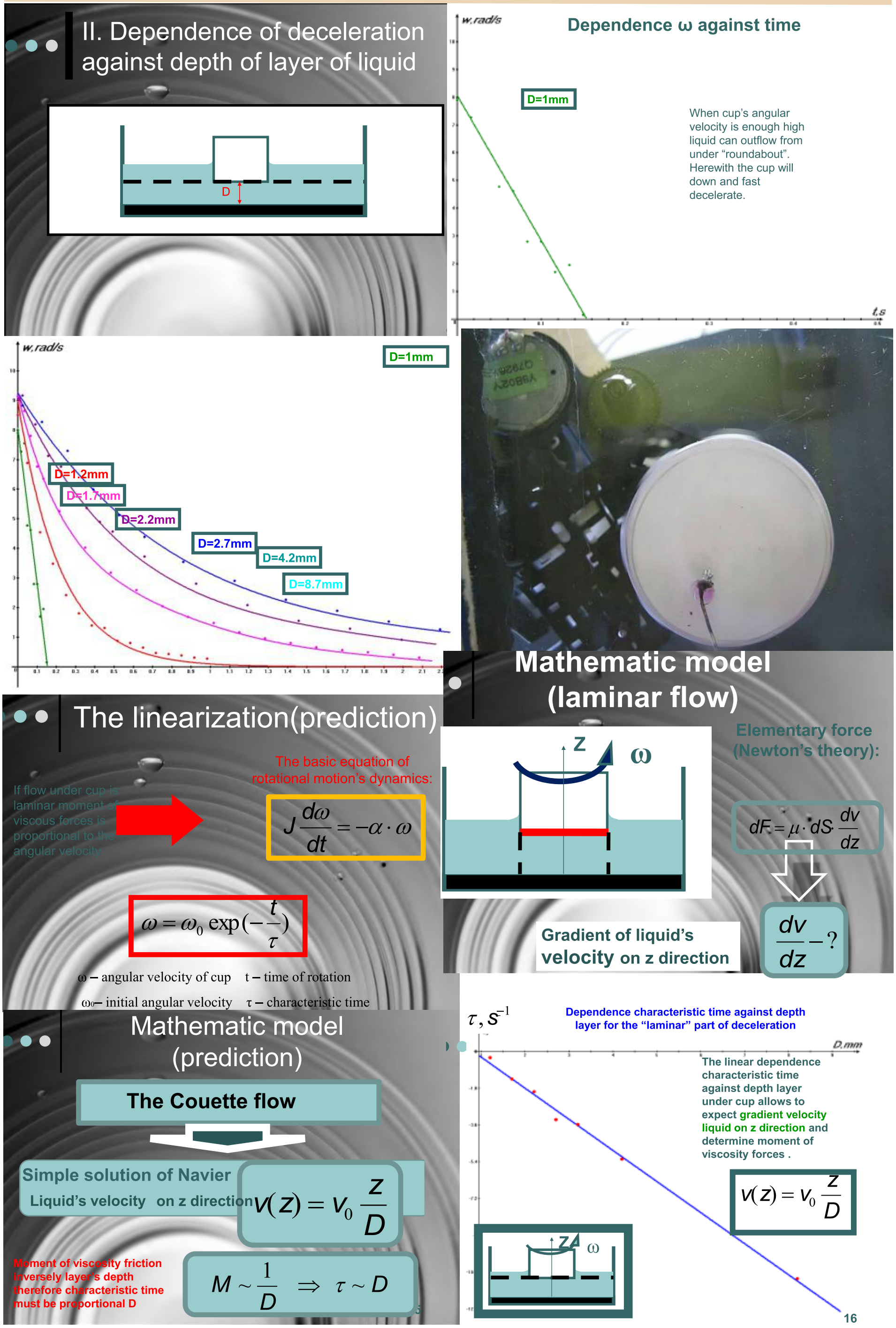

I. The forces of deceleration
$F_v \sim A \cdot \mu$
Viscosity of water and air:
$\mu_{water} = 1.00 \times 10^{-3}\ Pa \cdot s$
$\mu_{air} = 17.4 \times 10^{-6}\ Pa \cdot s$
$F_{air} \approx 8.7 \times 10^{-8}$
$F_{water} \approx 4.5 \times 10^{-6}$


The main forces of deceleration

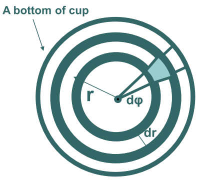

Subsidence of static cup
$m\vec{g}$
$\vec{F}_{st.}$
$\vec{F}_A$
H_{st}
$H_{st} = \frac{m}{\pi \cdot \rho \cdot R^2} + \frac{2 \cdot \sigma}{\rho \cdot g \cdot R} \cdot \cos\theta$
m – mass of the cup
R – radius of cup
ρ – density of liquid
θ – angle of contact


Experimental setup
Device
"Roundabout"
Surface




II. Dependence of deceleration against depth of layer of liquid
D
Dependence ω against time
w,rad/s
D=1mm
When cup's angular velocity is enough high liquid can outflow from under "roundabout". Herewith the cup will down and fast decelerate.
t,s
w,rad/s
D=1mm
D=1.2mm
D=1.7mm
D=2.2mm
D=2.7mm
D=4.2mm
D=8.7mm
Mathematic model (laminar flow)
Z
ω
Elementary force (Newton's theory):
$dF = \mu \cdot dS \cdot \frac{dv}{dz}$
$\frac{dv}{dz} - ?$
Gradient of liquid's velocity on z direction
The linearization(prediction)
The basic equation of rotational motion's dynamics:
$J\frac{d\omega}{dt} = -\alpha \cdot \omega$
If flow under cup is laminar moment of viscous forces is proportional to the angular velocity
$\omega = \omega_0 \exp(-\frac{t}{\tau})$
ω – angular velocity of cup
t – time of rotation
ω₀– initial angular velocity
τ – characteristic time
Mathematic model (prediction)
The Couette flow
Simple solution of Navier
Liquid's velocity on z direction
$v(z) = v_0 \frac{z}{D}$
$M \sim \frac{1}{D} \Rightarrow \tau \sim D$
Moment of viscosity friction inversely layer's depth therefore characteristic time must be proportional D
τ, s^{-1}
Dependence characteristic time against depth layer for the "laminar" part of deceleration
D,mm
The linear dependence characteristic time against depth layer under cup allows to expect gradient velocity liquid on z direction and determine moment of viscosity forces .
$v(z) = v_0 \frac{z}{D}$
Z
ω
16

Moment of viscosity forces



Velocity of liquid under cup on z direction:

$$v(z) = v_0 \frac{z}{D}$$

Elementary force:

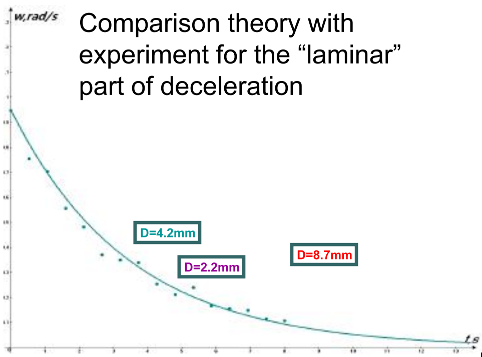
$$dF = \mu \frac{dv}{dz} \cdot dS = \mu \frac{\omega \cdot r}{D} \cdot d\varphi \cdot r \cdot dr$$

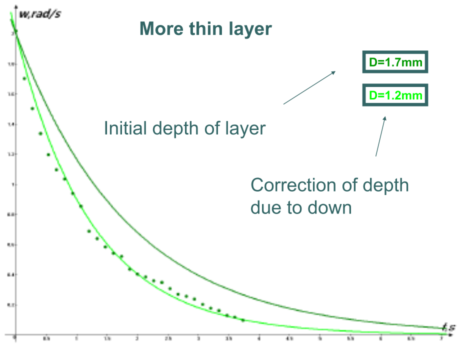
$$M = \int_0^{2\pi}\int_0^{R} dF \cdot r = \frac{\pi\mu R^4 \omega}{2D}$$

The law of cup's motion

$$\omega = \omega_0 \exp\left(-\frac{\pi\mu R^4}{2DJ} \cdot t\right)$$

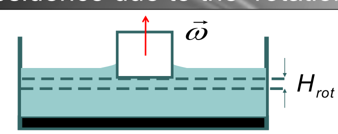
ω – angular velocity of cup
t – time of rotation
ω_0 – initial angular velocity
τ – characteristic time
J – moment of inertia
R – cup's radius
D – layer's depth of liquid
μ - viscosity





Movie with down

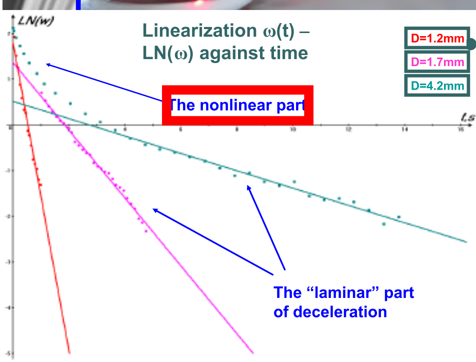
Subsidence due to the rotation

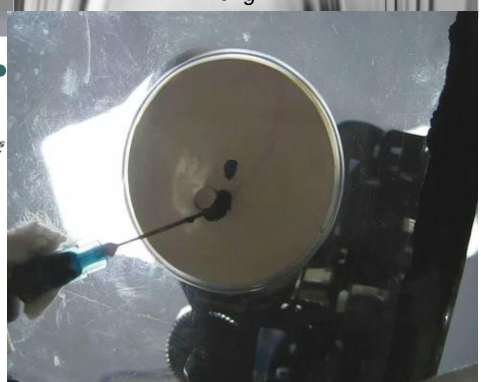


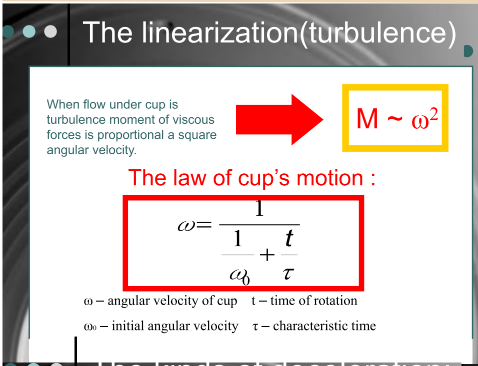
Condition for H_{rot}:

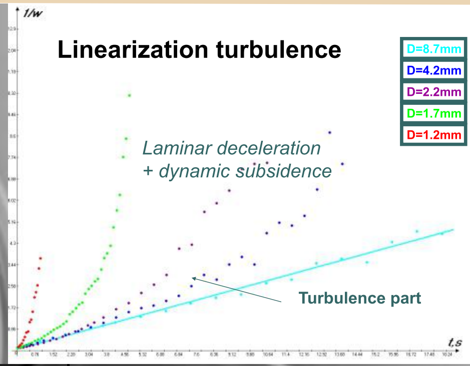
Forces of inertia = Hydrostatic forces

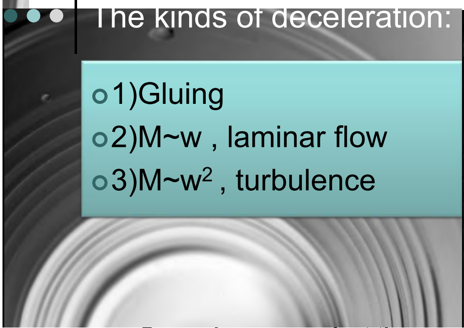
$$H_{rot} = \frac{\omega_0^2 \cdot R^2}{9 \cdot g} = 0{,}4mm$$

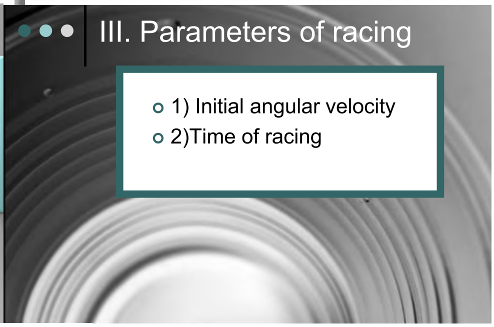


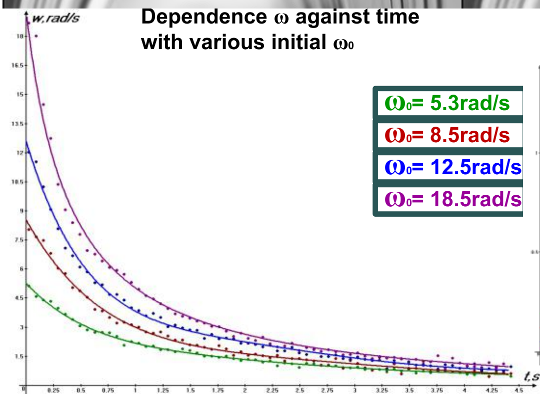


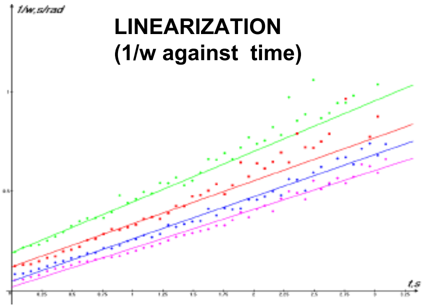

The linearization(turbulence)
When flow under cup is turbulence moment of viscous forces is proportional a square angular velocity.
M ~ ω²
The law of cup's motion :
ω = 1 / (1/ω0 + t/τ)
ω – angular velocity of cup t – time of rotation
ω0 – initial angular velocity τ – characteristic time

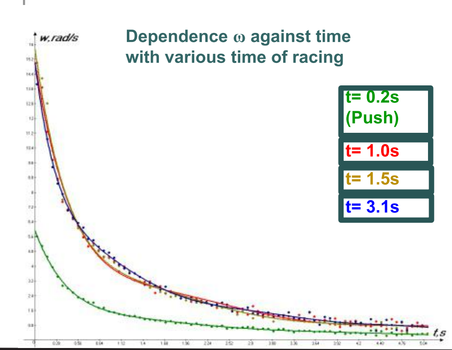

1/w
Linearization turbulence
D=8.7mm
D=4.2mm
D=2.2mm
D=1.7mm
D=1.2mm
Laminar deceleration
+ dynamic subsidence
Turbulence part
t,s

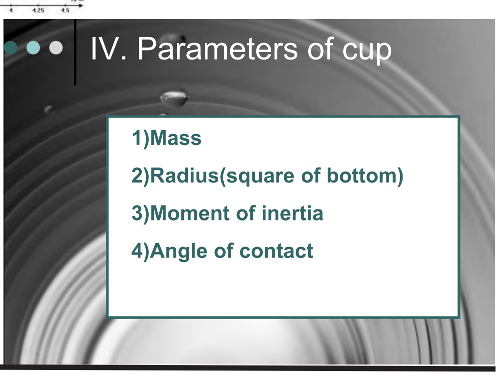

The kinds of deceleration:
1)Gluing
2)M~w , laminar flow
3)M~w² , turbulence


III. Parameters of racing
1) Initial angular velocity
2)Time of racing

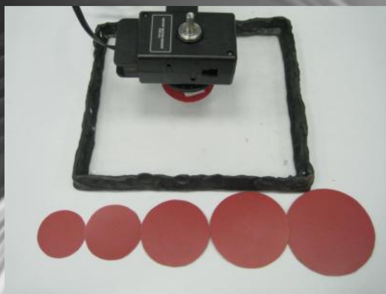

w,rad/s
Dependence ω against time
with various initial ω0
ω0= 5.3rad/s
ω0= 8.5rad/s
ω0= 12.5rad/s
ω0= 18.5rad/s
t,s


1/w,s/rad
LINEARIZATION
(1/w against time)
t,s

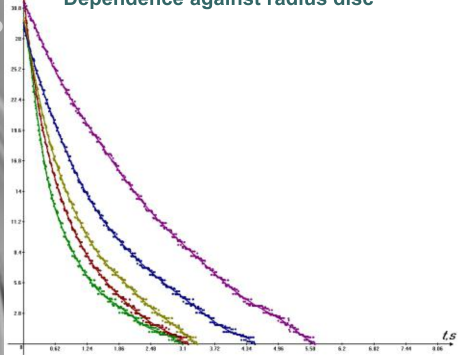

w,rad/s
Dependence ω against time
with various time of racing
t= 0.2s
(Push)
t= 1.0s
t= 1.5s
t= 3.1s
t,s


IV. Parameters of cup
1)Mass
2)Radius(square of bottom)
3)Moment of inertia
4)Angle of contact

Experiment with radius disc



Dependence against radius disc



V. Parameters of liquid

- 1) Viscosity
- 2) Density
- 3)Surface tension

Parameters of the roundabout

1) Depth of liquid under cup
2) Initial angular velocity
3) Duration of racing
4) A cup:
   a) Mass of cup
   b) Radius of cup
   c) Moment of inertia
   d) Contact's angle
5) A liquid:
   a) Viscosity
   b) Density
   c) Surface tension

Conclusions :

- 1)Depth of liquid layer determines character of deceleration
- 2)There are 3 different modes of cup deceleration:
  a) gluing
  b) laminar flows
  c) turbulence
- 3)Turbulent and laminar deceleration may be obtained during a single experiment.
- 4)Laminar mode is explained by model of Couette flow
- 5)The characteristic time doesn't depend on depth of liquid layer for turbulence mode.

Summary:

- The experimental base of deceleration was built for explanation phenomenon.
- The most important parameters were marked.
- The experimental investigation some

References:

Wikipedia: Couette flow.

A. D. Glinkin and V. A. Rukavishnikov. Laminar flow of a viscous incompressible liquid over the surface of solids of revolution. J. Eng. Phys. Thermophys., 39, 1 (1980)

Slezkin. Hydrodynamics.

The conditions for laminar flow

$$\mathrm{Re} = \frac{\rho \cdot v \cdot l}{\mu}$$

ρ – density of liquid μ – viscosity

v – characteristic velocity (ω*R)

l – characteristic size (D)

Boundary value in our experiments:

$$\mathrm{Re} \approx 100$$

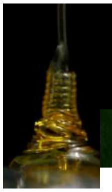
ART AN AMAZING FACT IN SCIENCE

Team Brazil

Team of Brazil
Problem 13: Honey coils

Problem 13
Honey coils

Liara Guinsberg



Problem 13

A thin, downward flow of viscous liquid, such as honey, often turns itself into circular coils. Study and explain this phenomenon.

Team of Brazil
Problem 13: Honey coils

Introduction

Theoretical formulation

- Surface tension
  - Plateau-Rayleigh instability
- Viscosity
- Newtonian fluids
- Fluid conditions
  - Initial conditions
- Coiling conditions
- Torsions and Tensions
- Regimes

Experiments

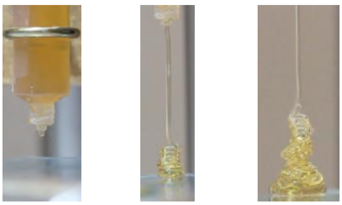
- Honey
- Cane molass
- Oils
- Shampoo

Comparison between the theory and the experiments

- Graph comparison
- Regimes and conditions

Team of Brazil
Problem 13: Honey coils

Video



Increasing height

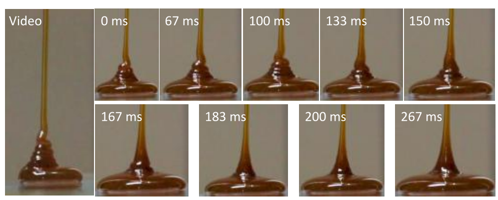
Team of Brazil
Problem 13: Honey coils

Plateau-Rayleigh instability

- The surface tension causes some oscillations in the jet, sometimes breaking it into droplets, to minimize surface area.

Instabilities

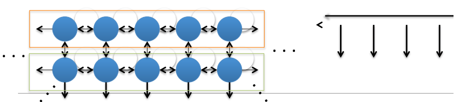
- Surface tension:



Team of Brazil
Problem 13: Honey coils

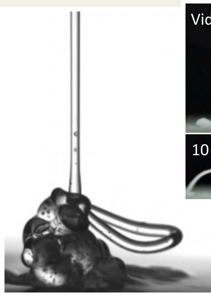
Surface tension

- The interior molecules have as many neighbors as they can.
- For the liquid to minimize its energy state, the number of higher energy boundary molecules must be minimized.
- The minimized quantity of boundary molecules: minimized surface area.

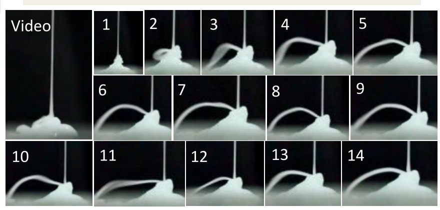


Shear thinning

- Happens on non Newtonian fluids
- The viscosity decreases with the increase of the shear stress.
- Causes phenomena like Kaye effect
- We can study it briefly with shampoo, glycerin and many others.



Kaye effect



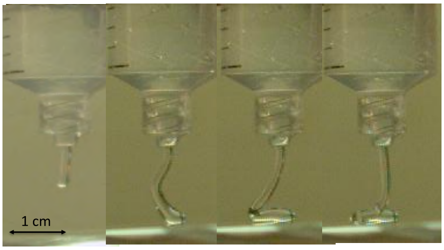
ART AN AMAZING FACT IN SCIENCE

Initial conditions

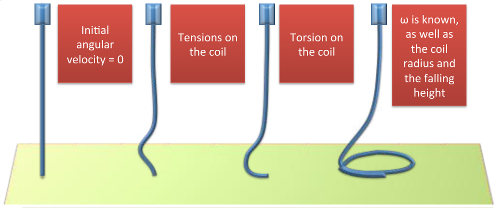
- First, we suppose the fluid stream is completely vertical before touching the solid surface:

That implies:

- No coiling formation before the fluid touches the surface



Boundary conditions

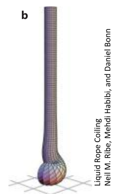


Torsions and tensions along the fluid rope

- Why does the jet changes its format after its collision with a rigid surface?
  - The jet has a velocity when touching the rigid surface
  - It has to slow down to zero, so there's a force directed upwards, that goes along the fluid stream and changes its form
  - There's a torsion caused by this tension
  - Thus, for the smaller energy, we can have the coiling phenomena.

Coiling conditions

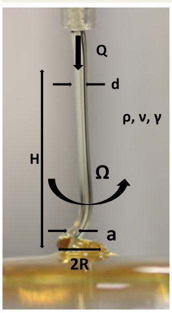
- Minimal viscosity for the coil to happen
- Maximum height, because of the Plateau-Rayleigh instability
- ace tension relevance, for visible coils minimum height.



Regimes

- We can see a relation of the coiling frequency with the height of fall
- As we increase the height, some buckling instabilities appear, and we define 4 regimes.

Theoretical analysis



H- Height
R- Coil radius
Ω- Rotational frequency
ρ- Density
ν- Viscosity
γ- Surface tension
a- Fillet radius at the contact point
d- Injection diameter
Q- Volumetric rate of fluid insertion

Definitions

$U_1 = R\Omega$ → Used in formulations

$\delta \sim \left(\frac{\nu Q}{g}\right)^{1/4}$ → Defines geometrical properties in the bending region

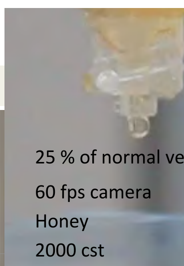
a_1 →

Theoretical analysis

- Viscous regime:
  - Smaller heights
  - Gravitational effect negligible
  - Inertial effect negligible

$$R \sim H$$

$$\Omega \sim \frac{Q}{Ha_1^2}$$



Theoretical analysis

- Gravitational regime:
  - Gravitational effects are the most relevant ones

$$\delta \sim \left(\frac{\nu Q}{g}\right)^{1/4}$$

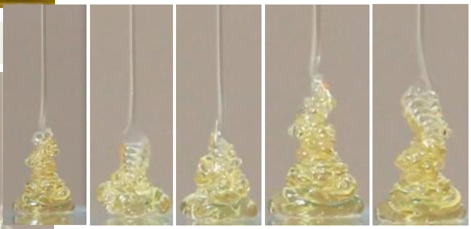
$$R \sim \delta\left(\ln\frac{H}{\delta}\right)^{1/2}$$

$$\Omega \sim \frac{U_1}{\delta}\left(\ln\frac{H}{\delta}\right)^{-\frac{1}{2}}$$

Gravitational regime movies

Honey, 2000 cst
60 fps
Fall height: 5 cm
Flow rate:
25% of original velocity

Silicone oil, 5000 cst
2000 fps
Fall height: 5 cm
Flow rate:
1.5% of original velocity



Theoretical analysis

- Inertial-Gravitational regime
  - Both gravitational and inertial forces are considerable
  - There're resonant frequencies

Inertial regime movies

Theoretical analysis

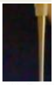
- Inertial regime:
  - Inertial effects are more important than the gravitational and viscous

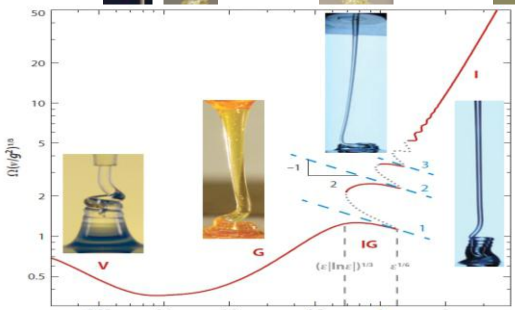
$$R \sim \left(\frac{\nu a_1^4}{Q}\right)^{1/3}$$

$$a_1 \sim (\nu Q/gH^2)^{1/2}$$

$$a_1 \sim (Q^2/gH)^{1/4}$$

$$\Omega \sim \left(\frac{Q^4}{\nu a_1^{10}}\right)^{\frac{1}{3}}$$





Liquid Rope Coiling, Neil M. Ribe,1 Mehdi Habibi,2 and Daniel Bonn3, Annu. Rev. Fluid Mech. 2012.

Instabilities

- From the equations: $R \sim \left(\frac{\nu a_1^4}{Q}\right)^{1/3}$ $a_1 \sim (\nu Q/gH^2)^1$
- We see, from the substitution of R, we have:

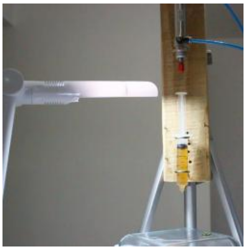
$$R \sim \left(\frac{\nu^3 Q}{gH^2}\right)^{\frac{1}{3}} \propto \nu \qquad a_1 \sim \left(\frac{\nu Q}{gH^2}\right)^{\frac{1}{2}} \propto \sqrt{\nu}$$

- There's a moment when the radius R is smaller than the filet radius a. The coil formation is ceased.

Experimental setup

ART AN AMAZING FACT IN SCIENCE

Experimental procedure

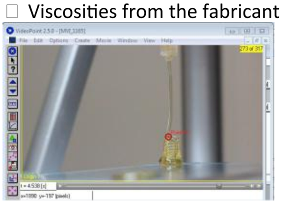


Material used	Viscosity
Corn syrup	1800 cst
Honey	2000 cst
Silicone oil	5000 cst
Silicone oil	500 cst

Obtaining data

Data analysis
Viscous regime
Gravitational regime
Inertial gravitational regime
Inertial regime
Instabilities

- We used a high speed camera (2000 fps)
- Height of the fluid measured by using a fixed ruler and Video Point®
- Viscosities from the fabricant of each fluid



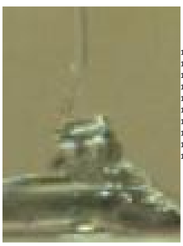
Viscous regime – Honey, 2000 cst

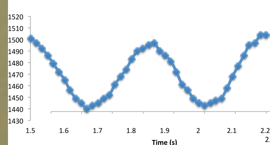
Data analysis
Viscous regime
Gravitational regime
Inertial gravitational regime
Inertial regime
Instabilities

Fall height	Angular frequency	Theoretical prediction	Relative error
1.0 cm	25 Hz	27 Hz	7.4%
4.0 cm	45 Hz	39.0 Hz	15.3%
8.0 cm	140 Hz	148 Hz	5.1%

Viscous regime | Gravitational regime | Inertial regime

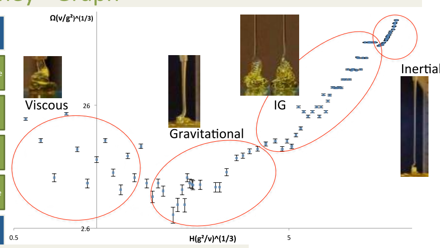
Obtaining data





Honey - Graph

Data analysis
Viscous regime
Gravitational regime
Inertial gravitational regime
Inertial regime
Instabilities



Viscous regime – Silicone oil, 5000 cst

Data analysis
Viscous regime
Gravitational regime
Inertial gravitational regime
Inertial regime
Instabilities

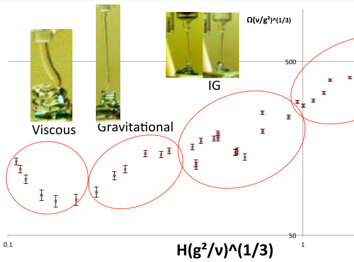
Fall height	Angular frequency	Theoretical prediction	Relative error
0.5 cm	121.2 Hz	111.2 Hz	8.2%
3.2 cm	154.8 Hz	156.4 Hz	0.9%
13.6 cm	689.2 Hz	662.8 Hz	3.8%

Viscous regime | Gravitational regime | Inertial regime

ART AN AMAZING FACT IN SCIENCE

Silicone oil graph – 5000 cst

- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities



- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities

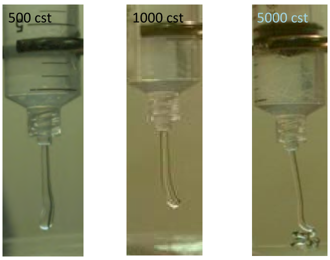
Viscosity variation

- For the viscosity variation, we used silicone oils with the same surface tension, density and fall height.

Viscosity	Surface tension	Density
500 cst	21.2 dynes/cm	0.970 g/cm^3
1000 cst	21.2 dynes/cm	0.970 g/cm^3
5000 cst	21.4 dynes/cm	0.975 g/cm^3
60000 cst	21.5 dynes/cm	0.976 g/cm^3
63775 cP	--	1.03 g/cm^3

Comparative videos

- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities



Comparing theoretical and experimental results

- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities

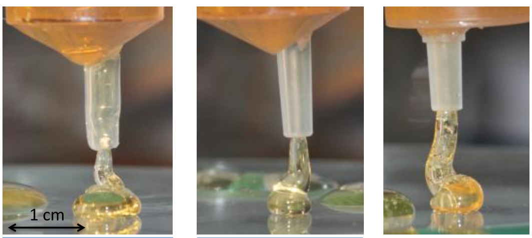
- From our instability analysis:
  - Surface tension reduces the visibility of the phenomena
- Experiment to see its effects:
  - Observe the smaller heights for the phenomena still be seen:
    - Honey (control)
    - Honey with salt (higher surface tension)
    - Honey with a bit of detergent (smaller surface tension)

Experimental setup – Honey and water

Cup with water
Honey
Syringe
Tripod
Pneumatic piston

Comparing theoretical and experimental results

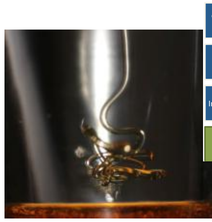
- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities



Honey - detergent	Honey - control	Honey - salt
0.6 cm	1.0 cm	1.3 cm

Fluid variation

- We can use another surrounding medium, such as water.
- We get some interesting phenomena:



Comparing theoretical and experimental results

- Data analysis
- Viscous regime
- Gravitational regime
- Inertial gravitational regime
- Inertial regime
- Instabilities

- Viscosity
- It's possible to notice changes in the coil formation by changing its viscosity

Conclusion

- The phenomena can be divided in 4 phases, depending on the fall height:

- The coiling can appear in many fluids, but the visualization depends on the surface tension and viscosity.

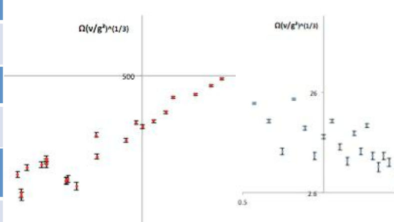
Conclusion

- We can analyze the problem in a quantitative way, depending on height, viscosity and flow rate.

Height	Angular frequency	Flow rate	Theoretical angular frequency	Error
0.5 cm	30.3 Hz	0.49 cm^3/s	27.8 Hz	8.2%

Height	Angular frequency	Flow rate	Theoretical angular frequency	Error
3.20 cm	38.75 Hz	0.49 cm^3/s	39.1 Hz	0.9%

Height	Angular frequency	Flow velocity	Theoretical angular frequency	Error
13.6 cm	172.3 Hz	0.49 $cm^3/$	165.7 Hz	3.8%



Fall height	Angular frequency	Flow velocity	Theoretical angular frequency	Error
1.0 cm	25 Hz	25 m/s	27 Hz	7.4 %

Fall height	Flow velocity	Angular frequency	δ parameter	Theoretical angular frequency	Error
4 cm	30 cm/s	45 Hz	0.93 cm	39 Hz	15.3 %

Angular frequency	Fall height	a_1 parameter	Theoretical angular frequency	Error
140 Hz	8.0 cm	0.2	148 Hz	5.1 %

References

- *Multiple coexisting states of liquid rope coiling By N. M. RIBE1, H. E. HUPPERT2, M. A. HALLWORTH2, M. HABIBI3,4 AND DANIEL BONN*
- Coiling of viscous jets By Neil M. Ribe
- Liquid Rope Coiling, by Neil M. Ribe, Mehdi Habibi and Daniel Bonn, Annu. Rev. Fluid Mech. 2012
- Mahadevan L, Ryu WS, Samuel ADT. 1998. Fluid 'rope trick' investigated. *Nature*
- The Bouncing Jet: A Newtonian Liquid Rebounding off a Free Surface, Matthew Thrasher,Sunghwan Jung,† Yee Kwong Pang,‡ Chih-Piao Chuu, and Harry L.
- The meandering instability of a viscous thread, Stephen W. Morris, Jonathan H. P. Dawes, Neil M. Ribe, and John R.
- Bending-Filament Model for the Buckling and Coiling Instability of Viscous Fluid Rope, Shin-ichiro Nagahiro, Yoshinori Hayakawa
- The folding motion of an axisymmetric jet of wormlike-micelles solution, Matthieu Varagnat, Trushant Majmudar, Will Hartt, Gareth H. McKinley

PROBLEM

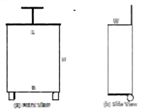
When one pulls along a **two wheeled suitcase,** it can under certain circumstances **wobble so strongly** from side to side that it can **turn over.** Investigate this phenomenon. Can one **suppress** or **intensify** the effect by **varied packing** of the luggage?

IYPT – AUSTRALIA
QUESTION 17: CRAZY SUITCASE

Reporter: Jeong Han Song

TERMS & DEFINITIONS

When one pulls along a **two wheeled suitcase**, it can under certain circumstances **wobble so strongly** from **side to side** that it can **turn over.** Investigate this phenomenon. Can one suppress or intensify the effect by **varied packing** of the luggage?



$L = length = 40\ cm$
$H = height = 50cm$
$B = distance\ between\ two\ wheels = 39cm$
$W = width = 20\ cm$

$\tau = Fd$

Detachment of both wheels

Different Positions of Centre of mass

FLOW CHART

Qualitative Analysis
- Stages of motion of the wobbling suitcase
- Condition of overturn

Quantitative Analysis
- Net Torque Equation
- Human Effect (Literature Review)
- Graphical Simulation (Theoretical Prediction)

Experiment
- Measurement of angular displacement
- Computational Analysis
- Angular Acceleration (Derivation of force)

Additional circumstances
- Walking frequency
- Coefficient of Restitution
- Different mass density
- Angle of tilt

Relevant Condition for Overturn

STAGE 1: INITIAL CONDITION

Titled

Net Force = 0

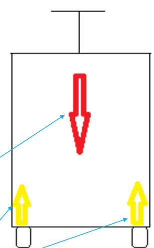
No External Force

Acceleration = 0 (i.e. Constant Speed)

Both wheels are in contact with the floor

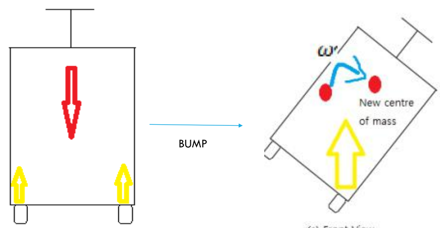
Weight of a suitcase

Normal Force by two wheels



(a) Front View

STAGE 2: EFFECT OF INITIAL DISTURBANCE



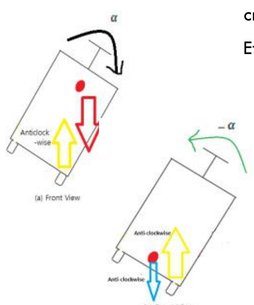
(a) Front View (a) Front View

STAGE 2: EFFECT OF INITIAL DISTURBANCE (TORQUE)

•Different effect depending on the position of weight

•Case 1: High weight
- Centre of mass now causes rotation about the supporting wheel
- Torque created by the center of mass
- Angular acceleration is present

•Case 2: Low weight
- Low centre of mass acts as a restoring force that opposes the original torque created by the initial disturba
- Diminishes the wobble effect

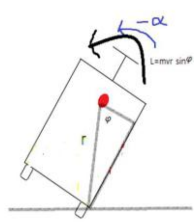


STAGE 3: HUMAN RESPONSE

Human exerts a periodic force that opposes the disturbance created by the weight.

Opposite direction to the torque created by the weight

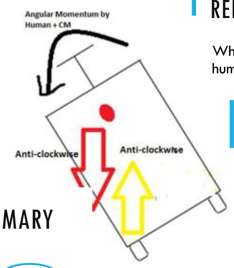
Effect of inertia



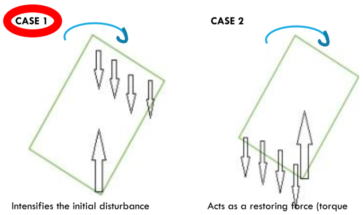
STAGE 4: POINT OF INSTABILITY

The restoring force overshoots

Overcompensation of restoring force would lead to the rather sharp increase in the oscillation.



QUALITATIVE MODEL – SUMMARY



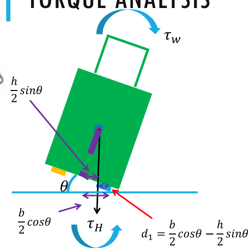
Intensifies the initial disturbance (torque is applied in the same direction as disturbance)

Acts as a restoring force (torque is applied in the opposite direction as disturbance)

STAGE 5: REPETITION AND AMPLIFICATION

When a suitcase meets a critical amplitude that exceeds what human can counteract, it overturns.

TORQUE ANALYSIS



Two Types of torque:

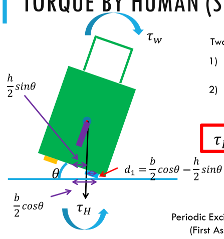
1) Torque by Weight
2) Torque by Human

Net Torque Equation:

$$I\frac{d\theta}{d^2t} = \tau_H - \tau_w$$

(Opposite Direction)

TORQUE BY HUMAN (SUHERMAN'S MODEL)



Two Fundamental Assumptions:

1) Puller's walking motion induces a periodic moment on the handle of suitcase
2) Puller exerts additional restoring moment to suppress the wobble proportional to rocking angle

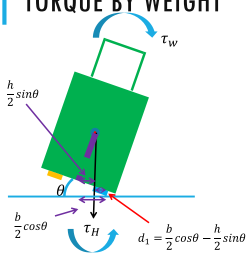
$$\tau_H = q_\theta \sin(\omega t) - k\theta \quad \dots (2)$$

Periodic Excitation Torque (First Assumption)

Restoring Torque (Second Assumption)

θ: angle of rocking
q_θ : amplitude of excitation torque
ω: walking frequency
k: constant for restoring torque

TORQUE BY WEIGHT



From basic torque equatio

$$\tau = F \times d_1$$

Force is equivalent to the

$$F = mg$$

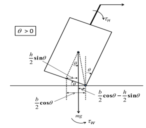
Shortest distance is:

$$\Rightarrow \frac{b}{2}\cos\theta - \frac{h}{2}\sin\theta$$

$$\therefore \tau_w = mg(\frac{b}{2}\cos\theta - \frac{h}{2}\sin\theta) \quad \dots (1)$$

NET TORQUE EQUATION

Combining Equation 1 & 2:



$$I\frac{d\theta}{d^2t} = \tau_H - \tau_w$$

$$I\frac{d\theta}{d^2t} = q_0 \sin(\omega t) - k\theta - mg\left(\frac{b}{2}\cos\theta - \frac{h}{2}\sin\theta\right) \quad \dots\theta > 0$$

Or

$$I\frac{d\theta}{d^2t} = q_0 \sin(\omega t) - k\theta + mg\left(\frac{b}{2}\cos\theta + \frac{h}{2}\sin\theta\right) \quad \dots\theta < 0$$

FINAL NET TORQUE EQUATION

Define: $S = +1, if\ \theta > 0$ $\quad S = -1, if\ \theta < 0$

SIMPLE

ACCURATE

Final Equation:

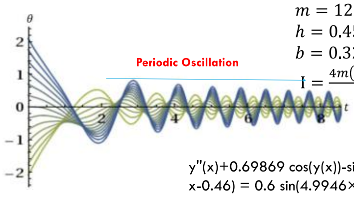
$$I\frac{d^2\theta}{dt^2} = q_0 \sin(\omega t) - k\theta - Smg\frac{b}{2}\cos\theta + mg\frac{h}{2}\sin\theta$$

b: bottom length of a suitcase
h: effective height
θ: angle of rocking
q_θ : amplitude of excitation torque
ω: walking frequency
k: constant for restoring torque

As effective height increases, net torque increases!

THEORETICAL PREDICTION – WOBBLE

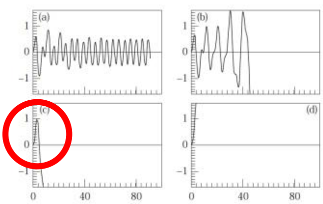
Sample Graph from our computer simulation (wolfram alpha) using values below:

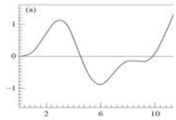


$$m = 12kg$$
$$h = 0.458m$$
$$b = 0.320m$$
$$I = \frac{4m(h^2+b^2)}{3} = 4.996\ kgm^2$$

y''(x)+0.69869 cos(y(x))-sin(y(x))+y x (2.3232 x-0.46) = 0.6 sin(4.9946×2.3232 x+0.426)

LITERATURE REVIEW: SUHERMAN'S RESULTS OVERTURN OF A SUITCASE

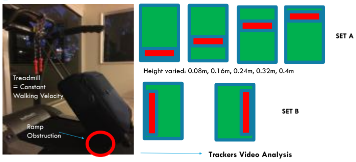




ROCKING ANGLE v TIME
OVERTURN ($\theta > \frac{\pi}{2}$)

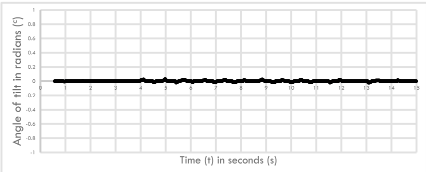
1. Sharp change in angular displacement
2. No wobble during the overturn

EXPERIMENTAL SETUP



SIMULATING THE EQUATION

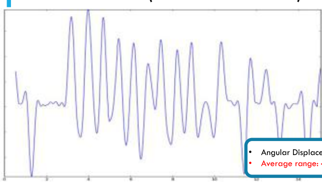
RESULT 1: 0.08M EFFECTIVE HEIGHT OF CM



- Very minimal angular displacement
- Inaccurate measurement (interval: 0.1s)
- Hard to observe trend or data

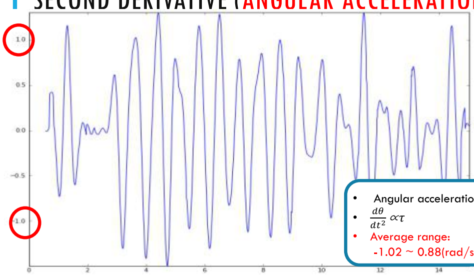
Fast Fourier Transform

ORIGINAL GRAPH (MAGNIFIED VERSION)



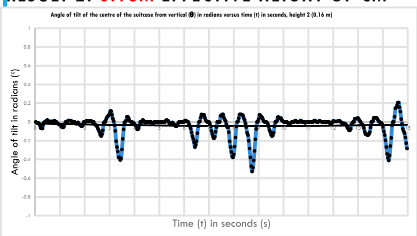
- Angular Displacement vs.Time
- Average range: -0.04 ~ 0.01 (rad)

SECOND DERIVATIVE (ANGULAR ACCELERATION)

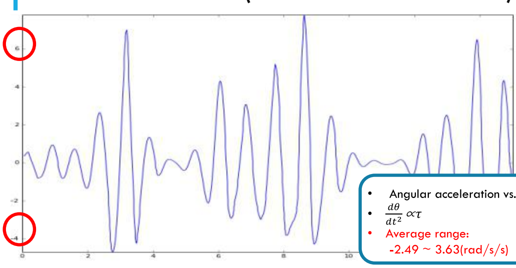


- Angular acceleration vs. tin
- $\frac{d\theta}{dt^2} \propto \tau$
- Average range: -1.02 ~ 0.88(rad/s/s)

RESULT 2: 0.16M EFFECTIVE HEIGHT OF CM

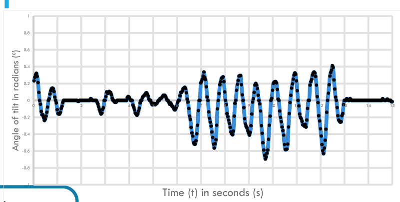


SECOND DERIVATIVE (ANGULAR ACCELERATION)

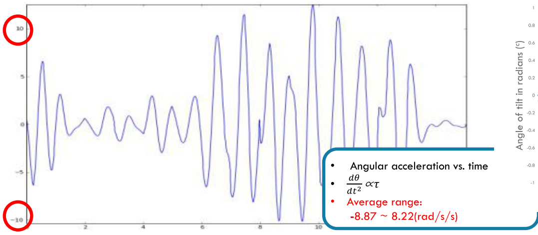


- Angular acceleration vs. time
- $\frac{d\theta}{dt^2} \propto \tau$
- Average range: -2.49 ~ 3.63(rad/s/s)

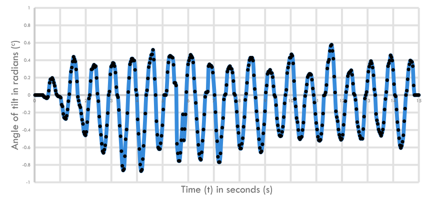
RESULT 3: 0.24M EFFECTIVE HEIGHT OF CM



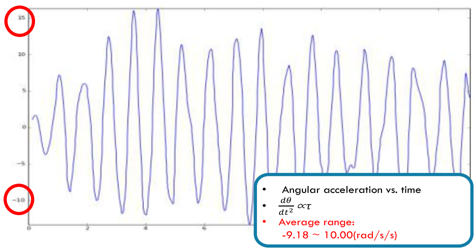
SECOND DERIVATIVE (ANGULAR ACCELERATION)



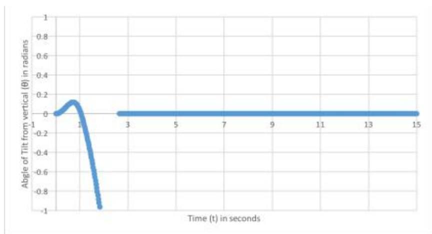
RESULT 4: 0.32M EFFECTIVE HEIGHT OF CM



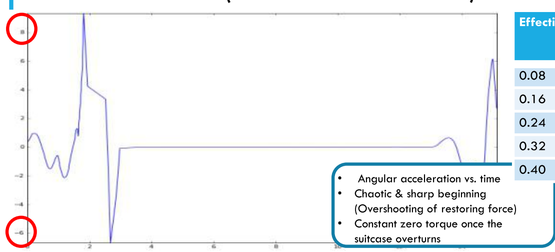
SECOND DERIVATIVE (ANGULAR ACCELERATION)



RESULT 5: 0.40M EFFECTIVE HEIGHT OF CM (OVERTURN)



SECOND DERIVATIVE (ANGULAR ACCELERATION)



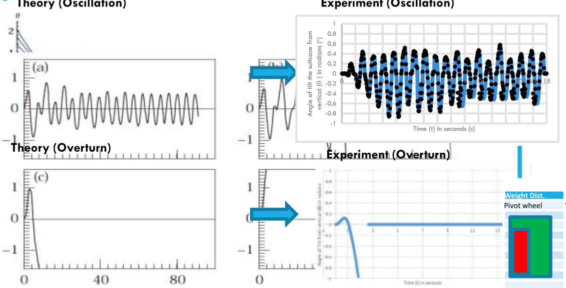
SUMMARY OF EXPERIMENTAL RESULT (SET A)

Effective Height (m)	Range of angular acceleration (rad/s/s)	Average angular acceleration (rad/s/s)
0.08	-1.02 ~ 0.88	0.95
0.16	-2.49 ~ 3.63	3.06
0.24	-8.87 ~ 8.22	8.54
0.32	-9.18 ~ 10.00	9.59
0.40	Overturn	N/A

As effective height increases:
=Increase in angular acceleration
e in torque
e in wobble
LIKELY TO OVERTURN

COMPARISON TO THEORETICAL PREDICTION

Theory (Oscillation) Experiment (Oscillation)



Verified!

SUMMARY OF EXPERIMENTAL RESULT (SET B)

Weight Dist.	Speed (m/s)	Angle	Wobbles	Overturn
Pivot wheel	""	70°	1	1
			1	1
			1	1
		60°	1	1
			1	1
			1	1
		50°	5	0
			2	1
			1	1
		40°	1	1
			1	1
			1	1

Weight Dist.	Speed (m/s)	Angle	Wobbles	Overturn
Obstructed wheel	""	70°	0	0
			0	0
			0	0
		60°	0	0
			0	0
			0	0
		50°	0	0
			0	0
			0	0

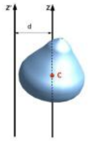
Potential outlier @ 50° for opposite wheel

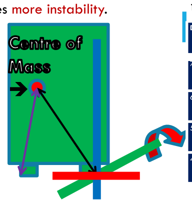
RESULTS DISCUSSION (SET B)

The closer the centre of mass to the obstructed wheel the less wobbles/overturns the suitcase will have (Parallel axis Theorem).

Having the centre of mass closer to the pivot wheel causes more instability.

$$I = I_{CM} + md^2$$





FURTHER CIRCUMSTANCES OF OVERTURN

- Walking speed
- Angle of tilt
- Mass density
- Coefficient of Restitution

1) Angle of tilt vs Walking speed

Degree of tilt	0.81 m/s	0.92 m/s	1.04 m/s
70°	O	O	O
60°	N	O	O
50°	N	O	O
40°	N	N	N

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APP FOR WALKING SPEED

ANGLE OF TILT

At 0.81 m/s, stable until high angles.
At 1.04 m/s, stability reduced (high variations in τ_H)

2) LOW WEIGHT: Mass density vs Walking speed

No added mass	0.92 m/s
70°	O
60°	O
50°	N
40°	N
1.5 kg mass	**0.92 m/s**
70°	O
60°	O
50°	N
40°	N
3 kg mass	**0.92 m/s**
70°	O
60°	N
50°	N

3) HIGH WEIGHT: Mass density vs Walking speed

No added mass	0.92 m/s
70°	O
60°	O
50°	O
40°	N
1.5 kg mass	**0.92 m/s**
70°	O
60°	N
50°	N
40°	N
3 kg mass	**0.92 m/s**
70°	N
60°	N
50°	N

For low weight:
As mass is increased, stability increases.
$\tau_w \downarrow$

For high weight:
As mass is increased, stability decreases.
$\tau_w \uparrow$

4) COR vs Walking speed

Indoor (COR 0.35)	0.81 m/s	0.92 m/s	1.04 m/s	Outdoor (COR 0.68)	0.81 m/s	0.92 m/s	1.04 m/s
70°	O	O	O	70°	O	O	O
60°	N	O	O	60°	O	O	O
50°	N	O	O	50°	O	O	O
40°	N	N	N	40°	O	-	-

- At lower walking frequency, suitcase was less stable for trials outdoors, due to higher COR and less energy loss.
- At higher walking frequency, energy loss is less significant due to balancing effect of higher walking frequency.

CONCLUSION

Investigated circumstances when suitcase wobbles and turns over.

1. Developed mathematical simulation to model the wobble (FFT)
2. Simulation verified -> Comparison to theory
3. Studied effect of varied packing of the luggage
   A. Significance of effective height of CM
   B. Effect of other positions of CM vs. Wheel Position
4. Considered other factors that influence the wobble
   A. Walking Frequency
   B. Angle of tilt
   C. Coefficient of Restitution
   D. Different mass density

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1

Invent Yourself

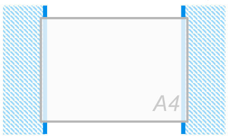
Boris Vavrík Katarína
Tureková Kamila Součková

Paper

standard officepaper

- areal density $80\ \mathrm{g/m^2}$
- thickness $0.1\ \mathrm{mm}$
- A4: $210\ \mathrm{mm} \times 297\ \mathrm{mm}$

our bridge: 280 mm



1 Invent Yourself

It is more difficult to bend a paper sheet, if it is

Using **a single A4** sheet and a small amount of glue, if required, construct a bridge spanning a **gap of 280 mm** .

Introduce parameters to describe the strength of your bridge, and optimize some or all of them.

Definition of Strength

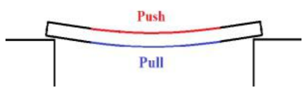
strength ≡ **maximal load** the bridge can hold **in its center**

- load placed over **constant width of the bridge (12 cm)**

BRIDGE OPTIMIZATION

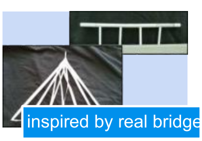
How a SimpleBridge Breaks

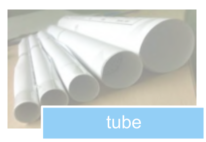
What Happened

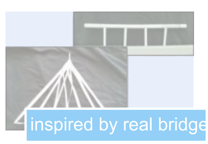


paper:
strong in pull,
weaker in push

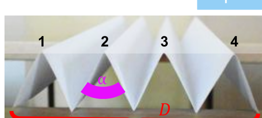
BridgeDesigns





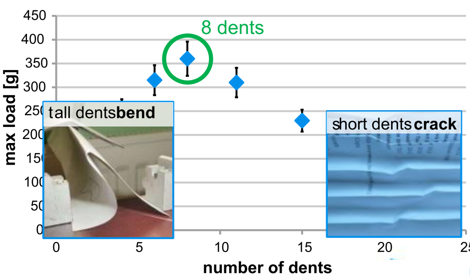


Accordion: Parameters

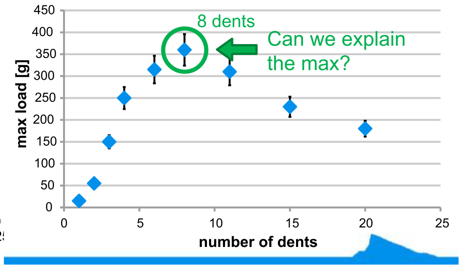


- number of dents N
- width of accordion D

Max Load vs. # of Dents for $D = 8$ cm

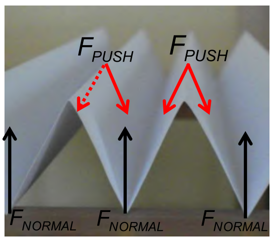


Max Load vs. # of Dents for $D = 8$ cm



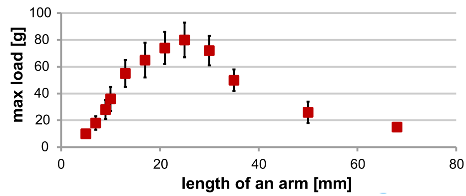
Force analysis

strength of bridge = strength of single dent N



Accordion: Explaining the Max

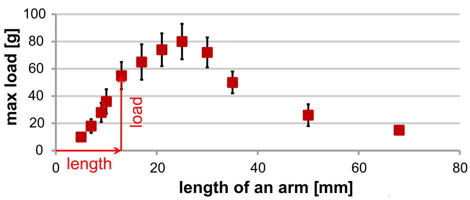
strength of bridge = strength of single dent N



Accordion: Explaining the Max

strength of bridge = strength of single dent N

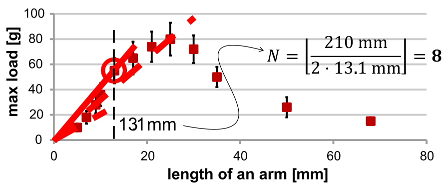
max: highest load/length ratio $\left(N \propto \frac{1}{\text{length}}\right)$



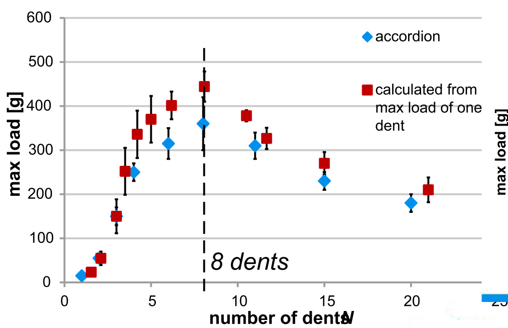
Accordion: Explaining the Max

strength of bridge = strength of single arm N

max: highest load/length ratio $\left(N \propto \frac{1}{\text{length}}\right)$

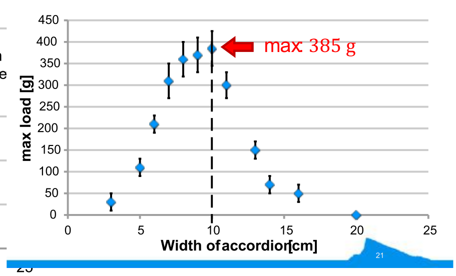


Measured Max Load vs N Single Dent



Max Load vs. Accordion Width

for 8 dents



Accordion: Optimal Parameters

max:
- 8 dents
- $D = 10$ cm

385 g

Modifying the Accordion

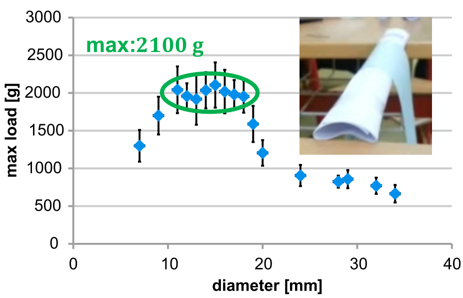
max load: **180 g**

low stability crashes near the center
useless

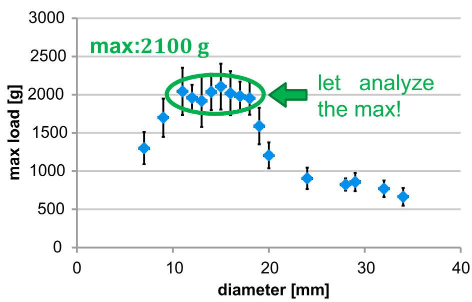
Tube: Parameters

- radius $r \Rightarrow$ number of layers $L = \frac{210\text{ mm}}{2\pi r}$

Max Load vs. Radius



Max Load vs. Radius



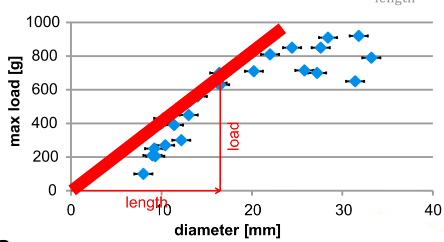
Analysis of Variables

need to separate the effect of
- radius
- number of layers

change radius but not number of l
experiment with **double layer tubes**

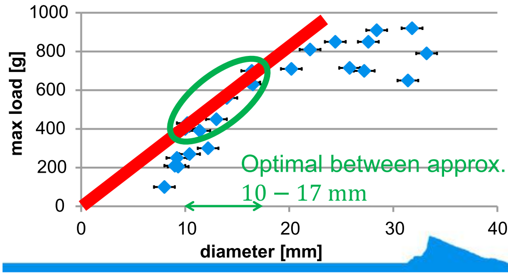
Max Load of Double Layer Tubes

max: highest load/diameter ratio ($N \propto \frac{1}{\text{length}}$)

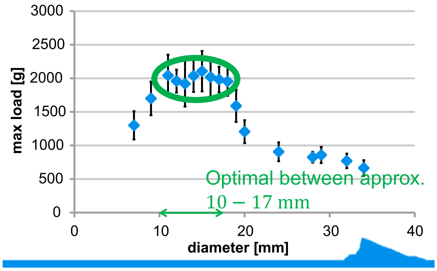


Max Load of Double Layer Tubes

max: highest load/diameter ratio ($N \propto \frac{1}{\text{length}}$)

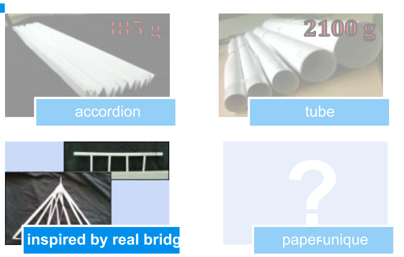


Max Load vs. Radius



Tube: Optimal Parameters

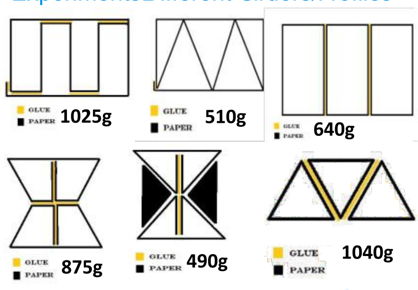
Maximal strength: with 15 mm diameter



Bridges Inspired by Reality

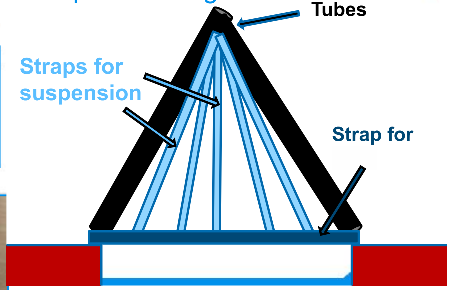
- Different girders
- Suspension bridge
- Pier bridge

Experiments: Different Girders/Profiles



Experiments: Different Girders/Profiles

Suspension Bridge



Suspension Bridge

limiting factor:
strength of

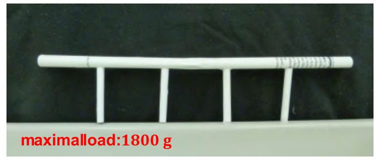
- **supporting tubes**
- **suspension straps**

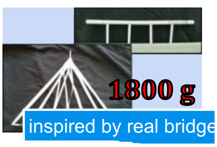
results

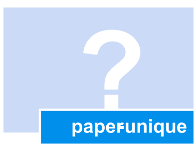
	max load	
narrower straps	1000 g	*straps tore*
thinner tubes	900 g	*tubes bent*

Pier bridge

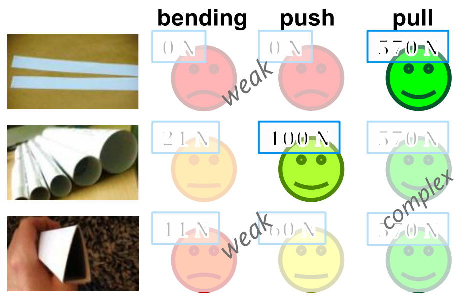
relevant parameter
strength of the tube under bending and pressure



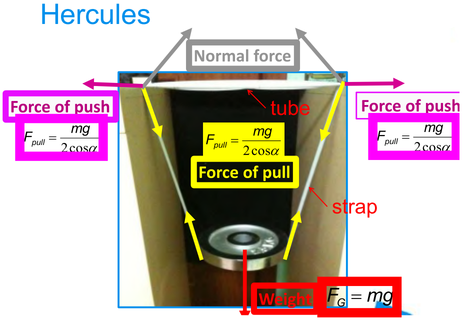




Applicability of Components

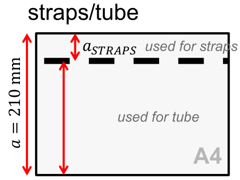


Hercules



Hercules: Free Parameters

- % of paper used for straps/tube



- angle of straps α

Hercules: Optimizing the Design

straps

$$\frac{mg}{2\cos\alpha} \leq wtG$$

tube

$$\frac{mg}{2\cos\alpha} \leq N_{LAYERS}K$$

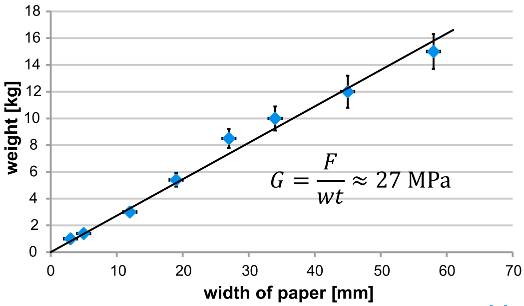
t: paper thickness
w: width of the strap
G: paper tensile strength
K: strength of a single tube layer

Tensile Strength of Paper Straps

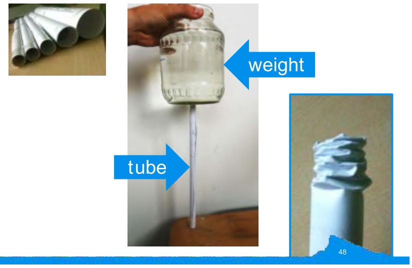
no precise material constants known

experiment
changing strap width,
measuring max load

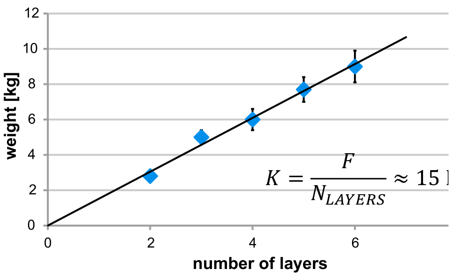
Tensile Strength of Paper Straps



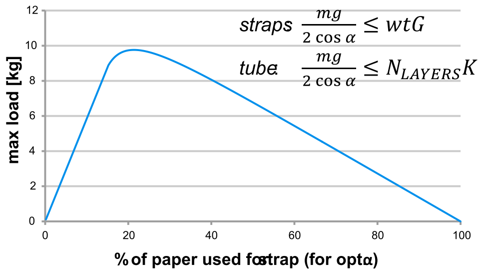
Strength of a Single-Layer Tube



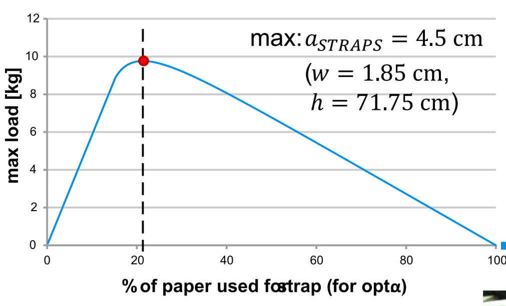
Strength of a Single-Layer Tube



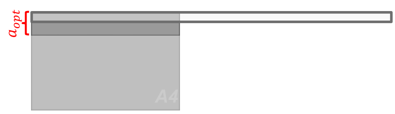
Hercules Strength Prediction



Hercules Strength Prediction

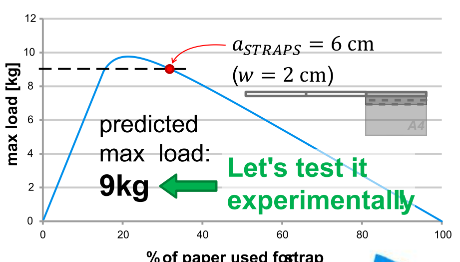


How to make a 1.85×71.75 cm strap out of a 4.5×29.5 cm paper?



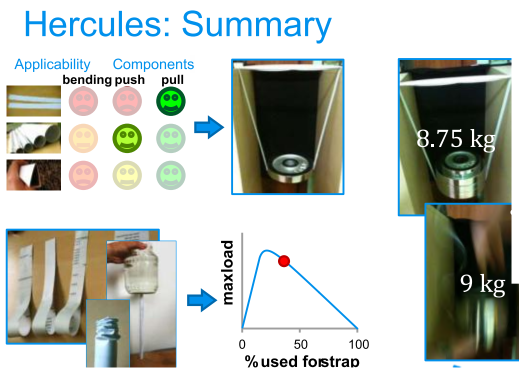
→ we chose best realizable parameters instead

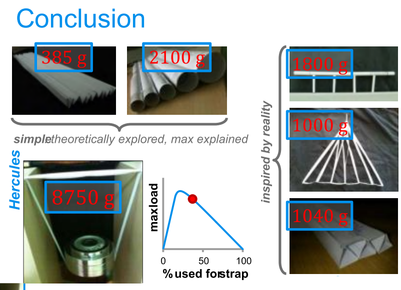
Hercules Strength Prediction

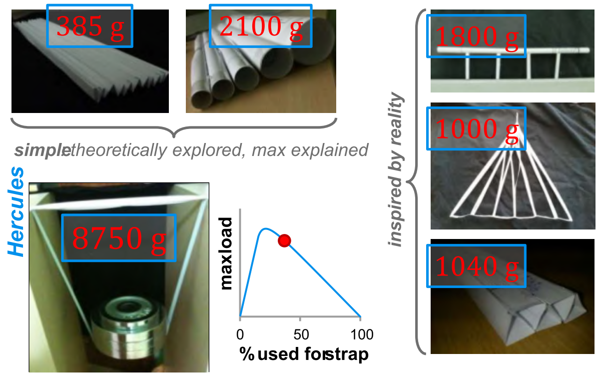


5 kg

7.5 kg


Hercules: Summary
Applicability
Components
bending push pull
8.75 kg
9 kg
maxload
0 50 100
% used for strap


Conclusion
385 g
2100 g
simple theoretically explored, max explained
Hercules
8750 g
maxload
0 50 100
% used for strap
inspired by reality
1800 g
1000 g
1040 g


385 g
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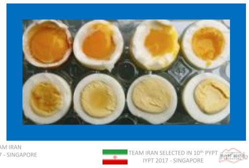
1800 g
1000 g
1040 g

ART AN AMAZING FACT IN SCIENCE

15. Boiled egg

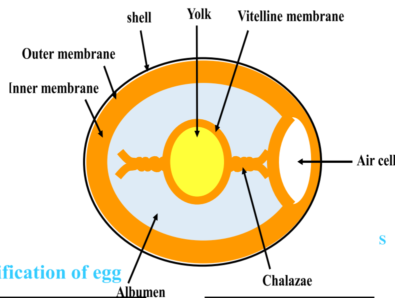
Rozhina Sedigh



15. Boiled egg

Suggest **non-invasive methods** to detect the degree to which a **hen's egg** is **cooked by boiling**. Investigate the **sensitivity** of your methods.

Anatomy of an egg

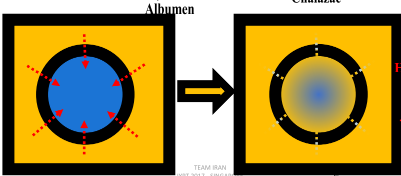


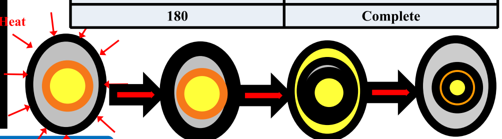
	Water [%]	Proteins [%]	Lipids [%]	Carbohydrates [%]	Mineral[%]
Egg white	88	10	0.03	0.9	0.6
Yolk	49	16	33	1	1.0
Shell	1.6	3.3			95

Protein	Protein fraction present in egg white[%]	Denaturation temperature[°C]
Ovalbumin	58	77

Boiling time (sec. In 100°C water)	Thickness of solidified albumen
30	1.9mm
60	2.4mm
90	3.35mm
120	4.4mm
180	Complete

solidification of egg

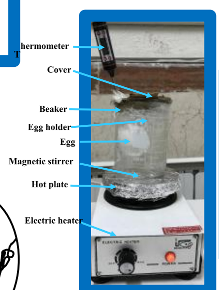




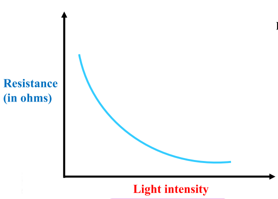
$$t = \frac{M^{3/2} c \rho^{1/3}}{K\pi^2 (4\pi/3)^{2/3}} \ln\left[0.76 \frac{T_{egg} - T_{water}}{T_{york} - T_{water}}\right]$$

$$t \propto \frac{r^2}{D^2 c^2 [\log(T - T_c)]^2}$$

t : cooking time (min)
r : radius of egg (mm)
D : thermal diffusivity
c : specific heat
T : egg temperature (C)
T_c: cooking temperature (C)

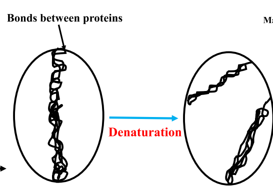


Resistance



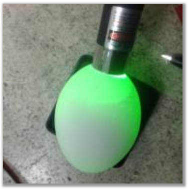
$$R = \frac{v}{I}$$

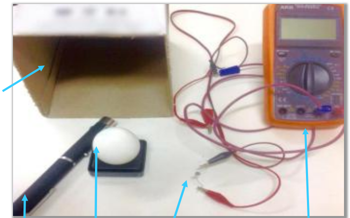
Denaturation



Egg Weight ≅60 g
Surface ≅53 cm²
Shell thickness ≅0.3 mm
Shell Weight ≅ 6 g
Egg white weight ≅34 g
yolk weight ≅19 g

Measuring the transparency between different parts of the egg





The light scattering method

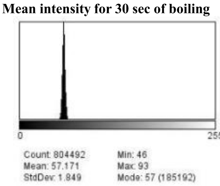
*results from Imagej
**all pictures taken by Canon DIGITAL IXUS 100 IS, exposure time 1.40 sec, ISO- 250, f/3.2 (aperture time)

	bottom	middle	upside
Raw	16.2 Ω	154.5 Ω	22.3 Ω
Soft-boiled	2.6 Ω	59.9 Ω	8.6 Ω
Hard- boiled	65.6 Ω	167.7 Ω	16.6 Ω

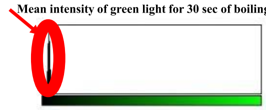
30 sec egg green light scattering & light intensity

30 sec boiled egg

Mean intensity for 30 sec of boiling



Mean intensity of green light for 30 sec of boiling

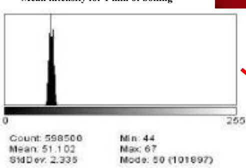


1 min egg green light scattered & light intensity

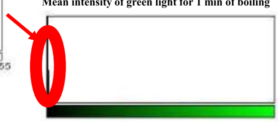
*results from Imagej
**all pictures taken by Canon DIGITAL IXUS 100 IS, exposure time 1.40 sec, ISO- 250, f/3.2 (aperture time)

1 min boiled egg

Mean intensity for 1 min of boiling

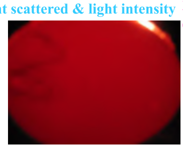


Mean intensity of green light for 1 min of boiling



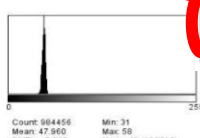
3 min egg green light scattered & light intensity

*results from Imagej
**all pictures taken by Canon DIGITAL IXUS 100 IS, exposure time 1.40 sec, ISO- 250, f/3.2 (aperture time)

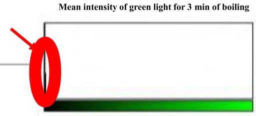


3 min boiled egg

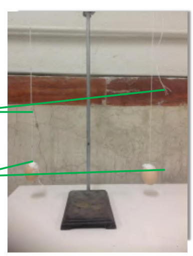
Mean intensity for 3 min of boiling



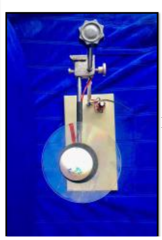
Mean intensity of green light for 3 min of boiling

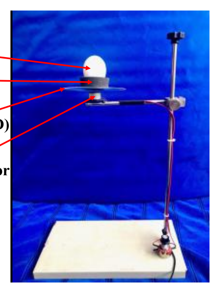


Pendulum method



Snipping method

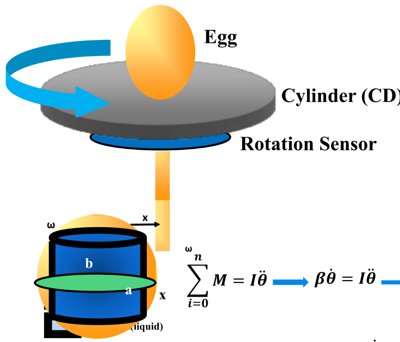




Measuring the speed of rotation

5 min boiled egg

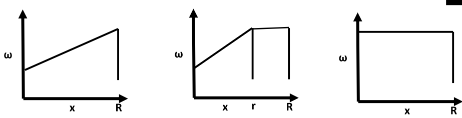
The primary speed of setup

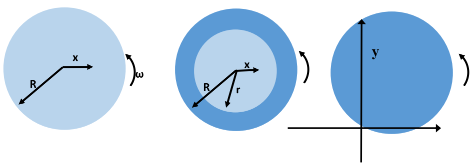


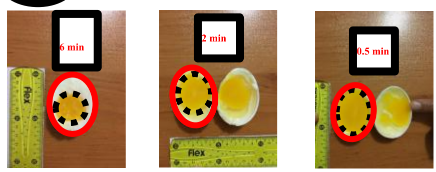
$$\sum_{i=0}^{n} M = I\ddot{\theta} \rightarrow \beta\dot{\theta} = I\ddot{\theta} \rightarrow I\frac{d\dot{\theta}}{dt} = \beta\dot{\theta} \Rightarrow$$

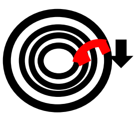
$$I\frac{d\dot{\theta}}{\dot{\theta}} = \beta\,dt \rightarrow I\int\frac{d\dot{\theta}}{\dot{\theta}} = \beta\int_0^t dt \rightarrow$$

$$I\ln|\dot{\theta}| = \beta t \rightarrow \ln|\dot{\theta}| = \frac{\beta}{I}t \rightarrow \theta = \frac{I}{\beta}\left(e^{\frac{\beta t}{I}} - 1\right)$$









$$Fvis = A\mu\omega$$

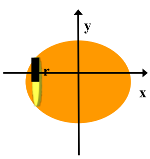
$$F = \mu\frac{d\dot{\theta}}{dy}$$

$$A = 4\pi xy$$

$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

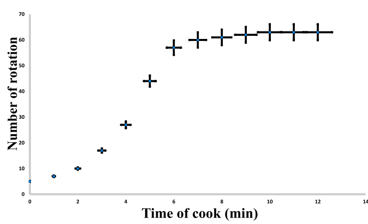
$$\int_0^b F_{vis} = \frac{4}{3}\pi a^2 b\mu\dot{\theta}$$

$$x = a\sqrt{1 - \frac{y^2}{b^2}}$$



$$F = 4\pi\mu\theta\int_0^a y\sqrt{1 - \frac{y^2}{b^2}}\,dy$$

$$F_{vis} = 4\pi\mu\left[\frac{1}{3}a^2 - \frac{1}{3}\sqrt{\frac{a^2 - b^2}{a^2}}(a^2 - b^2)\right]$$



The photo resistance method

- High error rate because of the multi meter.
- Only can predict the resistance transfer between 2-3 eggs.
- Not reliable relations between the parameters shown in the charts.(charts 1 & 2).

The light scattering method

- Each color-light scattered could be analyzed separately in the soft wares.
- The results could be announced with a high sensitivity degree. (the histograms show it as well).
- As the boiling time increases, the intensity of the light glinted decreases.
- As the boiling time increases, the intensity of the green light scatters, drop.

PROBLEM NO.16
SINKING BUBBLES

When a container of liquid (e.g. water) oscillates vertically, it is possible that bubbles in the liquid move downwards instead of rising. Investigate this phenomenon.

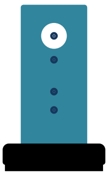
Reporter

Bahar Aghazadeh

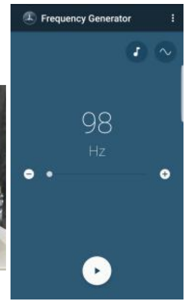
Approach

- What happens?
- Set up
- Acceleration
- Volume of the bubble
- Forces affecting the bubble
- Added mass
- Deferential equation
- Motions of the bubble
- Viscosity and sinking
- Density and sinking
- Conclusion

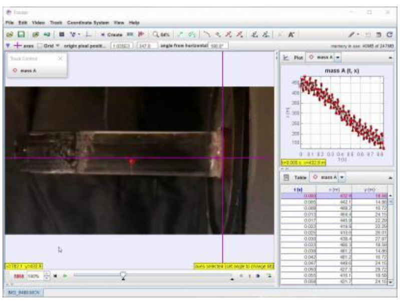
WHAT HAPPENS?



Set up



Extracting data



Volume of the bubble

- Ideal gas :

$$P_t V_b = \overset{\text{Const.}}{nRT}$$

$$P_t V_b = P_0 V_{b0}$$

$$P_t = P_0 + \rho x(g + A\omega^2 \sin \omega t) + \frac{\sigma}{2r}$$

$$V_b = \frac{P_0 V_{b0}}{P_0 + \rho x(g + A\omega^2 \sin \omega t) + \frac{\sigma}{2r}}$$

ACCELERATION

Movement Amplitude ↕

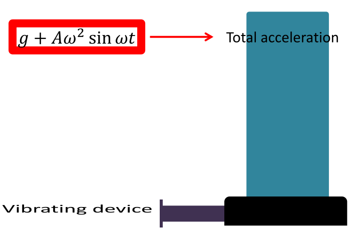
Movement amplitude= A

Frequency= ω

$x = A \sin \omega t$ → Displacement

$\ddot{x} = A\omega^2 \sin \omega t$ → Sinusoidal acceleration

$g + A\omega^2 \sin \omega t$ → Total acceleration



$$V_b = \frac{P_0 V_{b0}}{P_0 + \rho x(g + A\omega^2 \sin \omega t) + \frac{\sigma}{2r}}$$

$$\times \frac{H_0}{H_0} \qquad \times \frac{H_0 g}{H_0 g}$$

$$\left(\frac{\rho H_0 (g + A\omega^2)}{P_0}\right)^2 \ll 1$$

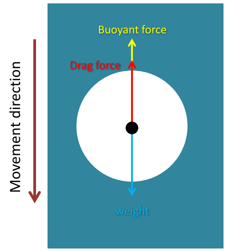
$$V_b = V_{b0}\left(1 - \gamma \frac{x}{H_0} - \gamma \frac{x}{H_0} W \sin \omega t - \frac{\sigma}{2r}\right)$$

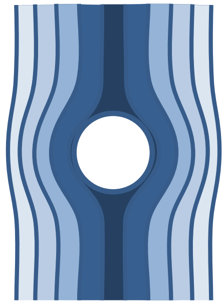
FORCES AFFECTING THE BUBBLE

Drag force $= -F_{(\dot{x})}$

Buoyant force $= \rho g V_b$

$$-F_{(\dot{x})} + (m - \rho V_b)(g + A\omega^2 \sin \omega t) = ma$$

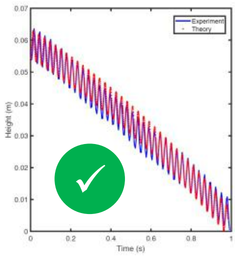




Theory vs. experiment

```
R = 0.001799;
H0 = 0.06;
AA = 0.003;
omega =2*pi*36;
rhof = 1000;

rhoa = 1;
P0 = 100000;
g = 9.8;
```



n

D

DRAG FORCE

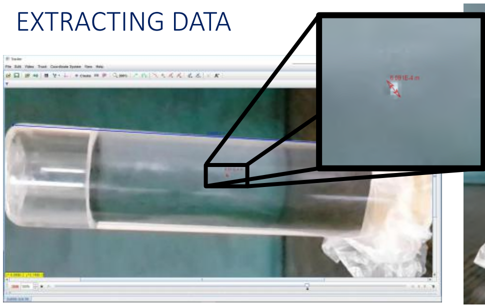
$$P_{in} - P_{out} = \frac{\sigma}{2r}$$

$$F_D = 6\pi\mu r V \qquad F_D = \frac{1}{2} C \rho V^2$$

EXTRACTING DATA

Buoyant force	$1.14 \times 10^{-6}\ N$
Drag force	$3 \times 10^{-6}\ N$

EXTRACTING DATA



Added mass

added mass

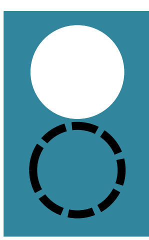
$m_0 = \rho x g$

$x = \frac{1}{2}$ *of the volume*

$m_T = m + m_0$

$$F = \frac{d((m + m_0)\dot{x})}{dt}$$

$$F = (m + m_0)\ddot{x} + \dot{m}_0 \dot{x}$$



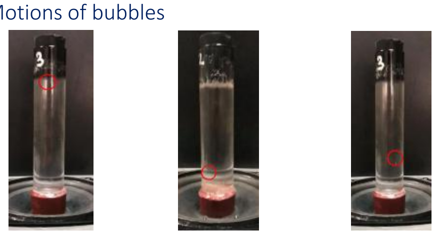
Differential equation

$F = (m + m_0)\ddot{x} + \dot{m}_0 \dot{x}$

$-F_{(\dot{x})} + (m - \rho V_b)(g + A\omega^2 \sin \omega t) = ma$

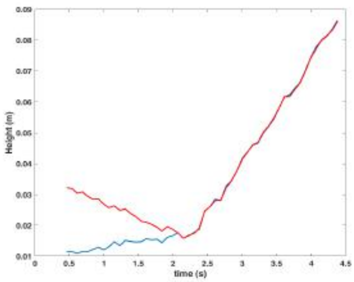
$$(m + m_0)\ddot{x} + \dot{m}_0 \dot{x} = -F_{(\dot{x})} + (m - \rho V_b)(g + A\omega^2 \sin \omega t)$$

Motions of bubbles

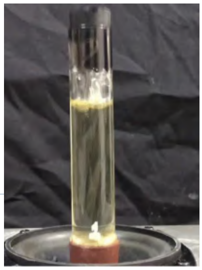


ART AN AMAZING FACT IN SCIENCE

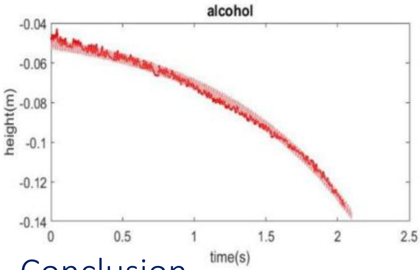
Motions of bubbles



Viscosity and sinking



Density and sinking



Theory
experiment

Conclusion

Volume of the bubble

$$V_b = V_{b0}\left(1 - \gamma\frac{x}{H_0} - \gamma\frac{x}{H_0}W\sin\omega t\right)$$

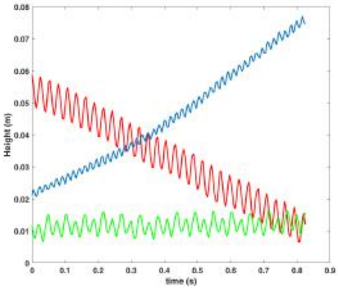
Forces affecting the bubble

1. Weight 2. buoyant force 3.drag force

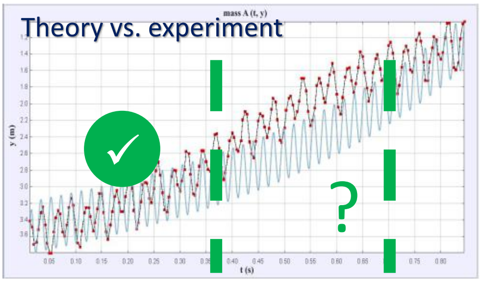
Mass of the bubble

$$F = (m + m_0)\ddot{x} + \dot{m}_0\dot{x}$$

Different motions of the bubble



Theory vs. experiment



Special case (volume increase)

Theory
experiment