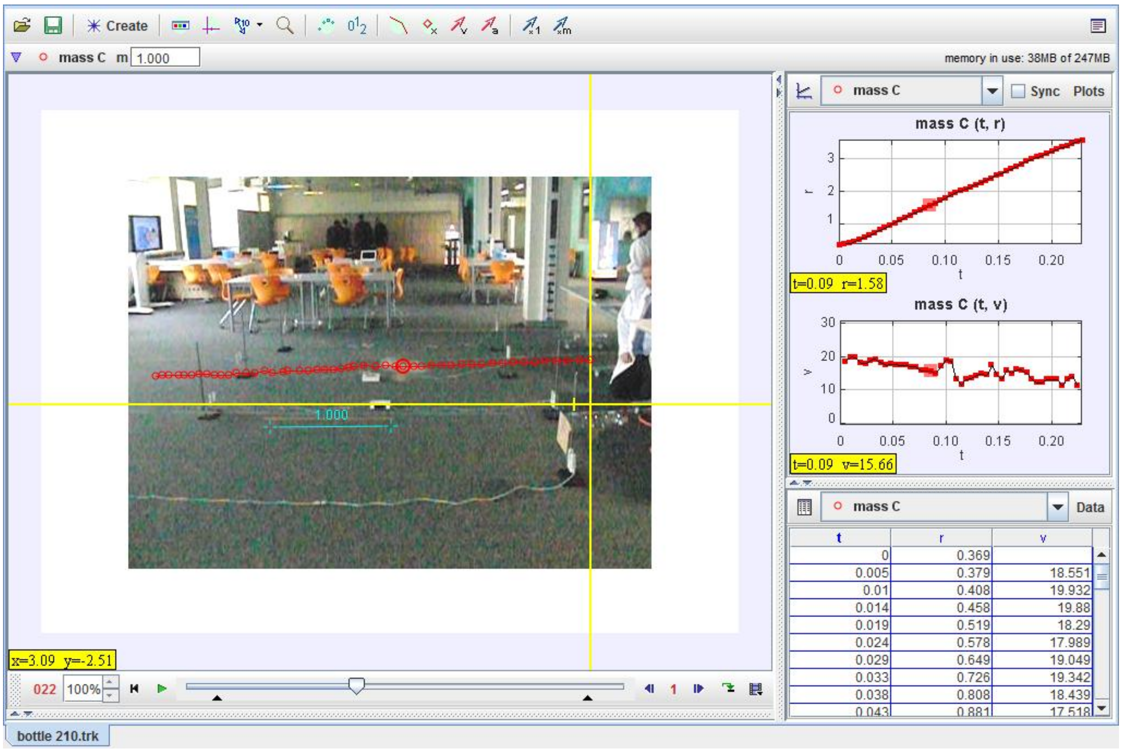
**Launching the Bloodhound Centre** Adrian Oldknow aoldknow@yahoo.co.uk

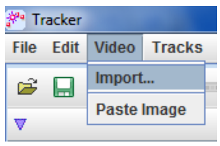
26th May 2011 saw the opening of the first Bloodhound Education Centre at the Manchester Communications Academy in Manchester. The photograph below shows staff preparing one of the workshops for the Year 7 students before they went to work. Large empty plastic drink bottles are suspended from strings across the room. Each carries a cardboard fin beneath designed to pass through a pair of light-gates attached to a sensing system in order to measure their average speed. The bottles are filled with compressed air until a critical level is reached and the bottle is fired off like a rocket – only more safely. Differently shaped nose cones can be attached to experiment with the effects of streamlining on air resistance. The purpose of this note is to show how much data can be gathered from such an experiment using a modern compact high-speed digital camera and analysed using readily available software.

The Casio Exilim series of digital cameras can take video clips at 210, 420 and 1000 frames per second. Ideally a tripod should be used for stability – but I didn't have on with me. Luckily there were some metre rulers in the workshop and so I placed one in the field of view as a reference for measurements.

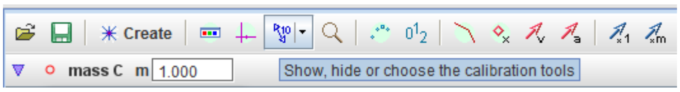

Now we have all that is needed to capture the data from an AVI digital video clip. The faster the frame rate, the poorer the video quality, but a good compromise is achievable at 210 frames per second. Fortunately there is a free software tool to help with the analysis – it is called *Tracker* and was developed by Doug Brown of Cabrillo College, California as part of the National Science Foundation's Open Source Physics programme. [http://www.cabrillo.edu/~dbrown/tracker/](http://www.cabrillo.edu/~dbrown/tracker/). The screen copy below shows the basic layout. Below the tool bar and a line of information there are four windows. The main display (upper left) is for the video playback and capture. Below it are the video controls. The upper right window displays 1, 2 or 3 graphs from captured data. The lower right window shows a table of captured data.



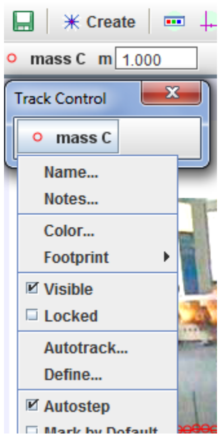

There are a few straightforward steps involved in the process. The first is to import your video clip using the Video menu option "Import" and locating the video clip file to load. When the first frame is shown in the main window you can use a right-click to open a context-sensitive menu and use it to zoom in or out – also to adjust the brightness and contrast. The video playback control allows you to play the video, to slide to any frame, and to single step forward or back.



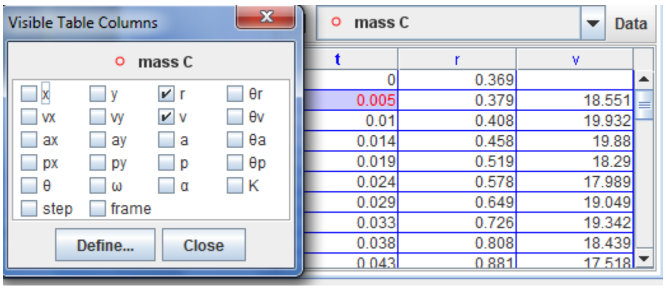

The last icon is used to open the Clip Settings menu where you select the first and last frames to use, as well as the correct frame rate. Normally any high-speed video is marked for play-back at 30 frames per second so that you view it in slow motion. Now the video has been set up, we have two more operations to carry out before logging the data from each frame. The first is to calibrate the experiment using the metre rule we conveniently placed in the field of view – or we could use the length of the bottle. The sixth icon on the tool-bar is used to select a tape-measure, or other tool, which can be dragged out near an object whose length you know - and then you can type in its length using your chosen units. The fifth icon is used to open up a set of axes against which the coordinates of points can be determined. The origin can be dragged to a chosen position, and the *x*-axis can be tilted to any preferred direction. Using context-sensitive menus the colours of the axes and the tape measure can be adjusted. The final step is to collect the data from each frame using the third icon to Create a New Track for a Point Mass.

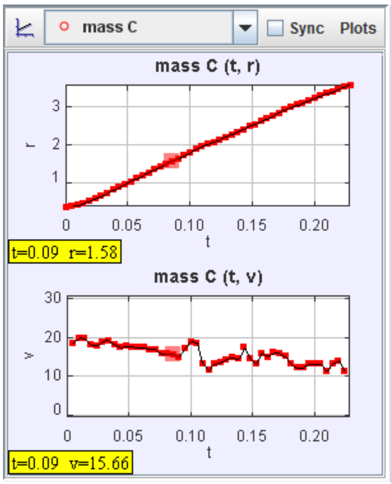



You can either track an object manually, using Shift-click to enter the position of the cross-hairs on the moving point of interest in each frame, or you can allow the software to try to Autotrack a chosen well-defined shape as it moves. Using the drop-down menu for the chosen object (called a "mass") you can change its colour, the symbol (called "Footprint") used to mark it on the display and whether or not to use Autotracking. The eighth, ninth and tenth icons can be used to adjust the number of markers shown to trace the path of the object, whether or not they are labelled, and whether a line is drawn to show the object's path.

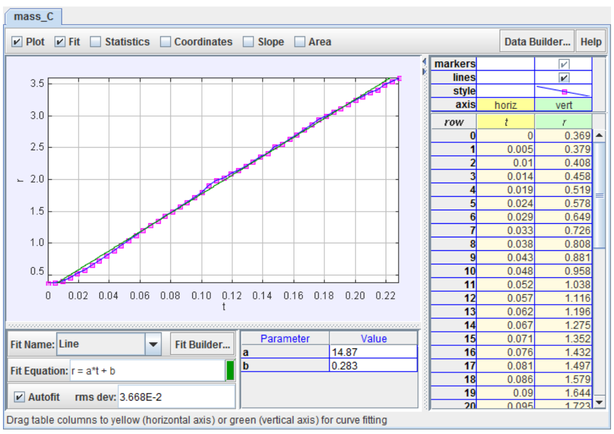


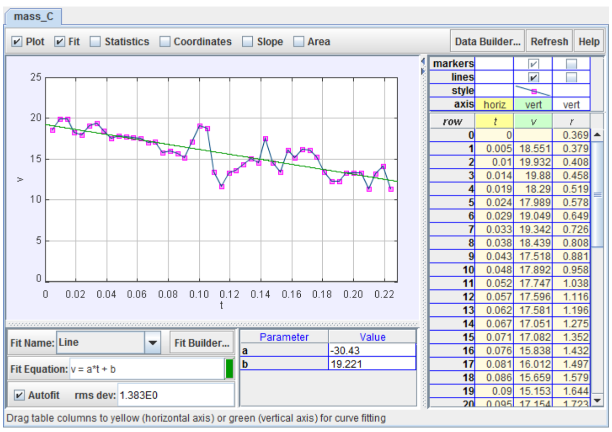

As each frame is marked, so the corresponding data is collected in the table, and also plotted on one or more graphs. The time data *t* is computed automatically from the frame number and video frame rate. The basic variables are the *x*- and *y*-coordinates of the position of the tracked object (the middle of the bottle) in each frame. I have chosen to hide *x* and *y* and instead to use the displacement *r* (metres) and velocity *v* ($ms^{-1}$) data variables instead. The velocity *v* is calculated numerically by the software.



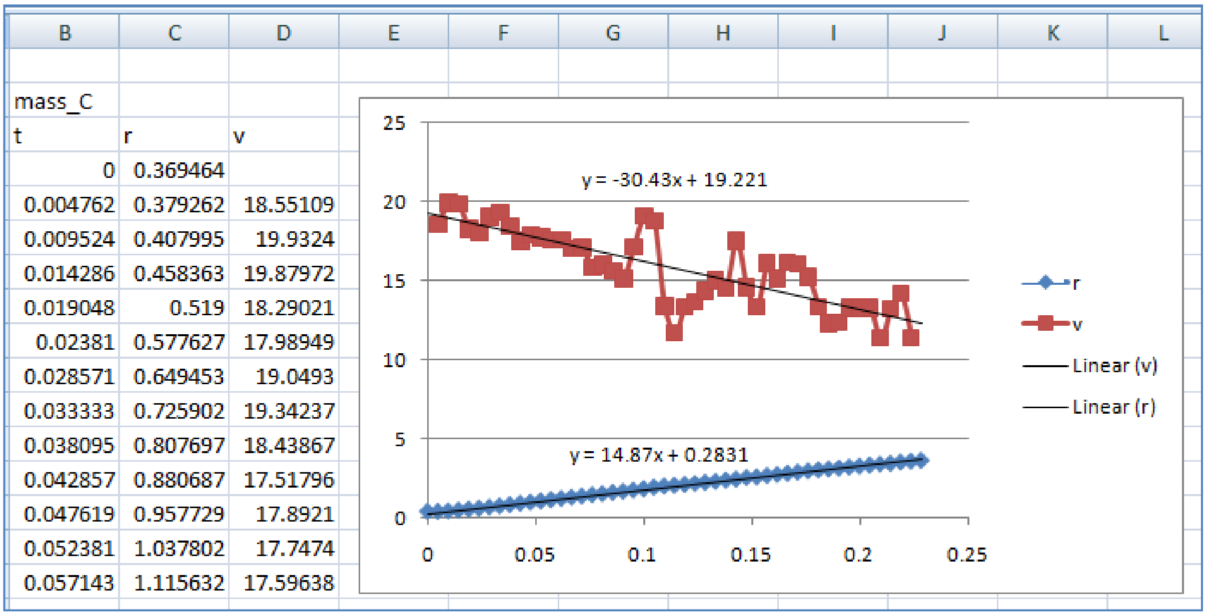

The graph window shows the graphs of both displacement-time (*r* against *t*) and velocity-time (*v* against *t*). As the video controller is used to step forward or back so the data for the corresponding position is highlit in both the data-table and the graphs. In all we can see that the whole action took less than a quarter of a second – that the bottle travelled about 3.5 metres along the string and that its launch velocity was nearly 20 metres per second or 72 kph or 45 mph. We can carry out a more detailed analysis either within *Tracker* or by exporting the data to another tool for mathematical modelling, such as MS *Excel*, *TI-Nspire* or *Geogebra*. A right-click on a graph brings up a menu from which the Analyze option can be selected to open a new window.



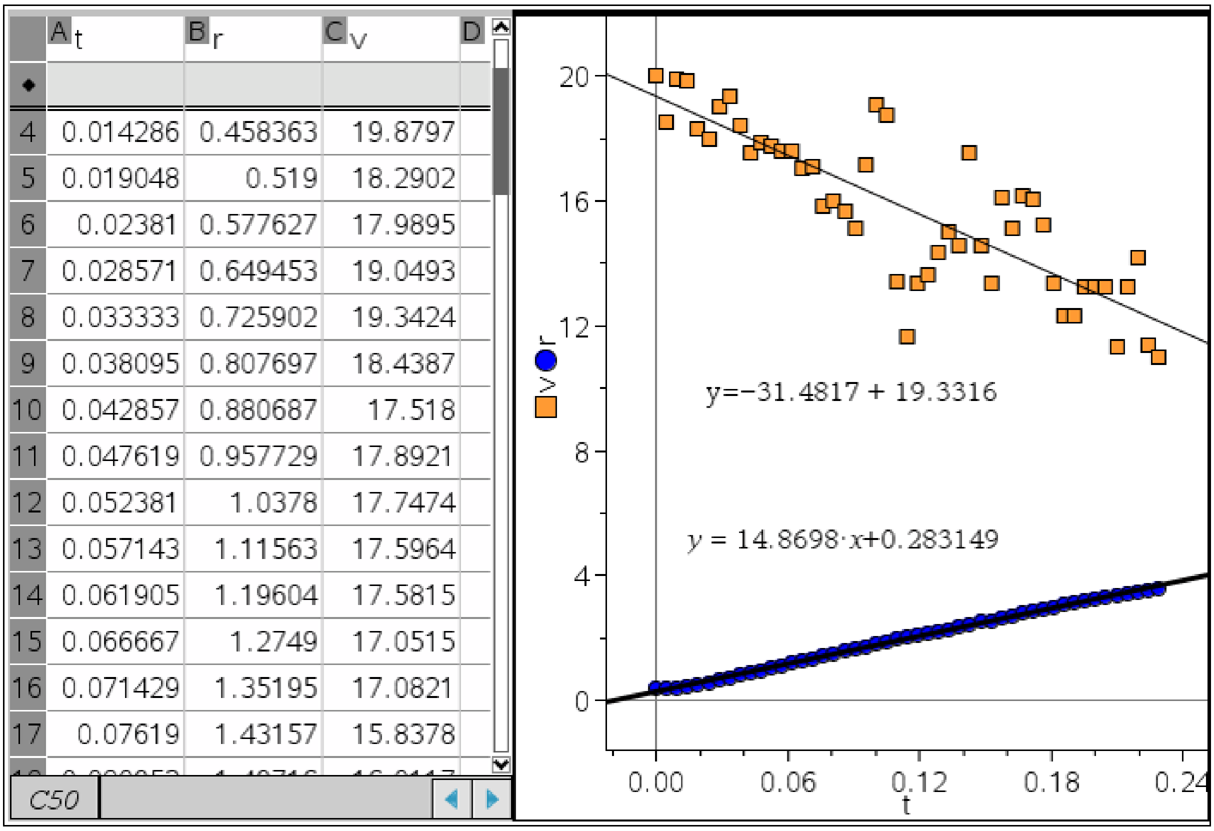

Here we can see that a linear function is a good fit to the *rt*-graph of displacement which has a gradient of 14.87 – and so is a good measure of the average speed of the bottle in $ms^{-1}$. But that the *vt*-graph is also quite well-fitted by a linear function, this time with a gradient of -30.43 – which gives an estimate of its average deceleration as 30 $ms^{-2}$ or about 3*g*. So while the bottle goes nothing like as fast as Bloodhound it would outstrip Usain Bolt – at least over the first couple of metres!

Here is an *Excel* analysis of the data which have been copied and pasted. Both scattergraphs are shown along with the linear “Trendlines” computed by *Excel* – which agree closely with those of *Tracker*.



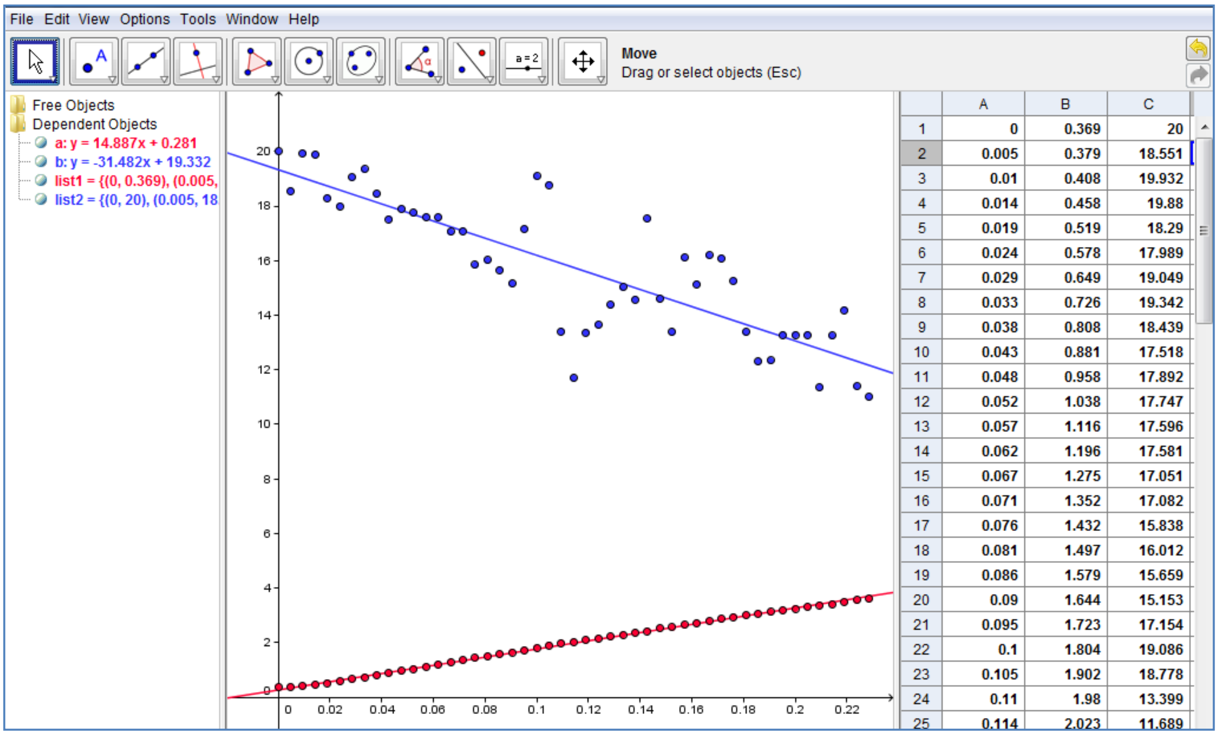

| t | r | v |
|---|---|---|
| 0 | 0.369464 | |
| 0.004762 | 0.379262 | 18.55109 |
| 0.009524 | 0.407995 | 19.9324 |
| 0.014286 | 0.458363 | 19.87972 |
| 0.019048 | 0.519 | 18.29021 |
| 0.02381 | 0.577627 | 17.98949 |
| 0.028571 | 0.649453 | 19.0493 |
| 0.033333 | 0.725902 | 19.34237 |
| 0.038095 | 0.807697 | 18.43867 |
| 0.042857 | 0.880687 | 17.51796 |
| 0.047619 | 0.957729 | 17.8921 |
| 0.052381 | 1.037802 | 17.7474 |
| 0.057143 | 1.115632 | 17.59638 |

The data have also been pasted into a *TI-Nspire* spreadsheet and displayed using a Data & Statistics view. In order to compute linear regression fits there must be no empty cells, so estimated values for the velocity *v* have been used for the first and last frames – hence the slight discrepancy in the velocity-time equation.



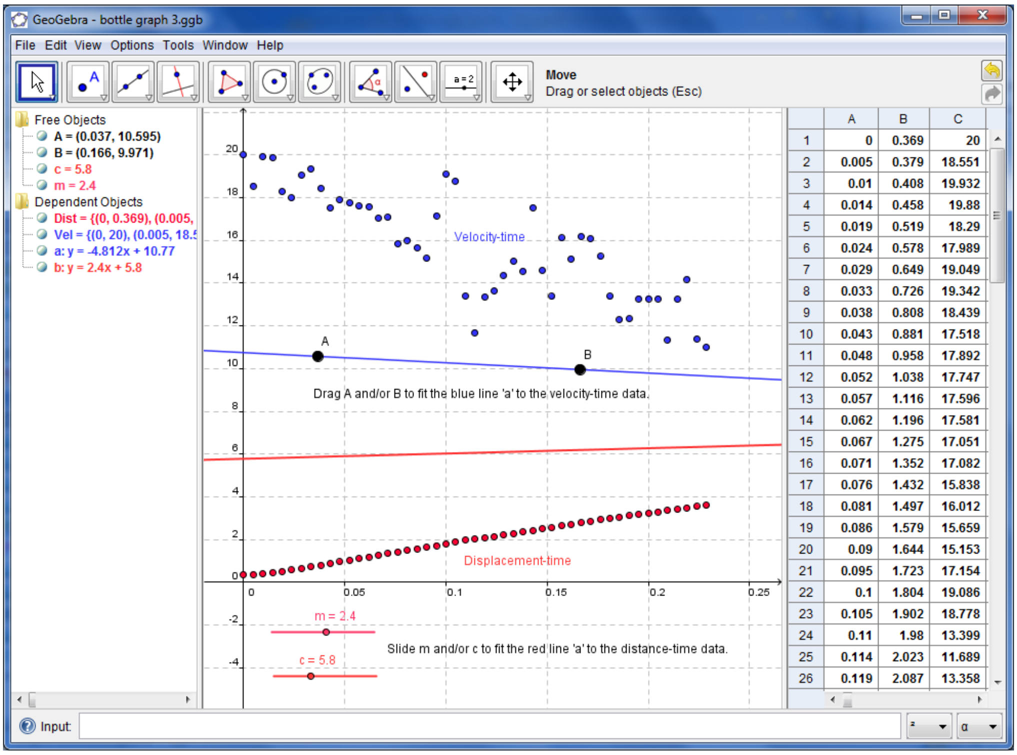

| | A t | B r | C v |
|---|---|---|---|
| 4 | 0.014286 | 0.458363 | 19.8797 |
| 5 | 0.019048 | 0.519 | 18.2902 |
| 6 | 0.02381 | 0.577627 | 17.9895 |
| 7 | 0.028571 | 0.649453 | 19.0493 |
| 8 | 0.033333 | 0.725902 | 19.3424 |
| 9 | 0.038095 | 0.807697 | 18.4387 |
| 10 | 0.042857 | 0.880687 | 17.518 |
| 11 | 0.047619 | 0.957729 | 17.8921 |
| 12 | 0.052381 | 1.0378 | 17.7474 |
| 13 | 0.057143 | 1.11563 | 17.5964 |
| 14 | 0.061905 | 1.19604 | 17.5815 |
| 15 | 0.066667 | 1.2749 | 17.0515 |
| 16 | 0.071429 | 1.35195 | 17.0821 |
| 17 | 0.07619 | 1.43157 | 15.8378 |

*Geogebra* is free software which can either be run via the web, or downloaded for installation from http://www.geogebra.org/cms/en/download . The *Geogebra* screen shows three views: algebra, geometry and spreadsheet. The data have been pasted into the spreadsheet and the estimated initial and final values for *v* inserted, as with *TI-Nspire*. Data from pairs of columns A,B and A,C have been converted into lists of points list1 and list2. Lines of best-fit have been drawn for both sets of data and their equations are shown in the algebra view. The slight discrepancies in the coefficients from the other software are due to the choice to round the data to 3 decimals.




So we have seen that data from a fun and safe experiment can be easily captured using just a camera and a free software tool, as well as easily analysed to provide reliable models for the effects of air-resistance on moving vehicles such as Bloodhound SSC. Simple rocket science with a lasting educational impact!

The *Geogebra* software can also export a file as a dynamic web-page in html – so that any user can interact with the page by dragging objects such as points and sliders. The revised file shown below replaces the two lines of best-fit by two lines which the viewer can drag to fit the data themselves.




Similarly the Teacher version of *TI-Nspire* can be used to create an interactive web-page where points and sliders can be dragged to fit lines to the data sets.