

Investigating Force and Acceleration with an Action Man[®] Bungee Jumper

Introduction



Figure 1 Beginning the fall
(Photograph courtesy Glyn Jones, York College)

Bungee jumping as we know it today started when the Oxford Dangerous Sports Club made a jump from the Clifton Suspension Bridge in Bristol back in April 1979. However, the origin of such jumps goes back centuries to the 'land divers' of Pentecost Island, one of the many islands making up Vanuatu north east of Australia. These 'land jumpers' used vines to support their jumps.

Since 1979 bungee jumping has become very popular, often just to provide exhilaration, but sometimes linked with raising money for charities. Jumps can be from bridges, towers, cranes and balloons. You might even recall seeing such a jump in the Bond film *GoldenEye* which, in 2002, was voted the best movie stunt.

The bungee cords are specially made for the task and are designed to stretch to two, three or even four times their original length. There are two main types, sheathed (often called *shok* or *mil-spec*) and all-rubber. The former have a rubber core encased in a cotton or nylon sheath and, depending on the weight of the jumper, between three and six of these would be bundled together. The all-rubber cords are made up of over one thousand individual strands of rubber tied together to form one solid core.

Modelling a bungee jump is not difficult to do once a good match has been found between a length of rubber cord and whatever is to do the 'jump' – in this activity an Action Man[®] toy. Other popular 'jumpers' include Barbie[®] dolls, teddy bears and Lego[®] people.

The Physics of Bungee Jumping

It is all about work and energy transfer. As the jumper leaves the platform and falls, so the gravitational field around him/her does some work. Initially this work speeds up the jumper (and the attached cord) but, as the cord goes taut, so even more work is done in stretching it, with energy being transferred in the process. Eventually, at maximum stretch, the cord then begins to do work against the gravitational field and moves the cord and the jumper back upwards, again transferring energy in the process. They then reach a height (lower than that from which the jump was made) when there is a momentary stop before the gravitational field does work on them again making them fall. If there was no sound, no air resistance and no heating of the bungee cord or the atmosphere, then the up and down oscillations would go on for ever. However, sound, heating of the atmosphere due to air resistance and heating of the rubber (try stretching a rubber band quickly several times and then touching your lips to it) and the atmosphere, all involve transferring energy away from the bungee rope. Therefore the oscillations eventually cease.

The tasks

Your tasks will be to investigate the following:

- how the force on a bungee jumper cord changes during a jump
- how the acceleration of a bungee jumper changes during a jump
- how the forces and accelerations are related during a bungee jump.

Measuring forces

Most of the force sensors available to schools and colleges to use with dataloggers are based on the use of strain gauges, as is the one that you will use here. A common form of strain gauge consists of very thin metal foil bonded to a slightly flexible surface as shown in Figure 2. They can vary in size from less than a millimetre to 10cm long.

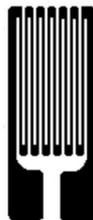


Figure 2 Strain gauge

As a force is exerted on that surface making it bend, so the metal foil stretches and increases in resistance. Incorporated in an electronic circuit this change of resistance produces a change of output voltage which is measured by the datalogger.

Force sensors can also be based on the piezoelectric effect. Such devices are usually made of a piezoelectric crystal of the ceramic PZT-5A (lead zirconate titanate) used in ultrasound imaging for both the production and reception of ultrasound. This device behaves in a similar way to a piezoelectric gas-lighter which, when its 'trigger' is squeezed, generates a large electric charge. This charge in turn produces an electric field and a voltage across the crystal resulting, in the case of the gas-lighter, of a spark jumping a small gap to light the gas. Figure 3 overleaf shows

the piezoelectric force sensor used on the Huygens probe to Saturn's largest moon Titan. As the probe penetrated the surface of Titan it measured the varying impact force to give an idea of what the surface might be made up of. The recorded voltages related to the impact forces.



Figure 3 Force sensor on the Huygens probe
(Courtesy Planetary and Space Sciences Research Institute, The Open University)

Measuring accelerations

To measure the acceleration of the model bungee jumper you will use the ultrasonic distance or motion sensing device called the ALBA Ranger, shown in Figure 4. It also makes use of piezoelectric crystals. A changing high frequency voltage fed to the transmitter makes its crystal expand and contract so producing an ultrasound pulse. The reception of an ultrasound pulse by the receiver causes its crystal to change in size and so produce a changing voltage. Hence the motion of an object reflecting such pulses can be detected.



Figure 4 ALBA Ranger ultrasonic motion sensor

Such sensors were first developed for Polaroid[®] autofocus cameras but are now produced for many dataloggers and robotic devices too. They work by sending out pulses of ultrasound at around 50kHz - a frequency beyond our range of hearing. By timing how long the pulses take to bounce back from an object, and knowing how fast (at the speed of sound) the pulses travel, the distance away of the object can be calculated. By plotting what is known as the second derivative with respect to time of the Distance-time graph an Acceleration-time graph is obtained - the computer programme deals with this automatically.

There are devices which measure acceleration directly and these are known as *accelerometers*. The ones which you are most likely to come into contact with consist of an integrated circuit (i.c.) in which, at a very small scale, there exists a central plate suspended on polysilicon springs positioned between two fixed plates. The central plate is attached to a mass and can move further into or out of the space between the fixed plates. This system is much like a parallel plate capacitor and indeed it works like one with the moving plate changing the capacitance as it alters its position. This change of capacitance, when linked to some electronic circuitry, affects the accelerometer's output voltage – the greater the acceleration the higher the output voltage and vice versa.

Another common means of producing an output voltage related to acceleration is with a mass bonded to a piezoelectric crystal, the same type of crystal as in the force sensor on the Huygens probe mentioned earlier. In an acceleration or deceleration the mass compresses or decompresses the crystal and so varies its output voltage in a manner which relates to the acceleration or deceleration it is sensing.

Unfortunately such devices do not initially appear to work as you might expect when used in the vertical plane. They are usually set up to measure what is commonly called the *g-force* which, when an accelerometer is held stationary in the vertical plane causes them to read $\pm 1g$ or $\pm 9.8\text{m/s}^2$, the + or – being dependent on which way up the accelerometer is pointing and the manufacturer of the accelerometer. In each case you might well have expected it to read 0m/s^2 . To get such a device to measure true acceleration in the vertical plane you then need to either add or subtract 9.8m/s^2 from all the data. Then, if the accelerometer reads $+9.8\text{m/s}^2$ when held stationary in the vertical plane, subtracting 9.8m/s^2 will bring its value to 0m/s^2 . If it reads -9.8m/s^2 when held stationary in the vertical plane adding 9.8m/s^2 will bring its value to 0m/s^2 too. Repeating the process with all the data will give values of the true vertical acceleration. You will not have to concern yourself with this here as you will not be using this type of sensor.

Setting up your investigations

If it has not already been done, first clamp the 'jumping platform' in a bosshead at the top of a retort stand as shown in Figure 5. Clamp the retort stand base firmly to a table or bench top with a G-clamp so that the 'jumping platform' overhangs the edge of the table.



Figure 5 'Jumping platform' mounted on retort stand

Mount the Force sensor on the protruding piece of dowel rod on the 'jumping platform' as shown in Figure 6, and set it to its $\pm 10\text{N}$ range.



Figure 6 'Jumping platform' with Force sensor attached

Now, unless it has already been done for you, firmly secure one end of the rubber (model bungee) cord to the Action Man's[®] feet. The length of this cord will need to be such that, on being dropped, the model bungee jumper falls to a height of around 25cm above the floor. **It must not hit the ultrasonic motion sensor.** Attach the other end of the rubber cord to the hook on the base of the force sensor.

Now place the ALBA Ranger ultrasonic motion sensor on the floor pointing directly upwards towards the model bungee jumper. You will need to place some Plasticene[®] or BluTack[®] underneath the ALBA Ranger to make it point in the right direction towards the Action Man[®]. Stick a square of plastic card onto the Action Man's[®] head or helmet to reflect the ultrasonic pulses as shown in Figure 7.

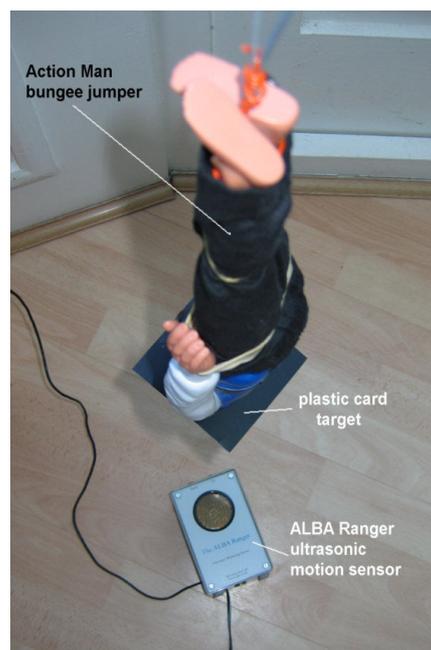


Figure 7 Action Man[®] with plastic card target attached and The ALBA Ranger ultrasonic motion sensor below

Connect the ALBA Ranger by serial or USB cable to a computer, plug in its power supply and switch **ON**. Similarly connect the ALBA Interface and Logger by serial or USB cable to the same computer, plug in its power supply and switch **ON**. Plug the Force sensor into Port 3 of the Interface and Logger. It should now all appear as in Figure 8.



Figure 8 Setup of the ALBA Ranger with the ALBA Interface and Logger and a Force sensor

NOTE: Instructions for use with a computer connected to a network may differ.

Switch **ON** the computer. You will need to launch two versions of the ALBA software and this is achieved in a rather different manner to usual. **Do not click on the screen icon.** First hold down the **Ctrl** key on the computer keyboard, click the cursor on **Start**, then **Programs**, then **ALBA** and finally **djb ALBA** in the drop-down menus that display. This will launch either the ALBA Ranger Startup screen and box or that of the ALBA Interface and Logger, both of which will look like that shown in Figure 9.

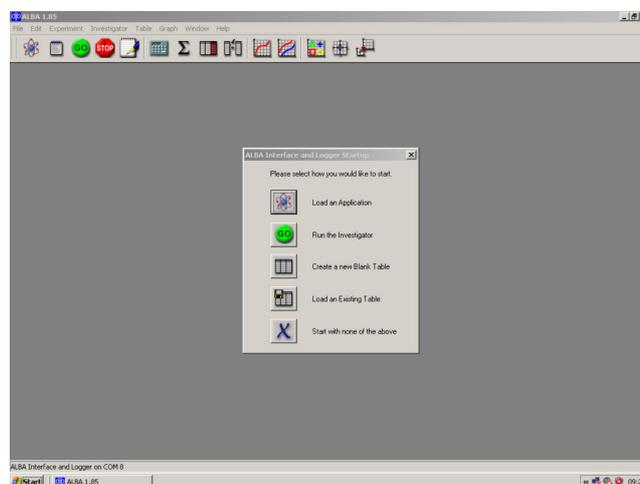


Figure 9 Startup screen and box

Click on the **Start with none of these** icon  and then click the Restore Down icon  in its top right-hand corner to reduce its size but then use the cursor (held down and dragged) to expand the screen to near half full size as in Figure 10.

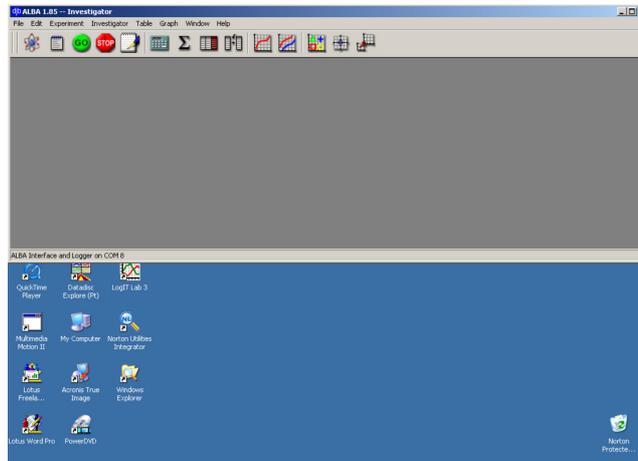


Figure 10 Startup screen now filling half the total screen

Again hold down the **Ctrl** key on the computer keyboard, click the cursor on **Start**, then **Programs**, then **ALBA** and finally **djb ALBA** in the drop-down menus that display. This will launch the other Startup screen for either the ALBA Interface and Logger or ALBA Ranger – whichever did not display before. Again it will look much like that of Figure 9.

Click on its **Start with none of these** icon  and, as before, click on the Restore Down icon  in its top right-hand corner to reduce its size but then use the cursor (held down and dragged) to expand it to fill the remaining half of the screen as in Figure 11.

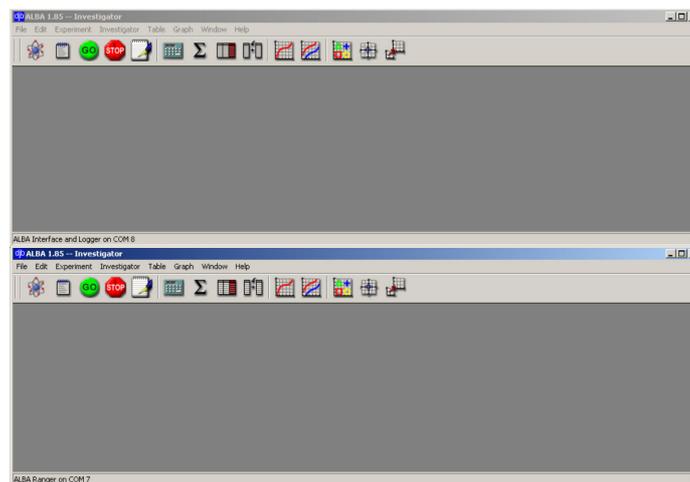


Figure 11 Startup screens now both displayed

Click the **GO** icon  in the Toolbar of the ALBA Ranger section of the screen to display the ALBA Ranger Setup box of Figure 12 overleaf. The bottom left-hand corner of each section of the screen indicates whether it is for the ALBA Ranger or the ALBA Interface and Logger.

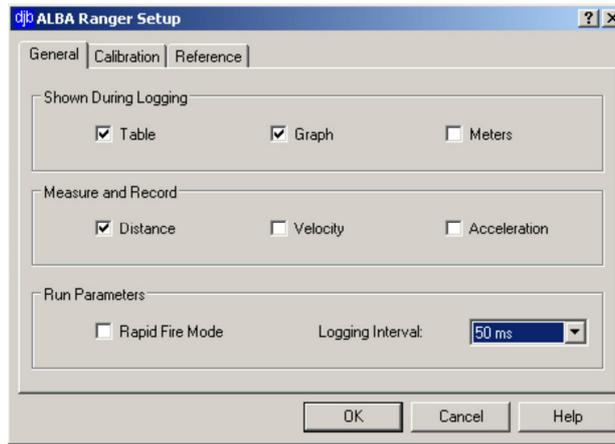


Figure 12 ALBA Ranger Setup box – General tab

The General tab should be displayed. Select on it, by clicking in the boxes, just Graph and Acceleration, leaving all other boxes unticked. Use the down-arrow to select a Logger Interval of 100ms. It should now appear as in Figure 13.

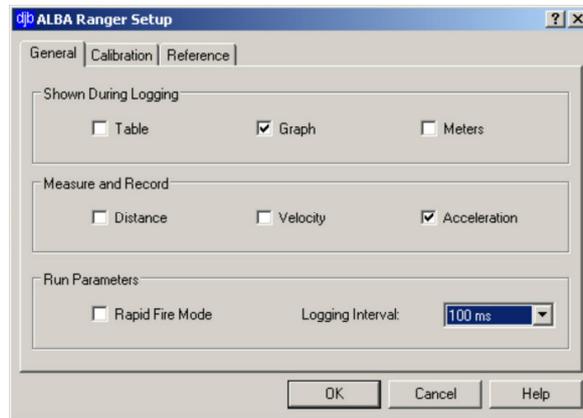


Figure 13 ALBA Ranger Setup box – General tab – options selected

Now click on the Calibration tab to display the Calibration box of Figure 14.

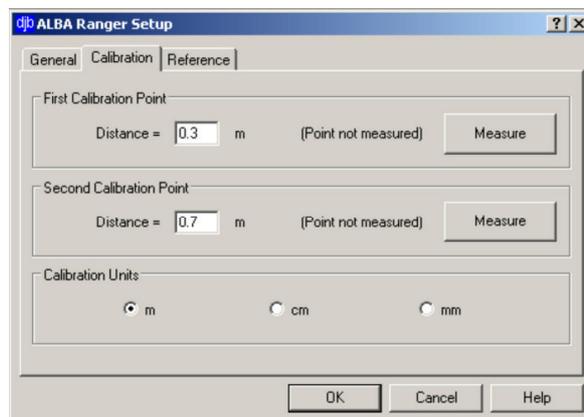


Figure 14 ALBA Ranger Setup box – Calibration tab

Select Calibration Units of metres by clicking in the 'm' radio button. Type in (if not already shown) the First Calibration Point distance of '0.50' m and the Second Calibration Point distance of '1.00' m as in Figure 15 on the following page.

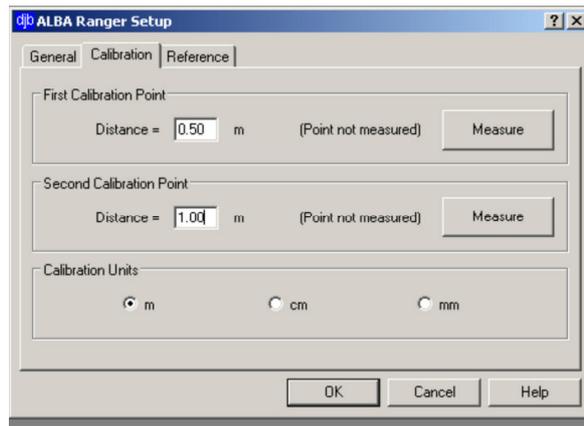


Figure 15 ALBA Ranger Setup box – Calibration tab – First and Second Calibration points

Place the model bungee jumper on the top of the 'jumping platform'. Now arrange a flat surface (a book) at 0.50m above the ultrasound sensor for the First Calibration Point and click its **Measure** button. Arrange the flat surface at 1.00m above the ultrasound sensor for the Second Calibration Point and click its **Measure** button. These two measurements will have calibrated the ultrasound sensor so that it will accurately measure distances.

You now need to set up the ultrasound sensor so that measurements of distance are made from the plastic card target attached to the bungee jumper's head/helmet instead of from the sensor itself. To do this click the Reference Point tab to reveal the Reference Point box of Figure 16.

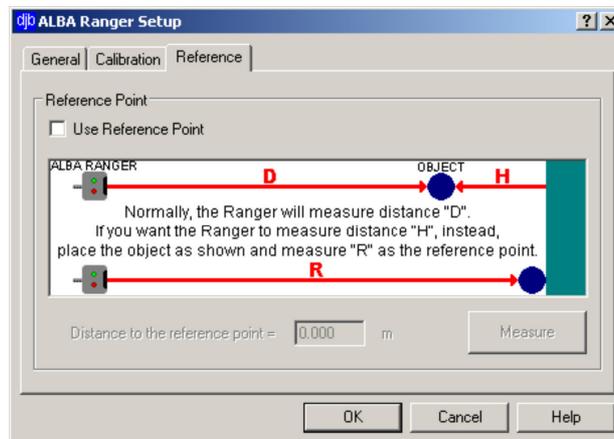


Figure 16 ALBA Ranger Setup box – Reference Point tab

Click in the box alongside 'Use Reference Point'. Now hold the model bungee jumper with feet uppermost immediately below the Force sensor hook. Click the **Measure** button so that this reference distance (the zero point) is recorded as in Figure 17 on the next page. It may well, of course, be a different distance to that displayed in Figure 17.

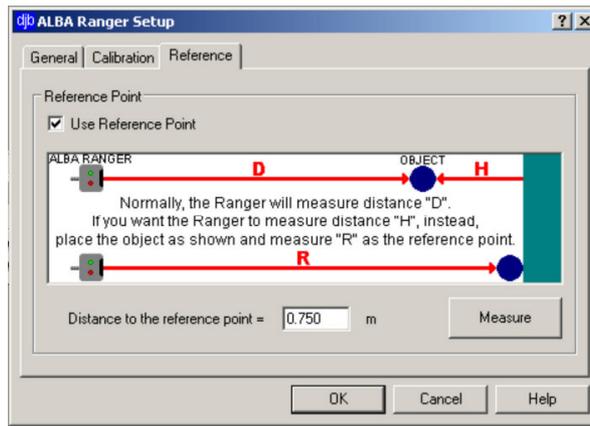


Figure 17 ALBA Ranger Setup box – Reference Point recorded.

Click the **OK** button to complete the ALBA Ranger Setup and display an empty Acceleration-time graph and the Setup Decimal Places box shown in Figure 18.

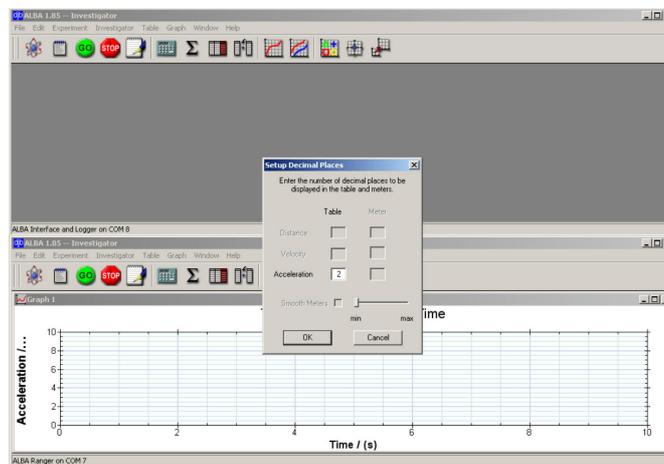


Figure 18 ALBA Ranger – Empty Acceleration-time graph and Setup Decimal Places box

Select '2' decimal places for the Acceleration if that is not already displayed, and then click the **OK** button. A **Press GO** box will now be displayed as in Figure 19.



Figure 19 Press GO box

Do not press the **GO** button. Click the cursor within the Press GO box and hold down and drag this box into the centre of the Acceleration-time graph. The ALBA Ranger is now setup and ready to go.

Now click the **GO** icon  in the Toolbar of the ALBA Interface and Logger section of the screen to display its Setup box as shown in Figure 20 overleaf.

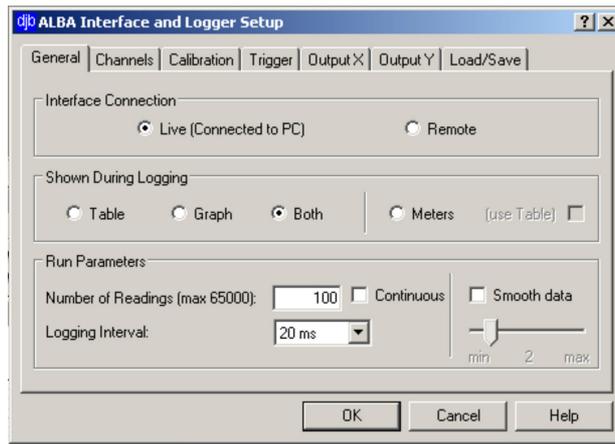


Figure 20 ALBA Interface and Logger Setup box – General tab

Select, by clicking in the respective radio buttons, Interface Connect: Live (Connected to PC) and Shown During Logging: Graph. Click in the box alongside 'Continuous' to select continuous logging of data and use the down-arrow to select Logging Interval: 100ms. Also click in the box alongside 'Smooth data' and move the slider below it to indicate '2'. It should now appear as in Figure 21.

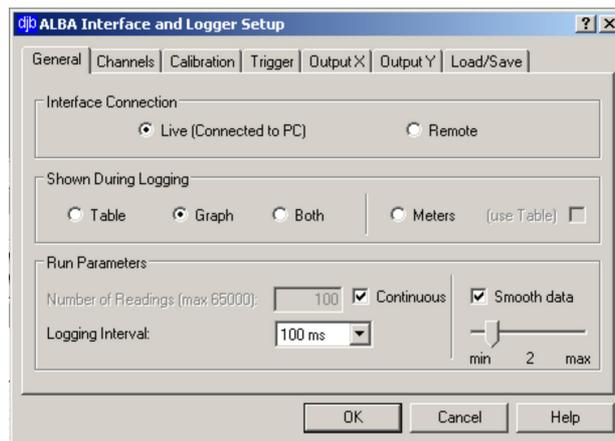


Figure 21 ALBA Interface and Logger Setup box – General tab – selections made

Now click the Channels tab. As the Force sensor is self-identifying this box should display as in Figure 22.

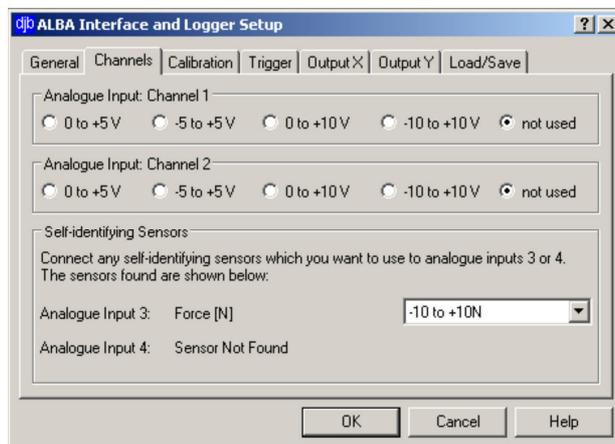


Figure 22 ALBA Interface and Logger Setup box – Channels tab - Force sensor identified

Calibration of the Force sensor should not be required and a Trigger is not to be used in this activity, so do not click on those tabs. Similarly the Output X, Output Y and Load/Save tabs will not be used, so at this point just click the **OK** button to display an empty Force-time graph and a Setup Table Headings as shown in Figure 23.

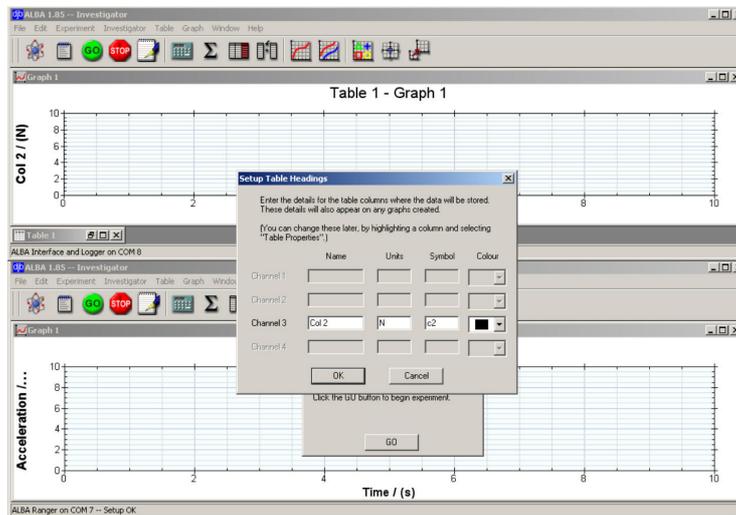


Figure 23 ALBA Interface and Logger – Empty Force-time graph and Setup Table Headings box

Type 'Force' into the Name box alongside Channel 3 and ensure that its units are shown as 'N'. Leave the Symbol box showing 'c2' and select a colour as in Figure 24.

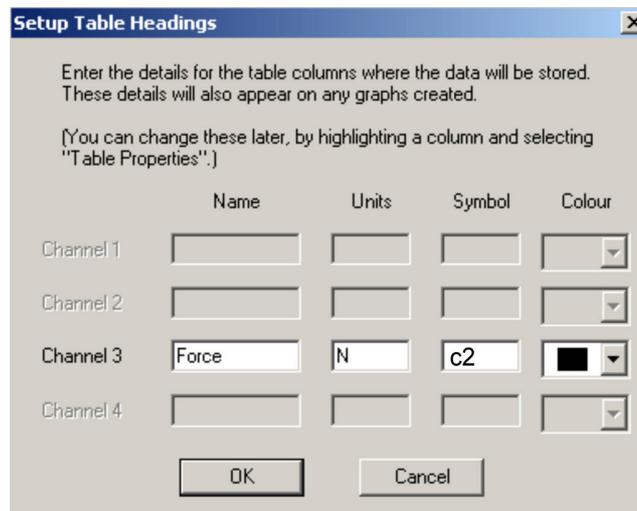


Figure 24 ALBA Interface and Logger – Setup Table Headings box

Now press its **OK** button. Another Press GO box should have appeared on the screen. **Do not** press the **GO** button. Click the cursor within the Press GO box and move this box into the centre of the Force-time graph. The ALBA Interface and Logger is now also setup and ready to go.

Position the model bungee jumper so that its feet are just below the Force sensor's hook, click the **GO** button within the Press Go box of the ALBA Interface and Logger section (it should still be highlighted) and let the model fall.

Let data be collected for **just over** 10 seconds, then click the **STOP** icons  on each section's Toolbar. You should now see both an Acceleration-time and a Force-time graph displayed with ALBA Information boxes overlaid, similar to that shown in Figure 25.

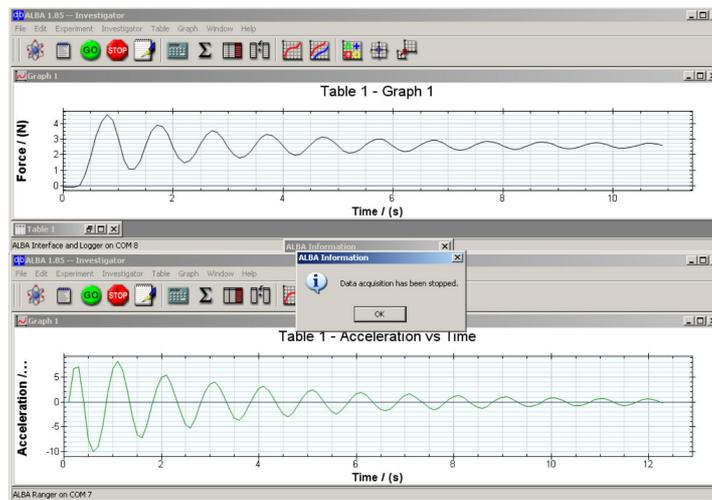


Figure 25 Typical Acceleration-time and Force-time graphs

Click the **OK** buttons of the two ALBA Information boxes indicating ‘Data acquisition has been stopped.’.

You now need to match up the displays of each graph to 10 seconds so that it is easy to compare forces and accelerations at the same times. Click on the **Edit Graph** icon  within the ALBA Ranger section to display the Edit Graph box – Axes Ranges tab similar to that of Figure 26.

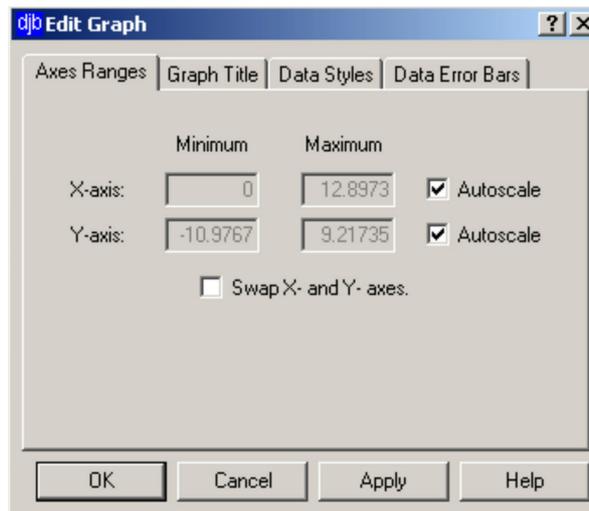


Figure 26 Edit Graph box – Axes Ranges tab

Untick the Autoscale box for the X-axis. Click the cursor in the box below X-axis Maximum and replace the value with ‘10’. Now click on the Graph Title tab to reveal the Graph Title box shown in Figure 27 on the next page.

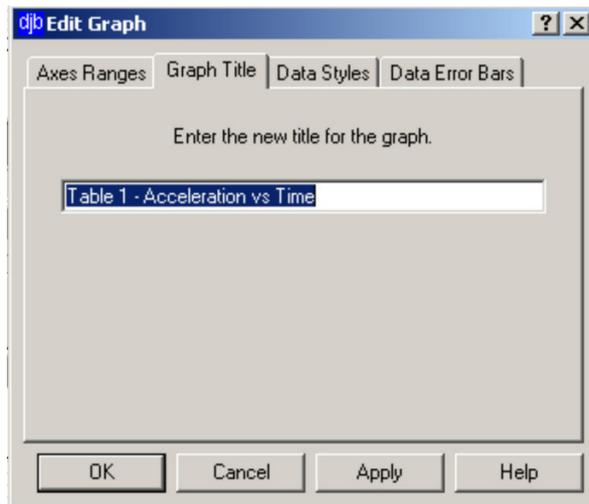


Figure 27 Graph Title box

Replace the existing title with 'Acceleration of model bungee jumper v Time' as in Figure 28.

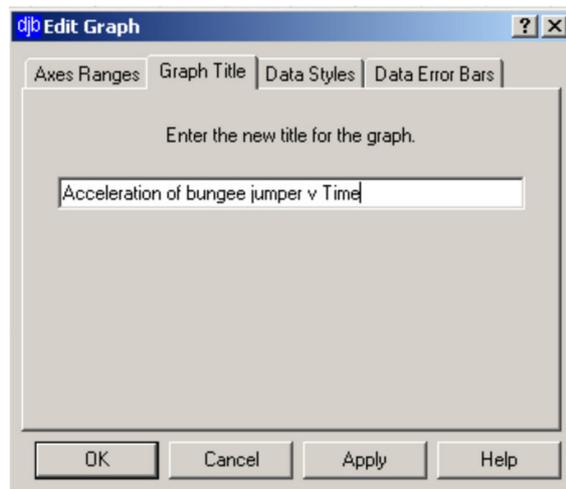


Figure 28 Graph Title box – new title for graph

Click the **Apply** button and then the **OK** button.

Now click on the **Edit Graph** icon  within the ALBA Interface and Logger section to display its Edit Graph box – Axes Ranges tab. Untick the Autoscale box for the X-axis. Click the cursor in the box below X-axis Maximum and, as before, replace the value with '10'. Now click its Graph Title tab and replace the existing title by 'Force on bungee cord v Time'. Click the **Apply** button and then the **OK** button. Both graphs should now match in time as in Figure 29 on the following page.

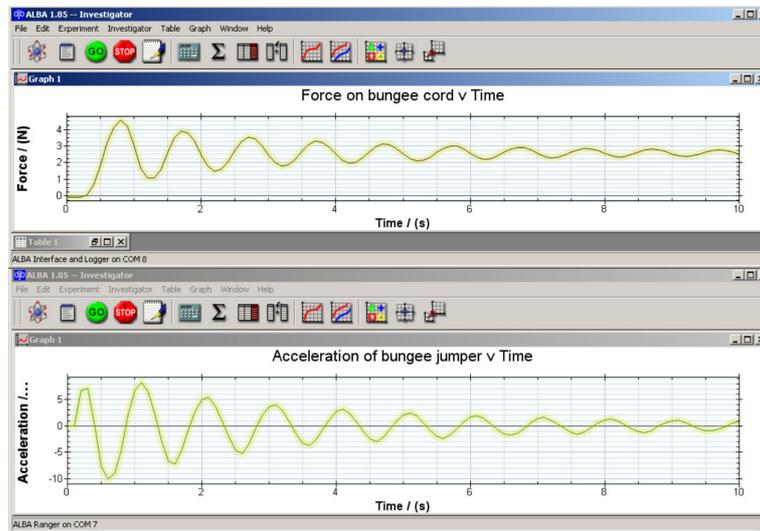


Figure 29 Acceleration-time and Force-time graphs with matching Time axes

Click on the line of each graph to remove the background 'line select'.

NOTE: If your graphs were not quite as you had hoped – usually caused by a wobbly oscillation of the model bungee jumper – then just click the **GO** icons  and follow through the setup details as before. Most, if not all, should have remained the same.

Reporting your findings

Comment on the graphs obtained, pointing out their key features and how and why these two graphs relate to each other.

Exiting the program and leaving things set up for the next user

For each section of the screen click on **File** in the Menu Bar and then **Exit** in the drop-down menu. Click the **Yes** button in response to 'Are you sure you want to Exit? All unsaved data will be lost.'. Unplug the Force sensor from the ALBA Interface and Logger and also unplug its power supply. Similarly unplug the ALBA Ranger's power supply. Now remove both serial or USB plugs from their ports.