

# Jumping on a scale



## Data acquisition (TI 83/TI84)

### Objective:

In this experiment our objective is to study the forces acting on a scale when a person jumps on it. The scale is a force probe connected to a CBL or a LabPro.

### Procedure:

- Before setting up the experiment make sure that you have the program [JUMP4S](#) in your TI-83/TI84 calculator. If not, download it. Short instruction on how to download [here](#).
- Step up on the scale
- Start the program JUMP4S and follow the instructions given at the screen. It is important that you do not move during the first phase of the experiment. When it is time to jump the calculator screen will tell you to do so. Now 200 data points will be collected at a rate of 100 points per second.
- When the experiment is finished the calculator screen will show a graph. The y-axis is the force acting at the scale in newtons and the x-axis is the time in seconds. Force data are stored in list L2 and time data in list L1. In list L3 you will find calculated values namely the net force acting at the jumper. These values are calculated from the readings of the forces at the scale by subtracting the weight of the jumper. And how is this weight known to the calculator? As you remember from above you were requested to stay still during the first phase of the experiment. Here your weight was recorded.



If you are unable to conduct the experiment there are files set up so that you can study the experiment and analyse previously collected data. Your options are shown below:

- [Get data to your TI83 or TI83 Plus](#). Short instruction how to download. Download data file [SCALEJUM](#).
-

# Jumping on a scale



## Data analysis (TI 83/TI84)

If you have any problems handling the graphing calculator help is available using the links that are underlined and highlighted in blue.

### Analysis 1: Discussion of the force on the force plate

Study the graph and try to figure out where the jumping person is at different times. Doing this, bear in mind that the force measured is the force on the scale. The following questions might help you.

- First there is a well defined plateau. What is the level of this and what does it mean?
- Next you see a dip in the force readings. Why?
- Find the minimum value during the first dip. What position of the jumper does this correspond to? How about the forces acting on the jumper?
- Try to find the following positions for the jumper:
  - when he is farthest down, before straightening his legs and goes upwards.
  - when he leaves the scale.
  - when he lands again.
- After landing the curve is not stable. Can you find the reason for this?
- What about the forces acting on the jumping person. Draw pictures including force-arrows of the jumper when he:
  1. Kneels in the beginning.
  2. Has almost left the scale.
  3. Is in the air, going up.
  4. Has just landed on the scale again.

### Analysis 2: Discussion of the force on the jumping person

Next step is to graph the net force acting at the jumper as a function of time. In our last exercise in analysis 1 we looked at forces on the jumper and in all four cases the weight was the same and the force from the scale differed. We can calculate the net force by subtracting the weight of the person from the readings from the scale. The weight is stored in F on the calculator and the subtraction has been made in the program. The net force, in Newton, is stored in list L3. [Make a graph of L3 versus L1.](#)

Compare this graph with the previous one. When do you have maximum, zero and minimum force?

### Analysis 3: The velocity of the jumper

In the previous section we graphed the net force as a function of time. Since momentum is the product of force and time and the initial momentum of the jumper is zero, the integral to any arbitrary interval end of the force-time-function is the momentum of the moving body at this moment. However, the graph is not a smooth one and it is impossible to fit a mathematical function to it. This means that we have to calculate the integral in a numerical way.

Let us approximate the force as constant during each short time interval. This means that the change in momentum can be calculated as  $F \cdot \Delta t$  in each interval. The time between two points is 1/100 of a second. Therefore we obtain the change in momentum by multiplying the elements of list L3 with 0.01. By writing  $L3 * 0.01 \text{ STO } L4$  at the home screen this is done and the result is stored in list L4.

Now we can sum the changes in momentum to get the total momentum at every time. In the beginning of the study the jumper is at rest and the momentum is 0 kgm/s. After the first 1/100 of a second the momentum has changed with the amount in L4(1). The next 1/100 of a second we add the momentum in L4(2) and so on. This is a cumulated sum of terms and there is a command (CumSum) for doing it on the calculator. The easiest way to find the command is in the catalogue and writing  $\text{CumSum } L4 \text{ STO } L4$  on the home screen will perform the operation and place the result in List L4, replacing the momentum changes that we had there before. The reason that we use list L4 again is that we need L5 and L6 later.

If you want to you can view the result by graphing L4 versus L1.

Having the momentum it is fairly easy to calculate the speed of the jumper at any given time.

We have that the momentum is: and thus . The weight of the jumper is stored in variable F.

To calculate the mass we simply divide the weight by 9.82. Since list L4 contains the momentum we get the velocity by:  $L4 / (F / 9.82) \text{ STO } L4$ . We now have the velocities in list L4.

[Make a graph of the velocity versus time.](#) Study the graph and try to figure out where the jumping person is at different times. How does it look if you compare it to the force-time-graph?

- Find the times corresponding to 0 velocity. Where is the jumper at these occasions? Go back to the first F(t)-graph and find the same points. Is it the points you had expected?
- There is a linear part in the middle. What does this mean? Can you guess the slope of the line? You can use the command [Select](#) to study a portion of the graph. Use linear regression to [fit a straight line to it](#). Is the slope what you had expected?

When you have finished your analysis you can compare it with this [completed analysis](#)

---

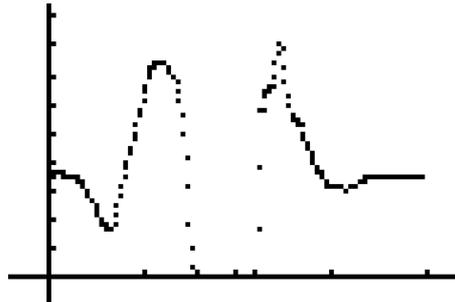
## Jumping on a scale



### Completed analysis (TI83/TI84)

#### The force on the force plate

The result of the jump that is available on the internet is shown below.



In the beginning there is a plateau when the person is standing still. The force level corresponds to the weight of the person. Before the jump this is measured and stored in register F on the calculator. In this case it is 887 N corresponding to a mass of 90.3 kg. Next in the graph is the dip as the jumper moves downwards bending his knees. The force from the plate will be reduced in order to get a downward directed net force and thus a downward acceleration. At the minimum the force is from the scale is 421 N giving a net force of  $887 \text{ N} - 421 \text{ N} = 466 \text{ N}$  downwards. Now the person is accelerating downwards with the acceleration

$$a = 466 / 90.3 \text{ m/s}^2 \approx 5.2 \text{ m/s}^2.$$

Now the jumper pushes away from the scale, but he is still accelerating downwards. Note that the point where he is back at 887 N only means that the acceleration is 0. He is still on his way down. As a matter of fact he is now at his largest downward speed. The lowest point is not reached until close to the top of the force-time graph.

The maximum force reaches 1870 N giving an upward acceleration of more than  $10 \text{ m/s}^2$ ,  $g$ . After this the force decreases until the jumper loses contact with the force plate at approximately  $t = 0.79 \text{ s}$ . From now until  $t = 1.10 \text{ s}$  he is air-bound. The air-ride lasts for 0.31 s.

At the time 1.10 s there is a safe landing. Once more the person is in contact with the scale, as can be seen from the readings. The maximum force on the scale during the landing is approximately 2000 N at  $t = 1.23 \text{ s}$ . After that there is a final swing around a certain value, the person's weight. The swing is the result of the damping in the spring coil in the force plate.

## The net force on the jumping person

The next step is to graph the net force on the jumper. As is easily understood the result is just a vertical shift of the previous graph.



We see that the net force is 0 at the beginning and at the times 0.40 s, 0.73 s and 1.12 s. These values can be found using TRACE on the graph.

The minimum forces are at 0.33 s and in the interval 0.79 s – 1.10 s. The first one is during the "kneeing" and the second is when the jumper is air-bound. Hence the net force is 880 N, close to --887 N, that is a downward force of 880 N, which is the force of gravity acting on the person. The acceleration is  $a = 880 / 90.3 \text{ m/s}^2 \approx 9.7 \text{ m/s}^2$ .

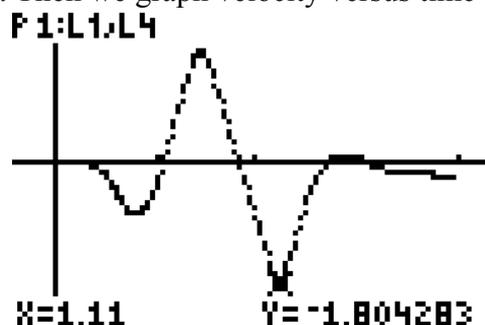
During landing there is a maximum net force on the jumper that is 1120 N. The upward acceleration on the jumper at this moment exceeds  $g$  and is  $a = 1120 / 90.3 \text{ m/s}^2 = 12.4 \text{ m/s}^2$ .

## The velocity of the jumping person

At the beginning the jumper is at rest. Hence the velocity is 0 and the momentum is 0 as well. A momentum change in an interval is calculated as the impulse on the body during this time interval. The net force is in list L<sub>3</sub> and the time interval is 0.01 s. The change in momentum is given by the net force times 0.01 as described in the analysis.

If we sum the momentum changes up to a certain time we get the momentum at that time. The first change gives the momentum after 0.01 s. The sum of the first two changes gives the momentum at 0.02 s and so on. The function to make this sum is the cumulated sum (CumSum) as described in the analysis.

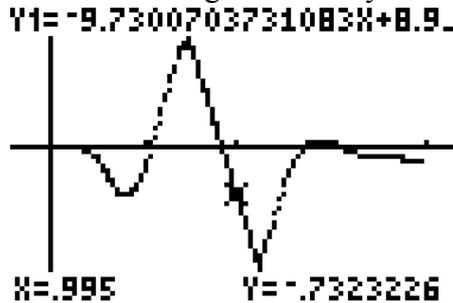
We now have a list with the momentum of the body at any given time and from this we can calculate the velocity at any given time. We do this by dividing the momentum with the mass as described in the analysis. Then we graph velocity versus time and get this:



Observe that the minimum velocity is at  $t = 0.40 \text{ s}$ . This is where the net force on the jumper is 0 and changes direction as discussed before. The maximum velocity at  $t = 0.73 \text{ s}$  occurs the next time the net force is 0.

At  $t = 0.79$  s the jumper leaves the scale and is air-bound for 0.31 s. In the graph we see this as a straight line. This is because the only force acting on the jumper is gravity and with a constant force we get a uniformly accelerated motion.

To find the slope of the linear part we [select](#) it and make a [linear regression](#) on the selected part. If we draw the regression line in the original velocity-time-graph it will look like this



The regression equation has a slope of  $-9.73 \text{ m/s}^2$ , which is reasonably close to the expected  $9.82 \text{ m/s}^2$ .

Another interesting thing to note is that the speed when leaving the scale is smaller than the speed when the jumper lands.  $1.67 \text{ m/s}$  compared to  $1.80 \text{ m/s}$ . This probably depends on how you jump and how you land. When you leave the scale you are in your most upright position, Legs stretched and toes barely touching the scale. When you land you try to do it soft with slightly bent knees. This give you a slightly longer way down than up, thus giving you more time to accelerate and a larger speed.

---