FROM A BALL THROW TO SPACE LEAPS

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Project's fiche

A. Title of the project: **FROM A BALL THROW TO SPACE LEAPS**
B. Created by: Elżbieta Kawecka
C. Physics thematic range – material point's motion, mechanical energy, gravity
D. School level: high school, extended level
E. Goals of the project's realisation in relation to physics curriculum:

i. General:

- Carrying out experiments and drawing conclusions based on results.
- Knowledge and ability to use physical laws and terms to explain natural processes and phenomena.
- Using information gained by text analysis.
- Using and processing information stored as text, tables, charts, schemes and graphics.
- Creation of simple physical and mathematical models in order to describe certain phenomena.

ii. Specific:

- Studying vertical upwards toss using the video-measurements technique (and optionally – ultrasonic motion detector),
- Creating and interpreting charts of motion parameters as functions of time,
- Explaining bodies' motion based on Newton's laws of dynamics,
- Describing motion in a gravitational field with the inclusion of medium's resistance,
- Explaining what is weightlessness and in which conditions does it exist,
- Creating a model of a falling body with the inclusion of air resistance.

F. Goals of realisation of the project in relation to other subjects curriculums:

i. IT:

- The implementation of computer programs used to register and analyse measurements results, modelling and simulating, and creating graphics, texts and multimedia presentations

ii. Mathematics:

- Using the properties of linear and quadric equations to interpret physical and geometrical dilemmas (also based in the practical context)

G. Project's duration – 7 hours (physics – 3, IT - 4)
H. Didactic materials and media:

- "Motion analysis with the Tracker program" manual,
- "What do throwing a ball and jumping on the Moon have in common?" presentation
- Description of the model „Parachute jump" and spreadsheet model,
- Different balls, e.g. ping-pong, tennis, volleyball and basketball,
- Digital camera e.g. in a smartphone,

- Tracker program to register and analyse motion using the video-measurements method,
- Short films showing ball's movement,
- Ultrasonic motion detector (optional),
- Spreadsheet or other program capable of creating a mathematical model and conducting a simulation,
- E-experiment "Tosses" and manual for the students,
- Videos: Felix Baumgartner's space jump and Alana Eustace,

I. Idea description:

The project connects physics, mathematics and IT while using videos and other materials concerning an astronaut's leap on the Moon, parachute jumps and jumping from "the edge of space". Students will learn the video-measurements technique (free software Tracker) and will use it to collect data from videos and analyse motion. They will learn what do throwing a ball and jumping on the Moon have in common. They will utilize videos available on the Internet and will use a digital camera to capture the movement of a ball tossed upwards. They will create charts of position and velocity over time and will calculate the Earth's gravitational acceleration, as well as the Moon's. They will acquaint themselves with an e-experiment "Throws" and will study the movement of balls thrown upwards under different gravitational pulls.

As their homework, they will seek out materials (videos, pictures, infographics, articles) concerning parachute jumping and records achieved in this field. They will prepare presentations concerning the parachute jumps physics containing numeric data useful to create a model. During the IT lesson, they will learn the basics of numeric modelling and will employ laws of physics learned previously to create a parachute jump model. They will compare their results with data found on the Internet.

J. Time-table:

Subject	Lesson	Number of hours
IT	Introduction to video-measurements – learning the Tracker program, collecting data from videos, chart creation and analysis.	2
Physics	What do jumping on the Moon and throwing a ball have in common? (Studying vertical throws, creating and analysing charts of motion parameters over time, analysing the changes of energy, analysing astronaut's movement during a jump on the Moon, calculating the Moon's gravitational acceleration).	2
Physics	„Space" jumps – students' presentations concerning parachute jumps, jumping from the stratosphere,	1

	records achieved and laws of physics (freefall, weightlessness, movement resistance, max velocity).	
IT	Numeric modelling. Creating a model of a parachute jump in a spreadsheet.	2

K. Literature + online sources,

- Tracker software and videos showing a ball's motion (mechanics_video.zip) - http://physlets.org/tracker/,
- Instructional video „Video analysis" – how to prepare a video good for video-measurements - https://vimeo.com/27475759
- e-experiment 'Tosses' and a manual for the students http://e-doswiadczenia.mif.pg.gda.pl/e_doswiadczenia-pl
- Space Jump infographic - http://infografika.wp.pl/title,Wielki-skok-czlowieka-z-krawedzi-kosmosu,wid,14992499,wiadomosc.html
- Felix Baumgartner Space Jump video - https://youtu.be/ApzVaZUiRiQ
- Article *P. Borys - Modelowanie skoku z „krawędzi Kosmosu", Foton 119, zima 2012* – downloadable at http://www.foton.if.uj.edu.pl/archiwum/2012/119

auxiliary

- „Motion and forces" module from the project ICT for IST - http://ictforist.oeiizk.waw.pl/upload/Motion%20Module_PL.pdf

Description of IT and physics lessons planned as part of the project

I

IT lesson's subject: **Video-measurements – data collection and analysis with the Tracker software**
Durations: 2 hours

Condensation: Introduction to video-measurements – orientation in Tracker software, data extraction from already existing videos, chart creation and analysis.

Plan of the course

1. Introduction – explanation of video-measurements, examples of motion analysis in the Tracker software
2. Download and installation of Tracker and mechanics' video clips by the students.
3. Running the program, data extraction from a chosen video showing an object's motion – students working under teacher's supervision and with the use of manual.
4. Exporting the data to a spreadsheet.
5. Creation and analysis of motion charts.
6. Instructional video „Video analysis" – how to make a good video for video-measurements.

7. Work in groups of 2 – making one's own video (e.g. a ball rolling on the table, a pendulum) using a smartphone's camera.
8. Homework – data extraction from student-made video, chart analysis.

Didactic tools:

- Tracker program (can be downloaded from https://physlets.org/tracker/)
- Manual on how to use the program
- Exemplary mechanic's video clips (can be downloaded from https://physlets.org/tracker/download/mechanics_videos.zip)
- Camera (smartphone, tablet)
- „Video analysis" – http://server3.streaming.cesnet.cz/others/uk/mff/kdf/videoanalysis.wmv or https://vimeo.com/27475759
- Spreadsheet

II

Physics lesson's subject: **What do throwing a ball and jumping on the Moon have in common?**
Duration: 2 hours

Condensation: Experimental study of vertical upwards throw, creation and analysis of charts of motion parameters as functions of time, analysis of energy transformations, analysis of an astronaut's motion during a leap on the Moon, calculating the gravitational acceleration of the Moon

Plan of the course

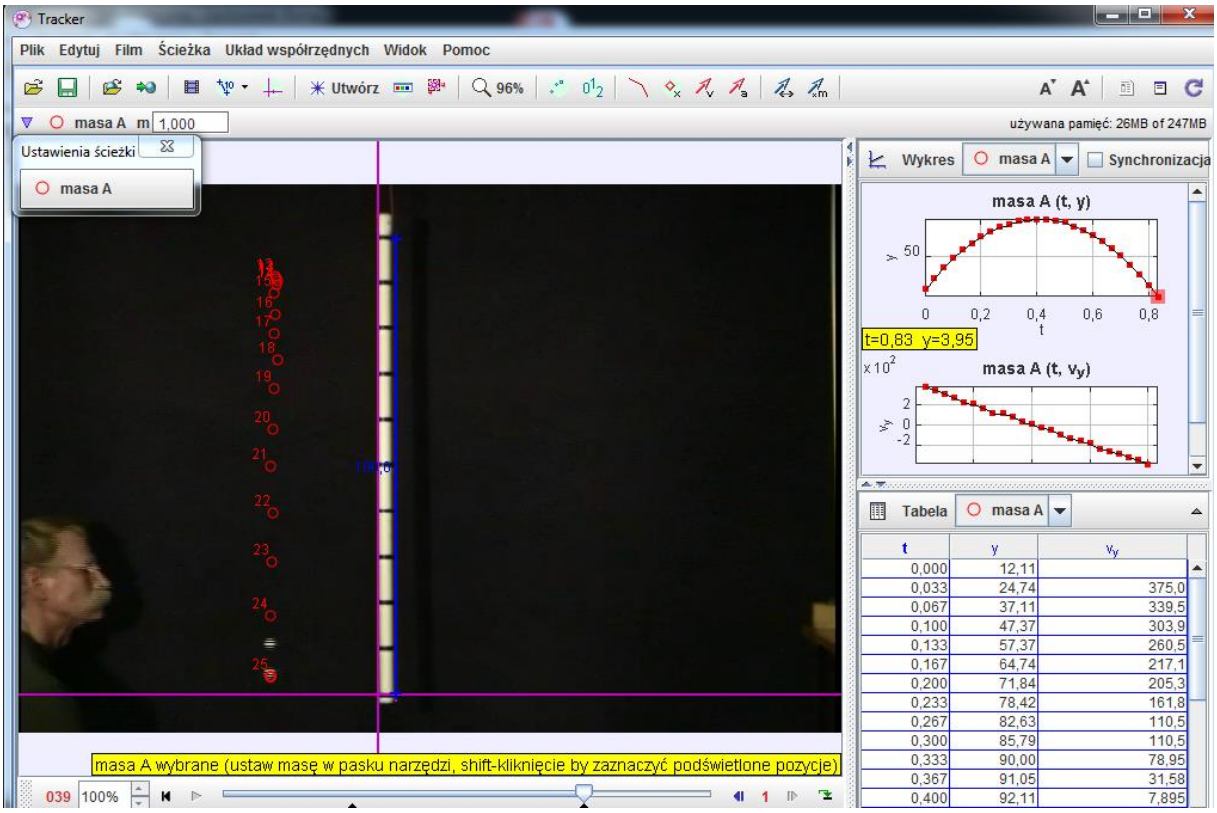
1. Introduction – students are divided into groups and assigned tasks.
2. Studying the motion of a ball thrown upwards – work in groups:
    - Filming motion of different balls, data extraction with the use of Tracker program, data analysis in a spreadsheet,
    - Measurements with an ultrasonic motion detector (optional),
    - Creating and analysing charts based on data from the spreadsheet, energy transformations analysis.
3. Summary – presentation and discussion over the measurements' results.
4. Leap on the Moon – data extraction from the video, motion analysis and discussion over the results, comparing motion charts with the charts of vertical upwards throw, calculation of Moon's acceleration
5. Comparison of vertical throw on Earth and on the Moon – exercise "Vertical throw" from the e-experiment "Throws'.
6. Summary. Homework.

Didactical tools

- Different balls, e.g. ping-pong, tennis, volleyball and basketball
- Camera (smartphone, tablet)
- Tracker program (can be downloaded from https://physlets.org/tracker/)
- Manual on how to use the program
- Exemplary mechanic's video clips (can be downloaded from https://physlets.org/tracker/download/mechanics_videos.zip)
- Data from the registration of a vertically thrown ball's position gathered with the use of an ultrasonic motion detector – file *BallThrowData.xlsx*
- Video „Leap on the Moon"
- E-experiment „Throws" – app and manual for students (can be downloaded from http://e-doswiadczenia.mif.pg.gda.pl/e_doswiadczenia-pl)
- Spreadsheet

Methodical remarks for the teacher concerning consecutive parts of the lesson

Ad 1) During the IT lessons students were acquainted with the Tracker program. It might be worth reminding them of the charts acquired during data extraction of a vertically tossed ball from the video ***BallTossUp.wmv***



Charts y(t) and v_y(t) of a vertically tossed ball acquired in the Tracker program with the use of video *BallTossUp.wmv*

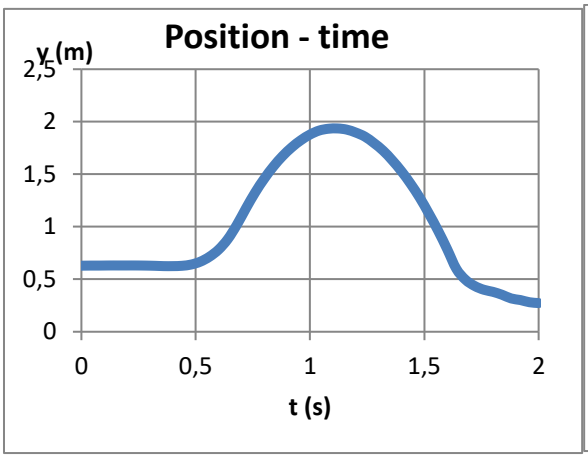
Ad 2) Work in groups.

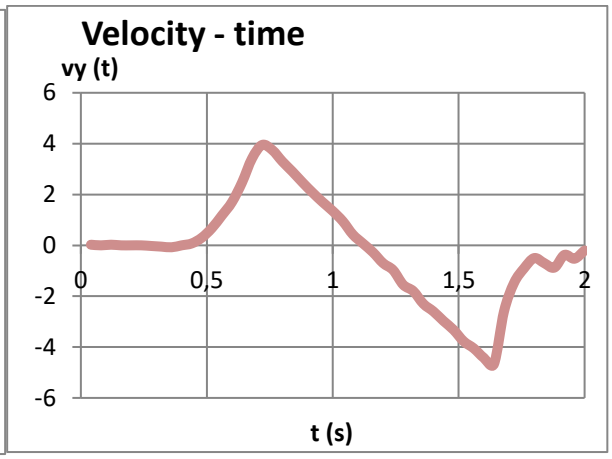
- Students film the motion of balls tossed upwards (each group has a different ball). It is crucial to have sufficiently fast cameras, background and a scale.
- Students use the Tracker program to extract data from their videos and then export this data to a spreadsheet.
- Each group has to create charts of position and velocity as functions of time and charts of kinetic and potential energy as functions of time.
- One group has to create charts based on the data gathered with the use of motion sensor.

Ad 3) Groups presenting their measurements' results. Discussion.

- Are the charts created by different groups similar? Are there any differences?
- Which mathematical functions best described the charts? Is it possible to calculate physical parameters of studied motions based on functions' coefficients?

Attention: Students should acquire the charts of position and velocity in time presented below while using the data from *BallThrowData.xlsx* file.





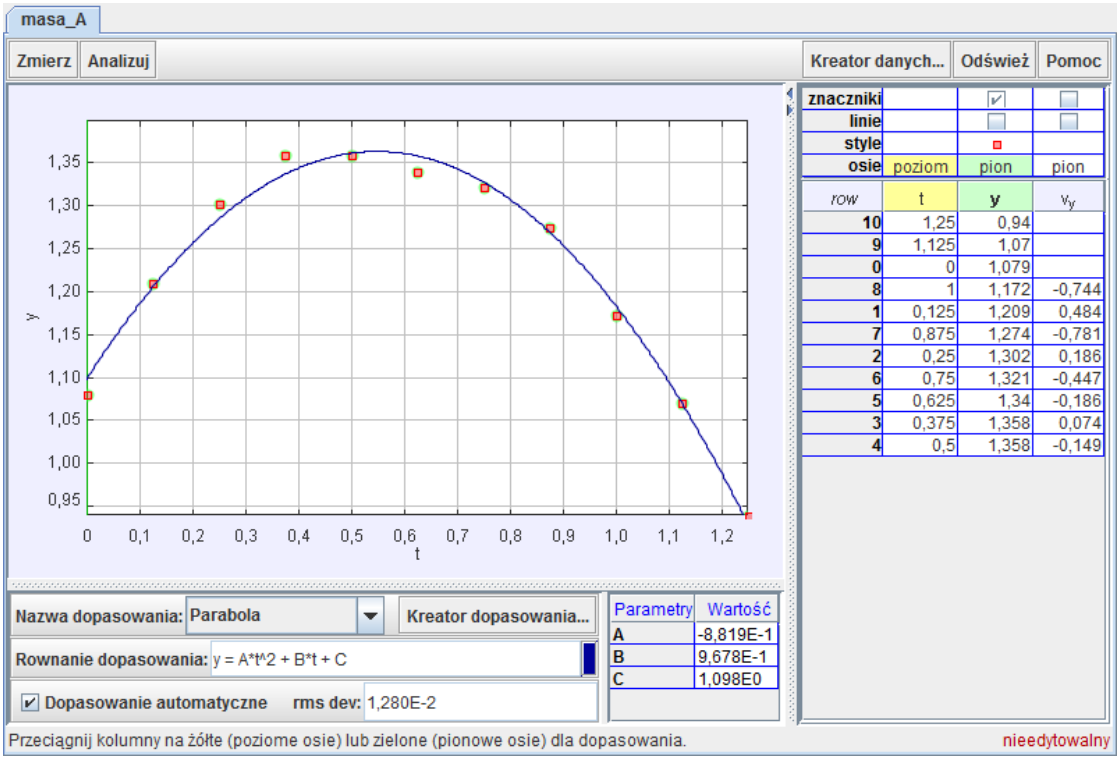
Results of the measurements of position of the upwards thrown ball achieved with the use of motion sensor (y=0) – charts in the spreadsheet

Vertical upwards throw – theory vs measurements' results

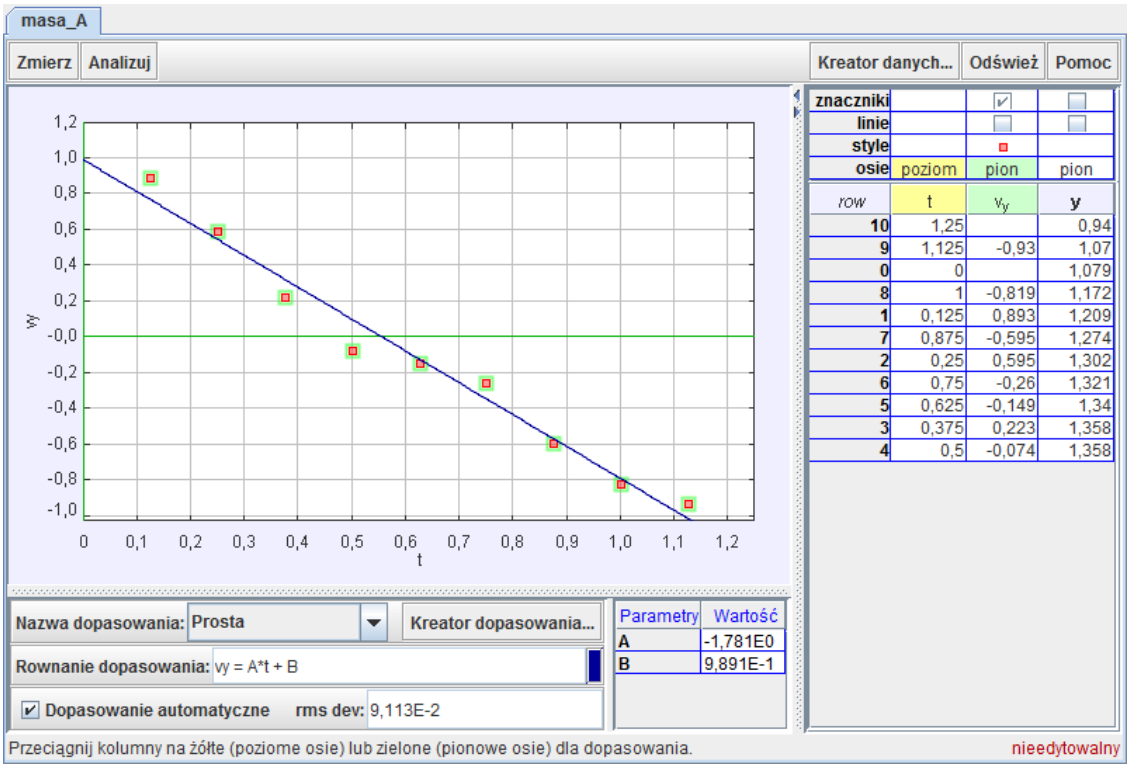
- When we ignore air's resistance the only force affecting the vertically tossed ball is a constant force F=mg directed vertically downwards.
- The chart of position in time is parabolic,
- Chart of the coordinate of velocity as function of time is a straight line,
- In the $v_y(t)$ chart alterations of ball's velocity during it's tossing and catching are also visible.

Ad 4) The teacher presents the "Leap on the Moon" video available on NASA website. Students conduct video-measurements with the use of Tracker program.
Attention: An exercise „Leap on the Moon" made as part of the project Video-measurements of the coach 6 programme has been described in the module "Motion and forces" (http://ictforist.oeiizk.waw.pl/upload/Motion%20Module_PL.pdf) created as part of the project ICT for IST.

The results of measurements of jumping astronaut's position, achieved with the Tracker program, are presented below. Matching a quadric function with y(t) chart or linear function with v(t) chart allows the calculation of Moon's gravitational acceleration.



Analysis of the "Leap on the Moon" video in Tracker program. The quadric equation matched with y(t) chart shows that the Moon's gravitational acceleration equals about 1,76 m/s^2 (2A).



Analysis of the "Leap on the Moon" video in Tracker program. The slope coefficient of the straight line matched with v_y(t) chart equals – 1,78, which means that the Moon's gravitational acceleration approximated with this chart equals about 1,78 m/s^2.

Ad 5) Studying the vertical toss on both Earth and Moon – exercise “Vertical toss” with the use of e-experiment “Throws”.

The teacher or a selected student prepares the set for e-experiment “Vertical toss”

Questions for the students:

- What will be the shapes of charts of ball’s position as function of time when thrown vertically upwards with the same velocity on both the Earth and the Moon?
- What are the differences between those charts?
- Are the times of motion of the ball on the Earth and on the Moon the same?

The teacher or a selected student runs the app and the students’ answers are verified.

Ad 6) Summary

- Charts of position as function of time for a ball tossed upwards have a parabolic shape just like the chart of position as function of time of a selected point of an astronaut’s backpack during his jump on the Moon.

- Charts of the coordinate of velocity as function of time in both cases are linear. Their slope coefficients are different due to different values of gravitational acceleration.

- Charts of position as function of time of balls with different diameters are not symmetrical. It is the effect of air resistance.

Homework

- Searching information on parachute jumps: history, achieved records and laws of physics.

- Preparing two presentations concerning the physics of parachute jumps (for volunteers).

III

Physics lesson's subject: **„Space" jumps**
Duration: 1 hour

Condensation: Students' presentations concerning parachute jumps and achieved records are the starting point of motion analysis with inclusion of air resistance and the introduction of the maximal velocity term.

Plan of the course

1. Introduction – video and an infographic "Felix Baumgartner's space jump".
2. Students' presentations concerning parachute jumping.
3. Experiments in groups of 2:
    a. Observation of motion and measurements of time of falling of objects having the same mass but different shapes (different areas of cross sections)
    b. Observation of motion and measurements of time of objects having identical shapes but different masses.
4. Presentation of the results of students' experiments.
5. Discussing the role air resistance plays during an object's fall and characteristics of resistance force's dependence on velocity, introducing the term of maximal velocity.
6. Calculating exercise – students check selected numeric data on the "Leap from space" infographic.
7. Introduction to motion modelling on IT lessons – how to describe object's movement with changing net force?

Materials:

- Leap from space infographic - http://infografika.wp.pl/title,Wielki-skok-czlowieka-z-krawedzi-kosmosu,wid,14992499,wiadomosc.html
- Video "Felix Baumgartner's space jump" - https://youtu.be/ApzVaZUiRiQ
- Article *P. Borys – Modelling the jump from the edge of space, Foton 119, winter 2012* – downloadable at http://www.foton.if.uj.edu.pl/archiwum/2012/119

IV

IT lesson's subject: **Numeric modelling. Creation of a parachute jump model in a spreadsheet.**
Duration: 2 hours

Condensation: Introduction to numeric modelling. Creation of a parachute jump model in a spreadsheet.

Plan of the course:

1. Introduction – what is numeric modelling and when is it used.
2. Elaboration on the algorithm used to calculate the value of position and velocity of objects affected by changing forces.
3. Creation of a simplified model of a parachute jump in a spreadsheet under teacher's supervision (manual).
4. Creation and analysis of charts for different values of model's parameters. Comparison of the results with actual data concerning parachute jumping.
5. Modification of the model – inclusion of the phase before parachute's opening.
6. Comparison of the results with actual data.
7. Summary – examples of phenomena that can be described with the use of created models.

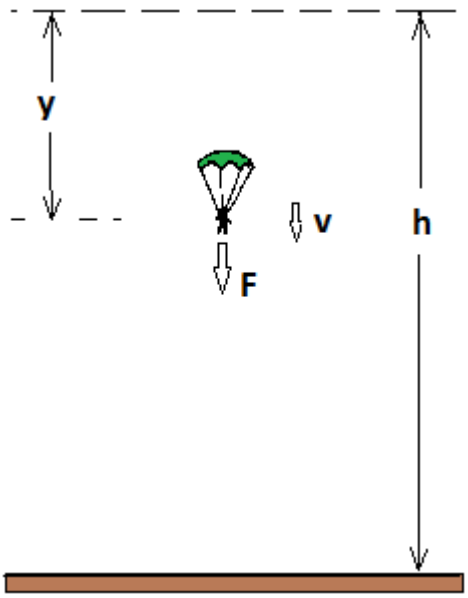
Materials:

- Description of a parachute jump model's creation in a spreadsheet.
- File *ParaJump.xlsx*
- Article *P. Borys – Modelling the jump from the edge of space, Foton 119, winter 2012* – downloadable at http://www.foton.if.uj.edu.pl/archiwum/2012/119

Parachute jump – creation of a model in a spreadsheet

https://cdn.pixabay.com/photo/2012/10/26/01/43/parachute-63045_960_720.jpg

Assumptions: In a simplified model we assume that the parachute opens right after jumper leaves the plane. We do not include the short period of time when he is freefalling.



Symbols:

h – altitude at which the jumper leaves the plane
t – time
y – distance travelled in time t
v – velocity at which he is falling after time t
m – combined mass of the jumper and parachute
d – parachute's diameter
Original conditions: t = 0, y =0, v = 0.

The jumper is affected by a constant force of gravity (m*g) and the force of air's resistance proportional to the squared velocity and the shape and area of the parachute's cross-section. The net force F, acting vertically downwards, is represented by the following formula:

$$F=m*g - b*v*v*d*d$$

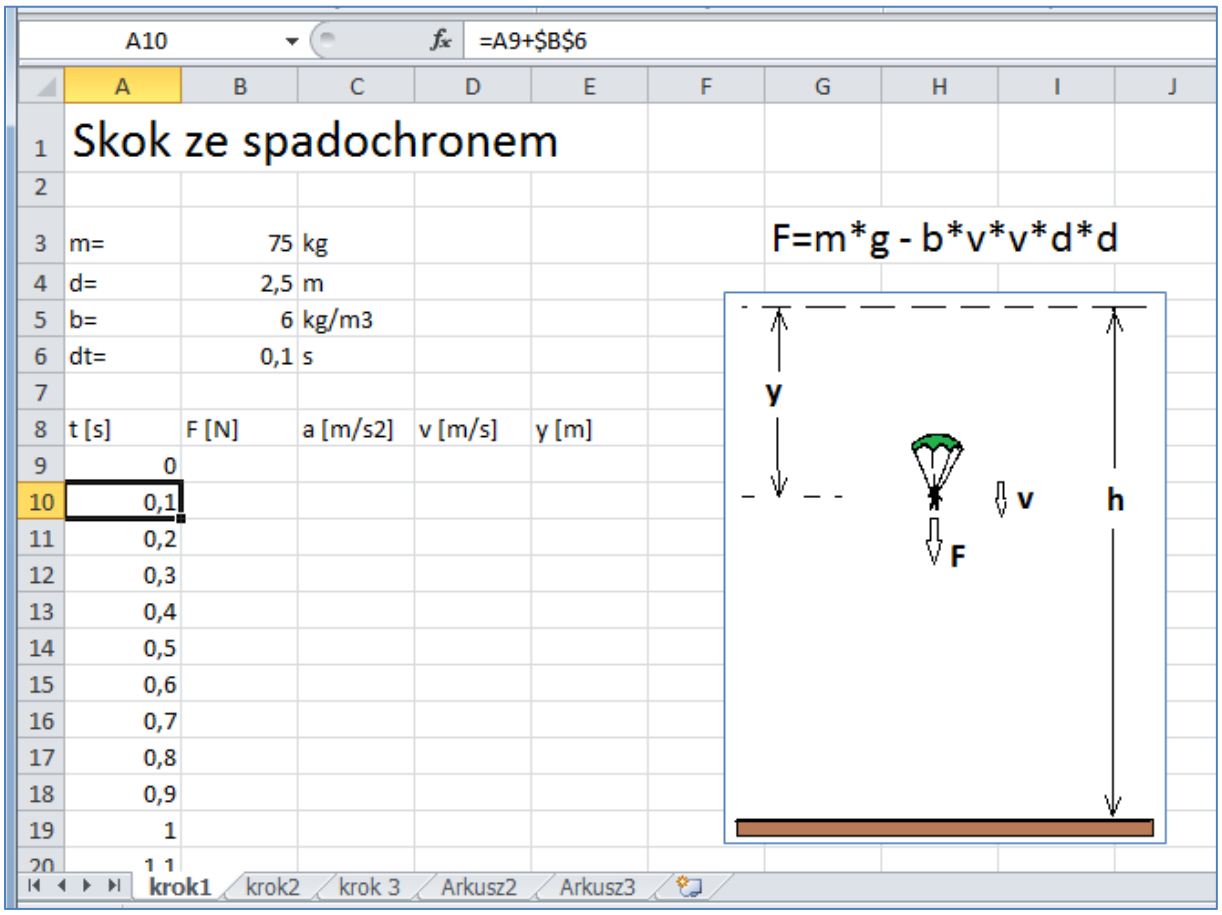
The coefficient b depends on the viscosity of the air and the shape of the parachute. Net force changes in line with the velocity, so it is imperative that we calculate consecutive values of position,

velocity and acceleration for short periods of time dt.
We assume the values of constants and parameters which can be changed later on in the model:
m = 75 kg
d = 2,5 m
g= 9,81 m/s^2
b =6 kg/m^3
dt = 0,1 s

The model will be constructed step by step according to the following algorithm:
$F=m*g - b*v_p*v_p*d*d$
$a = F/m$
$v = v_p + a*dt$
$y = y_p + v*dt$
$t = t_p + dt$
Consecutive values of variables will be calculated in corresponding rows of the spreadsheet (v_p, y_p, t_p denote values of variables in previous rows).

The following pictures show the consecutive steps of creating the model in the spreadsheet.

Step 1 – we input data and parameters, which are completely changeable; we fill out the time column (t) calculating following values of time (until t=6s) at each time step dt.



Step 2 – We calculate value of the force of gravity and fill out the original variables' values for t = 0.

B9 | f_x =9,81*B3

	A	B	C	D	E	F	G	H	I
1	Skok ze spadochronem								
2									
3	m=	75	kg				F=m*g - b*v*v*d*d		
4	d=	2,5	m						
5	b=	6	kg/m3						
6	dt=	0,1	s						
7									
8	t [s]	F [N]	a [m/s2]	v [m/s]	y [m]				
9	0	735,75	9,81	0	0				
10	0,1								
11	0,2								

Step 3 – We fill out the next row of spreadsheet with formulae. Addresses of cells containing values that should remain the same during copying should be preceded with the sign $ (np. B3).

B10 | f_x =9,81*B3-B5*B4*B4*D9*D9

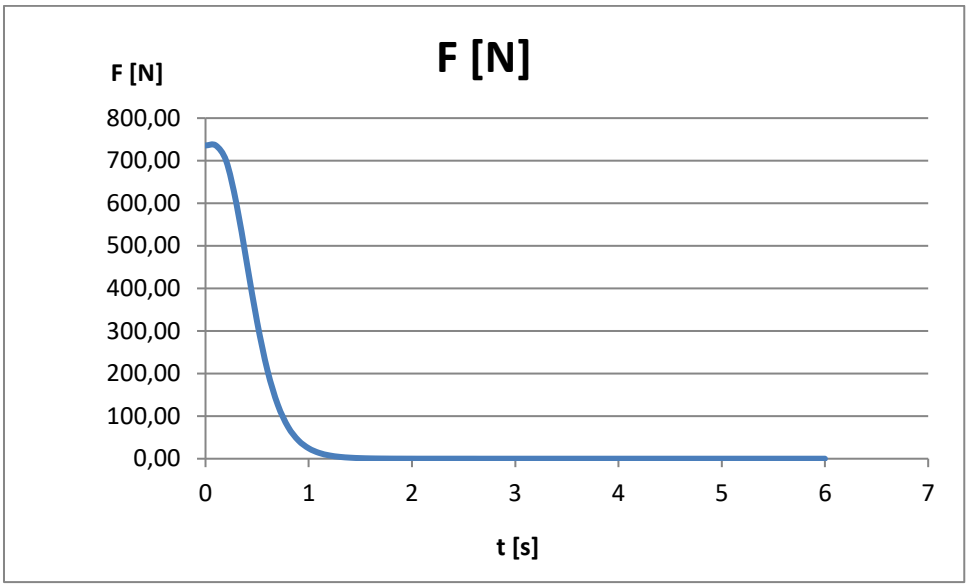
	A	B	C	D	E	F	G	H	I
1	Skok ze spadochronem								
2									
3	m=	75	kg				F=m*g - b*v*v*d*d		
4	d=	2,5	m						
5	b=	6	kg/m3						
6	dt=	0,1	s						
7									
8	t [s]	F [N]	a [m/s2]	v [m/s]	y [m]				
9	0	735,75	9,81	0	0				
10	0,1	735,75	9,81	0,981	0,0981				
11	0,2								

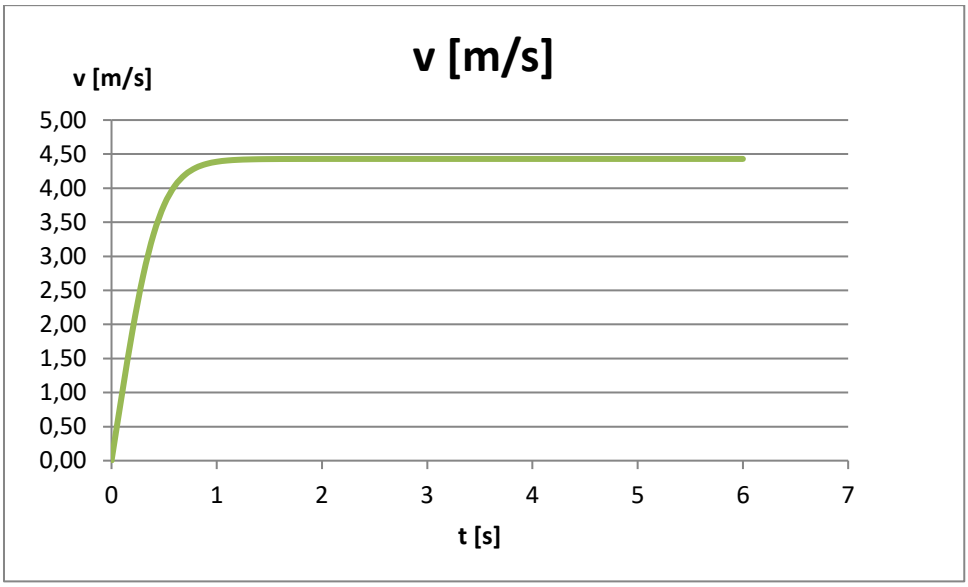
The next cells of row 10 should be filled out with the following formulae:

Cell's address	Formula
B10	=9,81*B3-B5*B4*B4*D9*D9
C10	=B10/B3
D10	=D9+C10*B6
E10	=E9+D10*B6

We calculate the remaining values by copying the formulae to the next rows of the table. We set the precision of calculated values to 2nd decimal place.

We create charts of force and velocity as functions of time.





Changes of mass or other parameters allow us to study how they affect the change of maximal velocity.

Students should look for typical values of the parameters and see how their changes affect the created charts.

Additional task.

Changing the model in way that includes the movement of the jumper before the opening of his parachute.