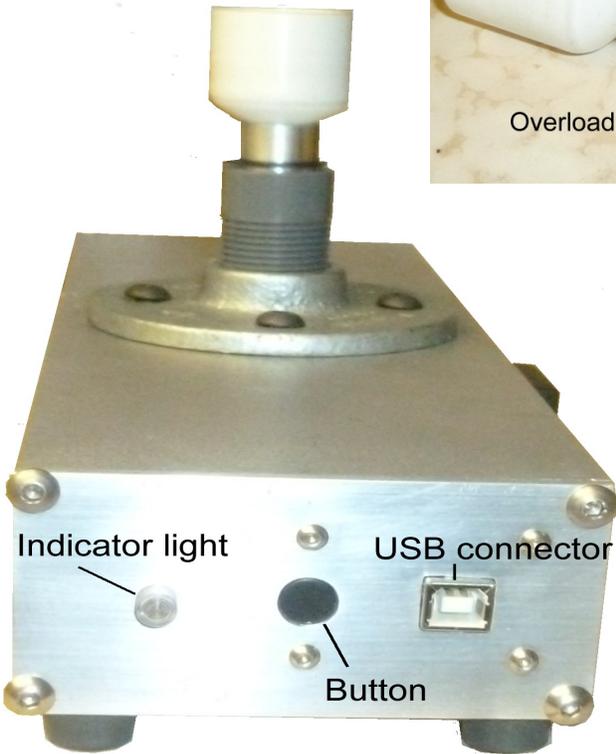
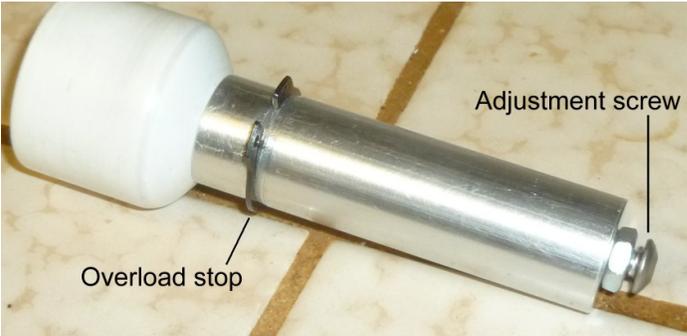
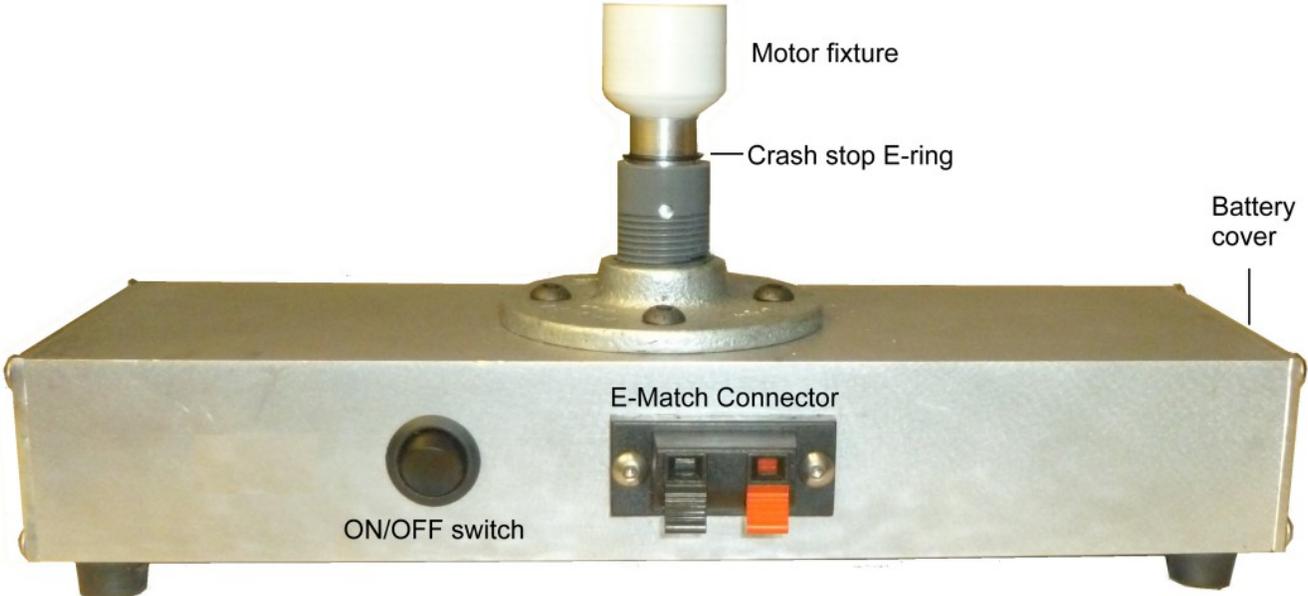


ACME ROCKET RIG

(Construction may vary slightly from these images)



General Description

Internally, the rig contains a load cell, a 24-bit delta-sigma ADC, a microcontroller, memory, and a serial input/output interface. It achieves better than 20 noise-free bits of measurement, but the output is presented as 16 bits. Normally it is fitted with a 100kg (220 pound) load cell so it can resolve load changes of around 1.5 grams. A nickel weighs 5 grams. Accuracy is not guaranteed at these low levels, as the load cell is only specified accurate and linear to 0.01% (10 grams for a 100kg cell).

When running, the rig sits in a continuous loop reading the load cell until it sees the load increase when the motor fires. It then goes into recording mode and records for a fixed period of about 10 seconds, at the end of which time it stores its measurements for later analysis. The last second of readings before the trigger is saved with the data, so the ignition point is always included in the recording. The normal sample rate is 80 samples/second (12.5ms/sample) and the normal measuring period is a little over 10 seconds. For long-burning motors this can be switched down to 40 samples/second and a measuring period of 20 seconds.

The rig has sufficient memory to store 18 recordings. If any of the 18 locations is marked unused, it will be used for the next recording. If the memory is full, the next recording will overwrite the oldest. The memory can be unloaded and released by command from the PC when the data is analyzed. There is a non-resettable run counter that increments every time a recording is made, and this can be used to identify which recording is which for analysis.

The accompanying PC software package includes everything necessary to set up and calibrate the rig, and to upload, store and analyze the data. Regrettably at this time only a Windows PC version is available, so Mac and Linux users are out of luck. However, every function of the rig can be accessed with a simple serial terminal program and although this is not so convenient for extracting data, it can be done with a few nerd skills.

Internally, the rig keeps all its recordings and internal calculations in metric units. There is a setting to report in pounds, in which case a conversion is made at the time the data is presented – it remains metric internally. The accompanying PC program always speaks to the rig in metric units, no matter what the setting of the rig, though it is able to present the results in either system of units.

Quick Start guide

Before you go out firing rockets, it's a good idea to attach the rig to a PC and check it out at least once. There is a pre-run check list below. At the very least, make a note of the last run number, as the motors you test will be recorded against incrementing run numbers starting from the next one.

On arriving at the shoot site, set the rig down securely and more or less level. You may think it worthwhile to stake, tie or sandbag it if you have powerful motors to test. When you are satisfied, with the chuck or fixture in place and *no motor installed*, turn the rig on. It will auto-zero itself and the indicator light will turn green.

Without turning the rig off again and losing the zero point, lift out the chuck or fixture and securely fix a motor to it. Replace the assembled fixture in the rig, which then makes a note of the starting weight for fuel calculations. If you are using an e-match to fire, hook it up now.

To start a recording run, press and hold the center button for about a second until the indicator light begins to flash red. Be careful not to touch the motor or fixture, as it will sense any increase in load as the motor firing and may start recording too soon. If you are firing manually, light the fuse at your leisure and retire to a safe distance. If you are firing by e-match, the delay started counting down when the light turned red, so you shouldn't linger. The indicator will start flashing red and blue when it fires the e-match, so if you see this going on for any length of time the e-match probably didn't work. Otherwise, either the fuse or the e-match will fire the motor. If you want to abort the run for any reason, press the button again before the motor fires to return to standby mode. The e-match will be disarmed and the light will turn green.

When the motor fires and the force exceeds the preset trigger force, the indicator light stops flashing and turns steady red when recording starts. The rig records for its preset time and then the indicator turns green again when complete. You can now mount and fire another motor, or turn the rig off and head for a computer to look at the results. It's a good idea to keep a notebook and note down the details of each motor as you test them, along with the run number, as it's easy to lose track.

The green light will flash if the battery voltage is low. The rig will continue to function for some unspecified time, perhaps days, but the writing is on the wall. Replace the batteries with six fresh AA alkaline cells. The battery is located behind the cover at the opposite end of the rig from the light and button. You will need an allen key to remove the plate and get to it.

Pre-Run Check List

Hook the rig up to a PC and run the accompanying PC program to check the rig parameters. These are saved internally and don't need to be set up every time, but they should be checked (and changed if necessary) at least once before you use the rig for the first time.

- Check that the rig is calibrated. Test it with a known weight of at least one percent of full scale (1kg, 2 pounds). The rig reads down to a couple of grams, a fraction of an ounce, but at very low readings some accuracy may be lost to friction. Calibration instructions can be found below if necessary.
- Check that the trigger force is sensible. The default setting is 500 grams, approximately one pound – it's a poor rocket that can't achieve that. A 2 ounce BP rocket should be able to push five pounds. But a bottle rocket may not.
- If you are using e-matches, check the e-match delay is adequate. The default setting is five seconds but you may wish a larger safety margin. If you are hand-lighting you can turn the e-match off by setting the delay to 0, but it doesn't matter if you leave it on.
- Use the LIST command to check that the memories don't contain data you haven't uploaded and may wish to analyze. Make a note of the last run number – the next test you run will be the number following this. It is not necessary to clear the memories, as the rig will first save to free memories, if any, and then overwrite older runs in order starting with the oldest. However, they can be cleared with the FREE command if required.

Calibrating the Rig

The rig is calibrated by placing a known weight on the fixture and telling the rig what it is, **in grams**. This establishes two points, no-load and the calibration weight, that determine the slope of the load cell characteristic in millivolts per kilogram. The values are stored internally and used subsequently to convert load cell output to real units. Once calibrated for a particular load cell it should not need to be calibrated again, though it doesn't hurt to check it from time to time to make sure the load cell hasn't drifted.

For the greatest accuracy the rig should be calibrated with a weight that is a substantial fraction of full scale, but in practice it can be done with quite a small load, since the linearity of the load cell is in the order of one part in 10,000. I calibrate the 100kg load cells with a 25 pound weight (11350 grams). The weight should not be much greater than 50 kilograms (110 pounds), as the calibration routine may overflow and introduce rounding errors at higher loads.

The accuracy with which you specify the calibration weight determines the accuracy of all subsequent measurements.

Place the rig on a level surface, connect to a computer and turn it on. When the light is green, place a known weight on the fixture, then from the computer, enter the command:

SPAN xxxxx

where xxxxx is the known weight **IN GRAMS**. It will not work with pounds.

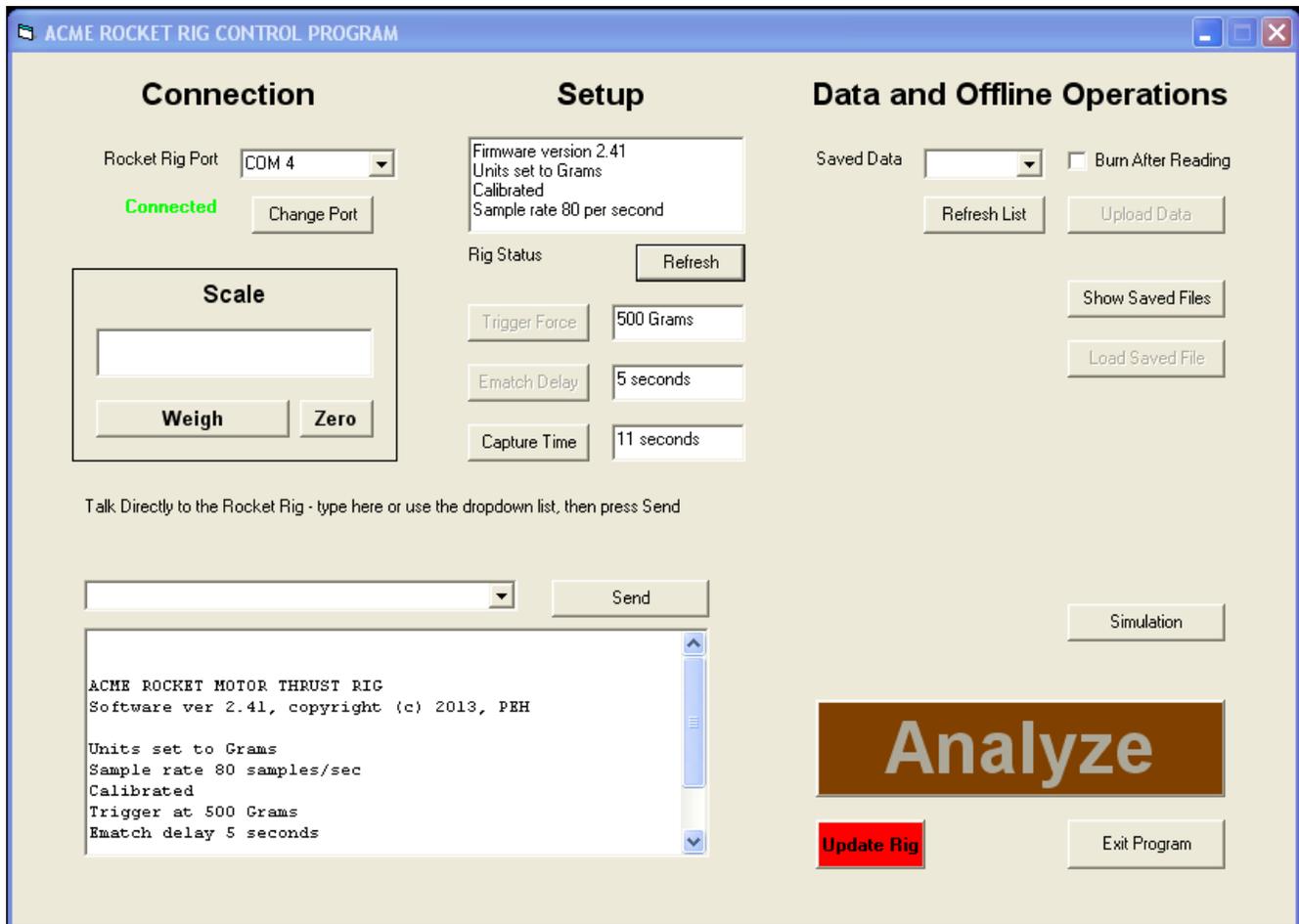
Communicating with a computer

Because I am a nerd, I originally designed the rig to suit my geekish preference of talking to it directly with a terminal program such as Hyperterminal. When it was brought to my attention that most people would have some difficulty with that, especially when it came to saving the data, I created a PC program to take all the mystery out of it, and that is the recommended way of using the rig. However, the direct commands are still there, and are the only way to perform some operations like calibration.

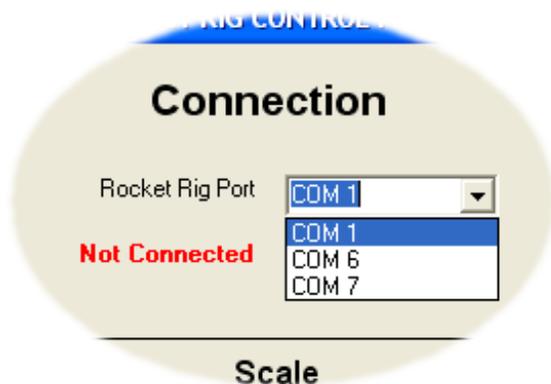
The rig has a USB interface for communications that will appear on your computer as a serial port. The USB interface uses FTDI devices, which are a common and most stable type. As with all USB devices the computer needs a driver, which is in the Drivers folder on the accompanying CD. If your computer has seen an FTDI device before the drivers are probably already installed. Otherwise, when you connect the Acme rig for the first time the computer will go into the "found new hardware" routine and you can point it at the CD.

Drivers can be downloaded from the FTDI site, <http://www.ftdichip.com/Drivers/VCP.htm>. You want the VCP drivers.

Download and install the PC application, RocketTestSetup300.exe. It creates a folder on your hard drive called RocketTest, and underneath this a subfolder called DATA in which it will store your uploaded data files. It will optionally place an icon on your desktop. Connect the rig with the USB cable and turn it on, then start the RocketTest program. A screen will open looking very much like this.



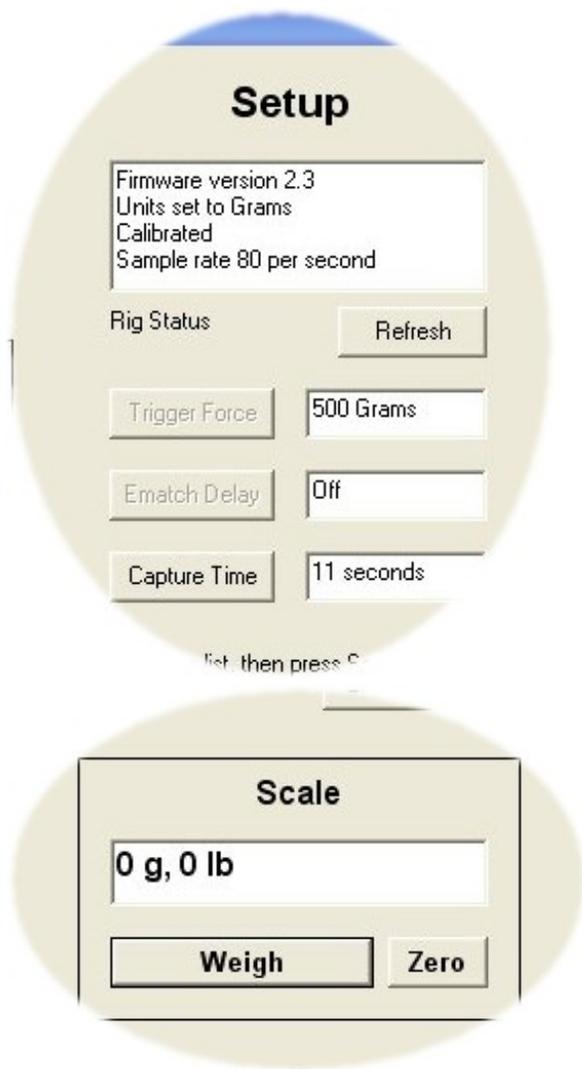
At first you may not have a connection. The program will check your computer and count the available COM ports, then present them on this dropdown. (The actual ports displayed will depend on your computer). Determine which one the rig is connected to, highlight it and click **Change Port** to select it. Then turn the rig off and on, and if you have the right port the legend will change to a green **Connected**. This may take a bit of trial and error if you have many ports listed.



Once you establish a connection, the program will remember it and use the same port in future, so you should only have to go through this once for any particular computer – although, I have found,

Windows will assign a different COM port number to the same USB device if it is plugged into a different USB socket, in which case you'll have to do it again.

Once you have a connection, the Rig Status box should fill with information as shown below. If the box is blank, clicking the **Refresh** button should fill it. This shows the rig firmware (internal software) version, the display units (Grams or Pounds), whether the rig is calibrated or not, and the sample rate (80 or 40 per second). The buttons below allow you to change some setup items.



The **Trigger Force** and **Ematch Delay** buttons are grayed out (disabled) until you change the value in the box to the right, at which time the button becomes active – clicking it sets the new value and the button grays out again. The **Capture Time** button is a toggle – clicking it toggles between 11 seconds and 22 seconds. The time change is achieved by changing the sample rate between 80 and 40 per second, which is reported in the Rig Status window.

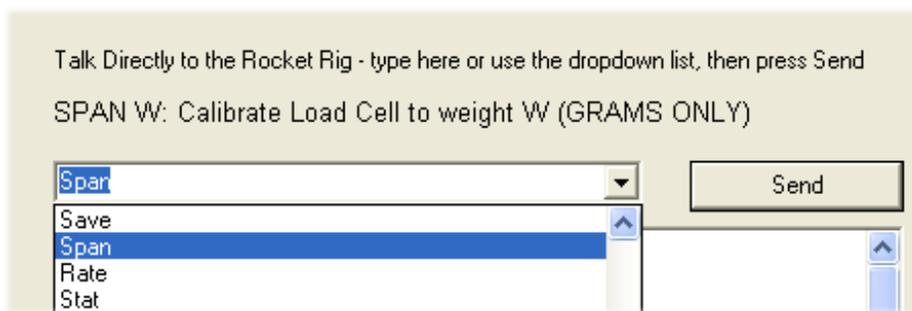
Typical settings are 500 grams (about a pound) for the trigger force and 5 to 10 seconds for the Ematch Delay. Most rocket motors burn for less than ten seconds, so the 11 second setting is right for most motors, but for particularly long burning motors it can be changed to 22 seconds.

The **Scale** window should be self-explanatory.

If you place some weight on the fixture and click **Weigh**, it will report the reading in grams and pounds. Note, not a continuous reading! It reads once every time you click.

The **Zero** button will zero the reading, effectively taring the rig to whatever weight is on the fixture at the time. This tare is not stored, but will persist until either the scale is zeroed again with no load, or the rig is turned off.

This next box is essentially a terminal program that lets you operate the rig using the direct commands. This is what you have to use to calibrate the rig.



The drop down lists all the built-in commands, and when you highlight one, a tool tip prompt appears to explain it. In the example on the left, SPAN is highlighted and the tip informs you

what it does. In this case, to calibrate, you would type the calibration weight in the text box (for example, SPAN 10000) and click the **Send** button to send the command to the rig. Note,

you do not have to use the drop-down list, as the text box is completely free form and will send anything you type, but it's a handy reference. There is a complete command list at the end of this document.

On the right hand side of the window are the controls related to reading and analyzing the data.

The top box is used to retrieve data from the rig. Initially, the drop-down box will be empty.



Clicking **Refresh List** sends a request to the rig to return a list of its memory contents. This will be returned as a list of run numbers, which are used to populate the drop-down box. When you select one, the **Upload Data** button becomes active, and clicking it will upload the stored data to the PC. This is held in memory, and also

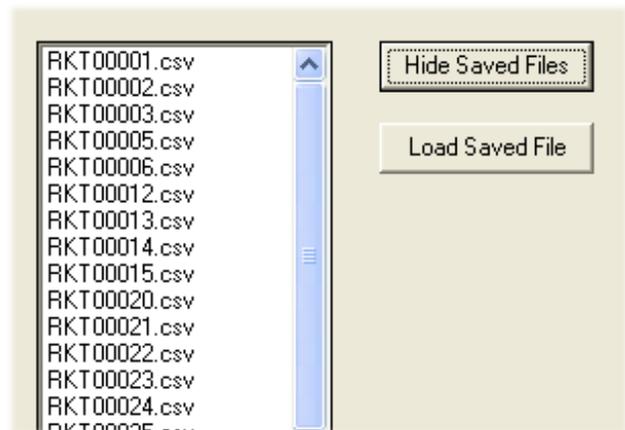
written out automatically to a file in the DATA folder under the RocketTest folder. The file is automatically named as RKTnnnnn.csv, where “nnnnn” is the run number. For example, uploading run number 29 would be saved as RKT00029.csv. The file extension “csv” stands for Comma Separated Values, which is a file format understood by Excel and similar programs – you are not restricted to my program to analyze the data.

If you check the box **Burn After Reading** before clicking the **Upload Data** button, the data will be automatically deleted from the rig.



Previously saved files can be recalled and analyzed also. A full list of files in the DATA folder can be displayed by clicking the **Show Saved Files** button, when something like this appears -

Select the file you want to look at from the list box, and click **Load Saved File** to recall it to memory. Note, you do not have to have the rig connected and turned on to do this. It is always available off line.

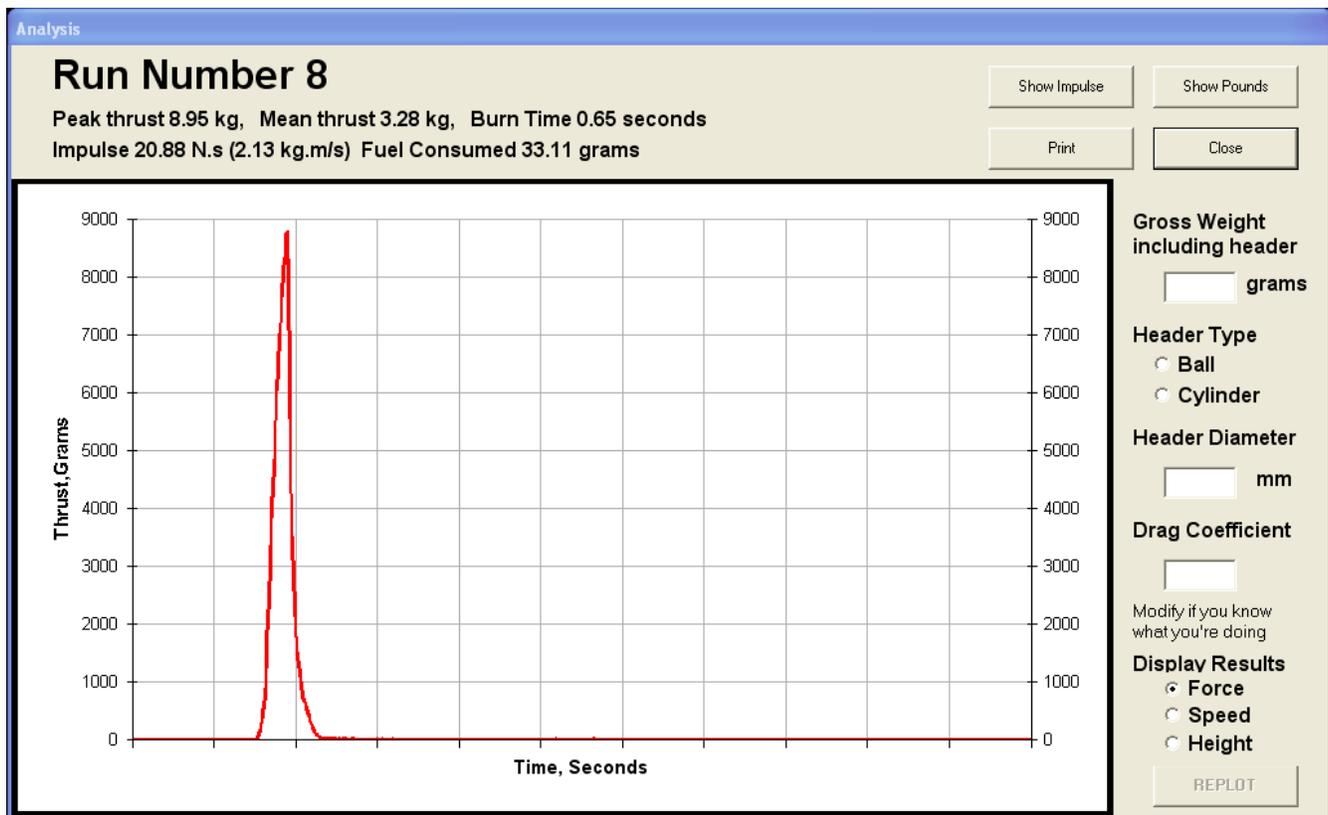


When a data file has been retrieved to memory, either from the rig or from disk, the large orange **Analyze** button will light up, allowing you to click it and move on to the Analyze screen.

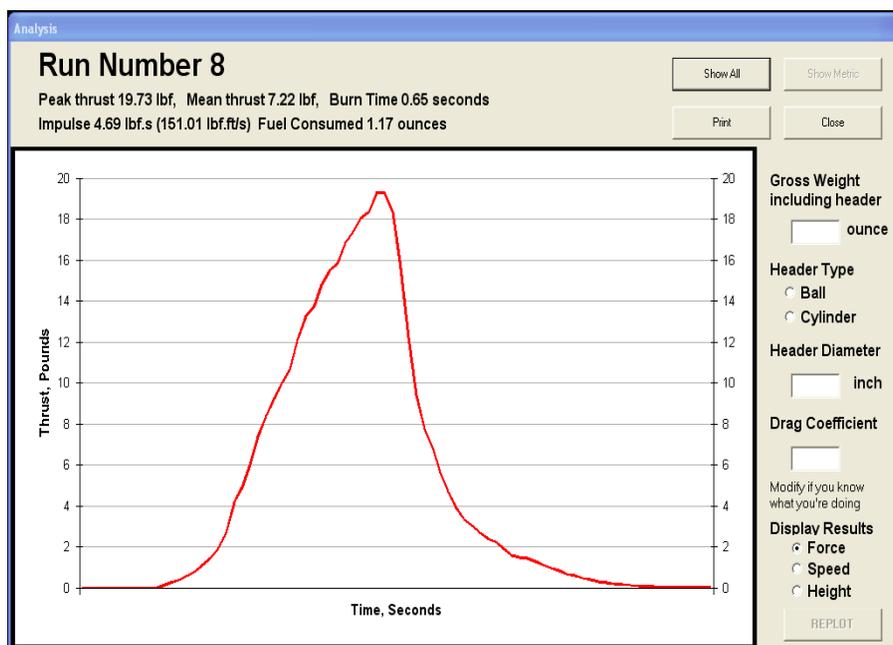


We'll come back to the “**Simulation**” button and the red “**Update Rig**” buttons later.

The Analysis Screen



There's a lot going on in this screen. Initially it displays the full trace of measured force, with numerical values in metric units.



The impulse is calculated by integrating the curve, for the range of values during which the instantaneous force is greater than 2.5% of the initial static load. The **Show Impulse** button zooms the display to just this area of the curve. Much useful information can be found this way. For example, the motor that produced the trace above was hand rammmed, and you can see steps in the curve from the rammmed

increments. The zoomed display always covers a whole number of seconds.

The units of Impulse are Momentum, allowing the theoretical speed of the rocket to be calculated given its mass. The fuel consumption is calculated by subtracting the final static load from the initial. Fuel weight loss is assumed to be linear over the impulse period, to a first approximation, and is adjusted for on the display so that the initial and final static loads appear the same. The unadjusted values are saved in the CSV file in case you wish to apply a more rigorous analysis with another program.

The **Show Pounds** button will convert the Metric display and numerical values to English units. When you're displaying English units, the button reads **Show Metric** to convert the other way. The **Print** button sends the whole Analysis window to the default printer, formatted to fit the default page size.

Rocket Science

Given additional details such as the weight of the complete assembled rocket and header, and its shape, we can apply some mathematics to calculate the speed and altitude versus time. You can calculate either in metric units of pounds-feet, and convert freely between them using the **Show Metric/Show Pounds** button, but don't get them mixed up or your rocket may crash into Mars.

Gross Weight including header
 ounce

Header Type
 Ball
 Cylinder

Header Diameter
 inch

Drag Coefficient

Modify if you know what you're doing

Display Results
 Force
 Speed
 Height

REPLOT

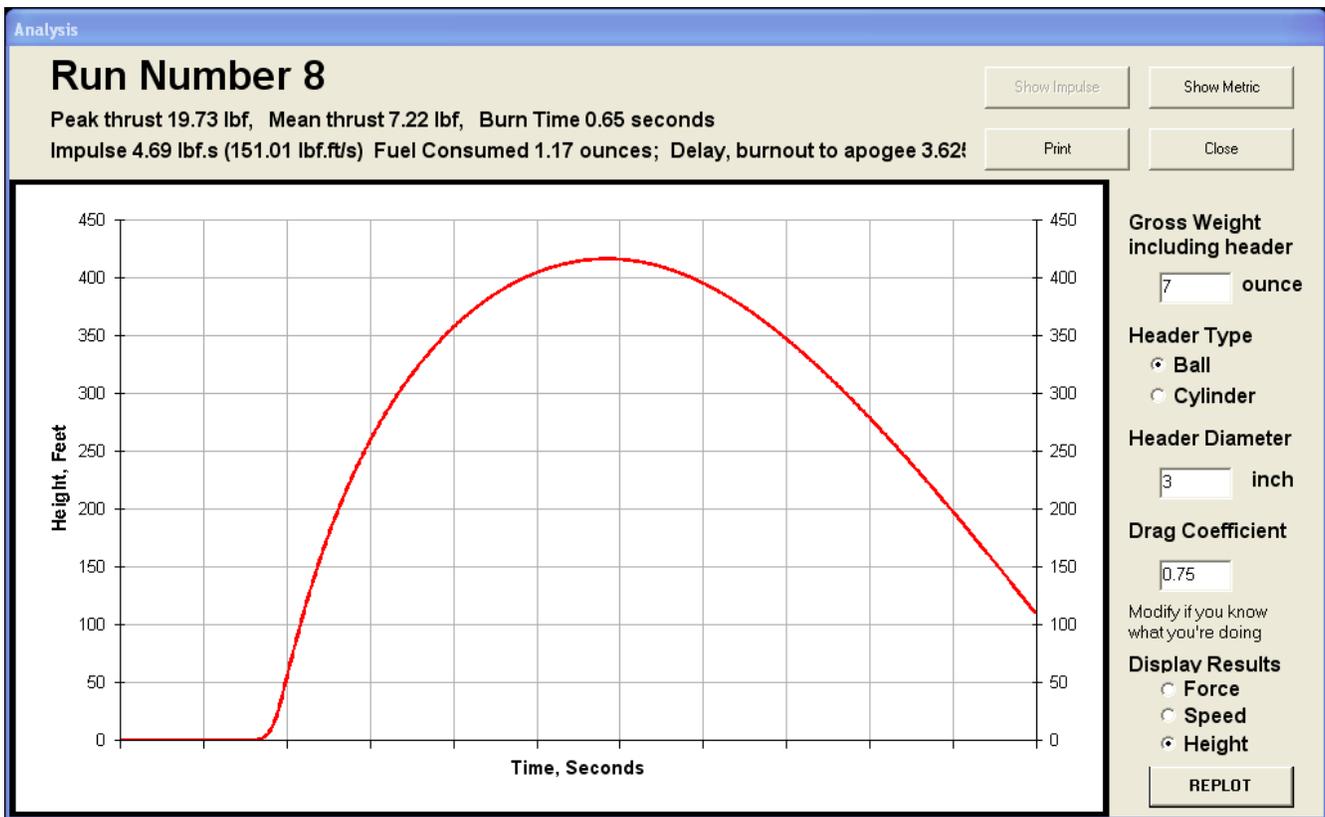
The Gross Weight includes the motor, the header and the stick, and is the total weight the motor has to lift. It must be entered in ounces or grams.

The Header Type, ball or cylinder, affects the aerodynamic drag coefficient. Select one or the other. This places a default value in the Drag Coefficient box.

Enter the header diameter, in inches or millimeters. 1 inch is about 25mm. This assumes the header is circular in cross section.

The drag coefficient depends mainly on the header shape, if the header area is much larger than the motor cross section. A sphere has a drag coefficient of approximately 0.5, and a flat ended cylinder approximately 1.1. A rocket stick adds some unknown drag, but as the motor body and stick are long compared to their cross section and generally narrower than the header, I arbitrarily add a drag coefficient of 0.25, giving values of 0.75 and 1.35 for a ball and cylindrical header respectively. These values are automatically inserted when the **Header Type** is selected, but can be edited manually if a better estimate is determined by experience, or if a different header shape is used.

You can now check the box for **Force**, **Speed** or **Height** , then click the **REPLOT** button to see the results plotted graphically against time.



The **Close** button returns you to the previous screen.

New for revision 3 and later versions



Everything you can do with real rocket data, you can now do with simulated data. Press this button on the opening screen to go into the Analysis screen in simulation mode.

Notice the two new buttons near top center.

Analysis

SIMULATION

Peak thrust 0 kg, Mean thrust 0 kg, Burn Time 11.19 seconds

Buttons: Change Impulse, Show Impulse, Show Pounds, Change Profile, Print, Close

Edit Impulse

Set Impulse, Units, Time

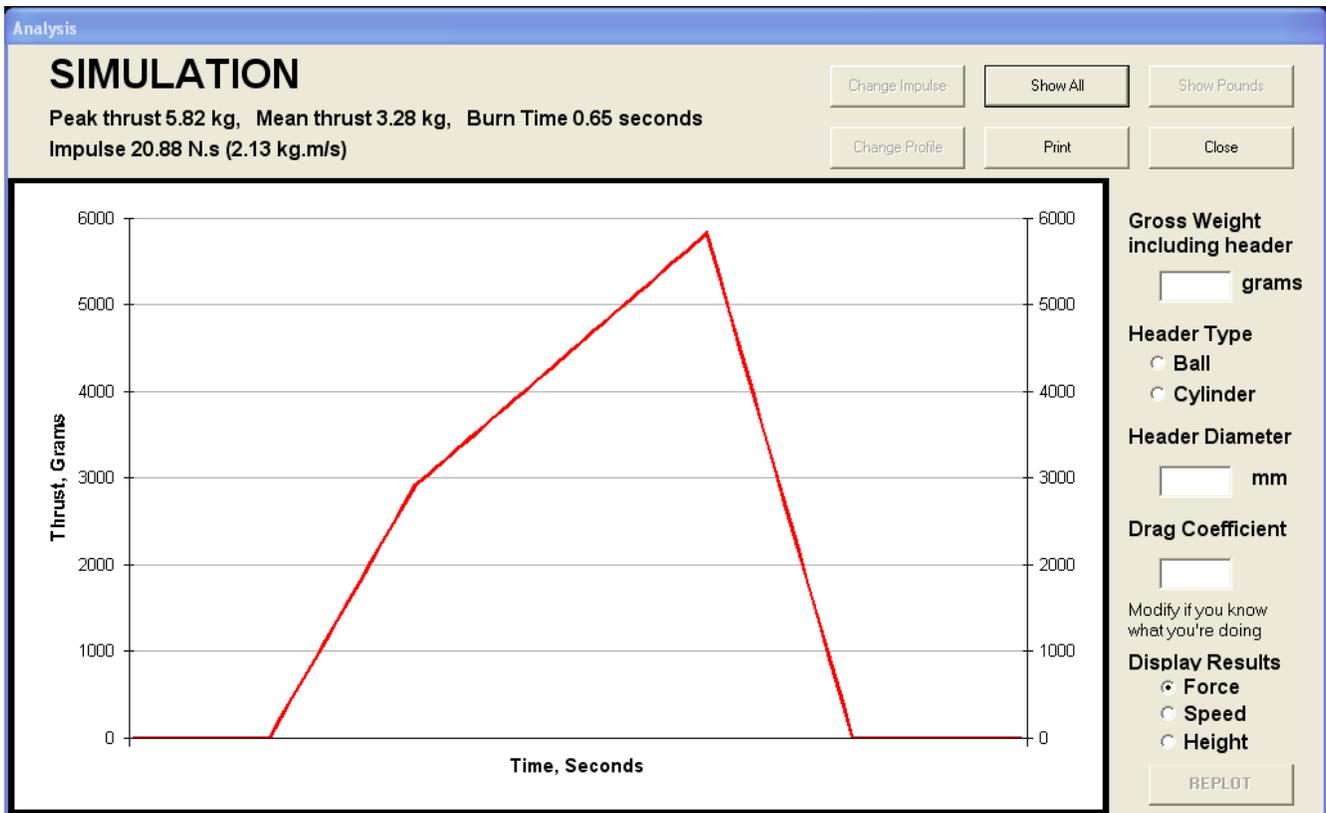
Impulse: 20.88 N.s

Newton.seconds lbForce.seconds
 Kg.meters/second lb.feet/second

Burn Time: 0.65 seconds

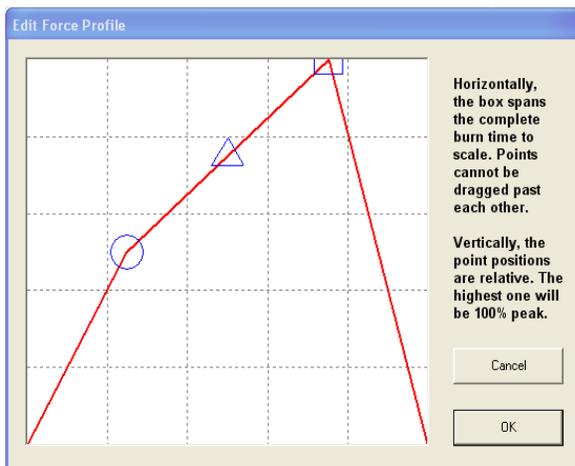
Buttons: OK, Cancel

Change Impulse sets the amount of power provided by your simulated rocket, in whichever are your preferred units. I'm going to try and recreate by hand the example trace shown previously, so I entered its impulse in Newton-seconds. I could as easily have given it in pounds-feet, but I'm a metric kind of guy. I also entered the burn time as 0.65 seconds. When I click **OK** I get this -

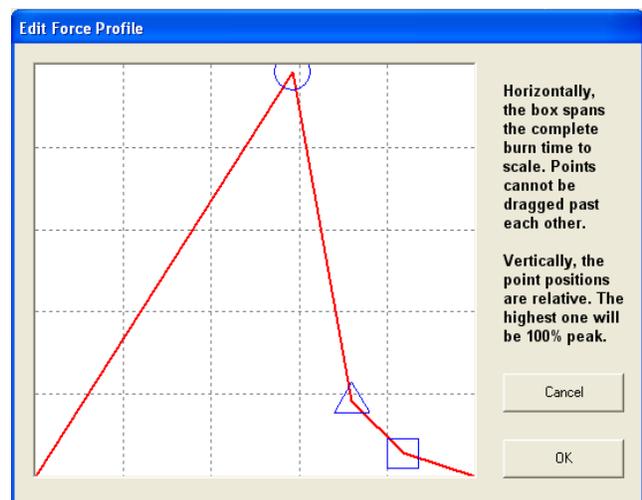


(Expanded Impulse view shown)

Now that doesn't look exactly like the example above, which is where the **Change Profile** button comes in. Click it and this appears:

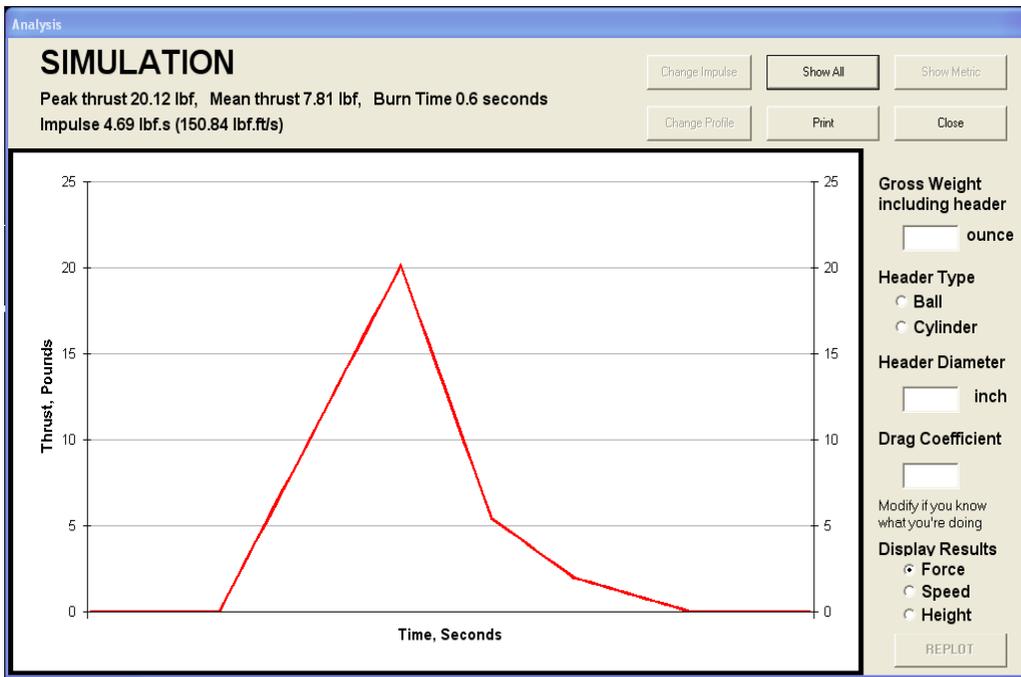


It is the impulse, with three line break points indicated by the circle, triangle and square. You can click on these three points and drag them until the shape is approximately what you want to see.

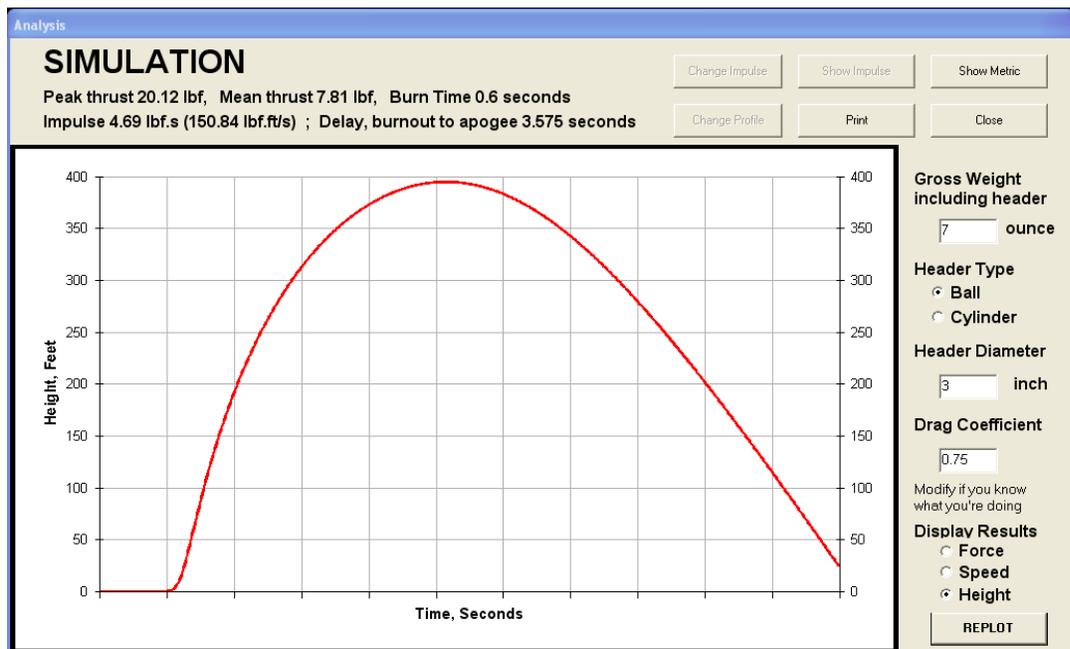


I could have included more than 3 break points, but it becomes very cluttered.

Click **OK** to return to the main screen, where we see this (next page):



Well, it could be better, but that's sort of the same shape. Now I can input the rocket header parameters and see what results I can expect.



It's not exactly the same as the example, but it's close. The point of the simulation is to help you estimate the impulse and burn time you need to provide to lift a given weight and size header to the height you want. From that, you can determine the size and fuel type of the motor you need.

Play with this. Use the **Change Profile** tool to see what difference it makes to have a fast or a slow ignition and rise time. It may help you to decide whether to fuse at the top of the core or at the nozzle.

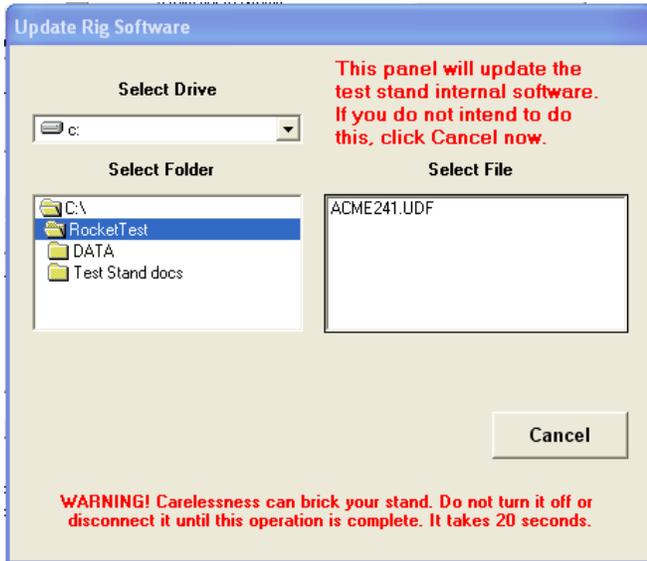
The Red Button



From time to time I may make changes to the other part of the rig software, the part that runs inside the rig itself. This button will update the internal program.

When there's an update, I will issue a special file with a .UDF extension. On clicking the red button, the following window

appears:

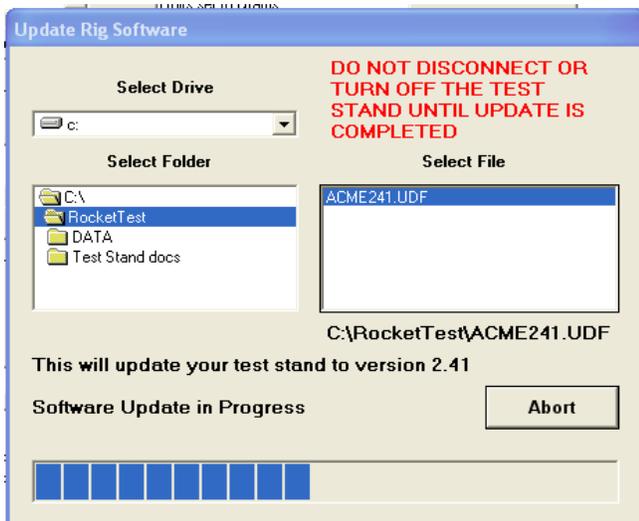
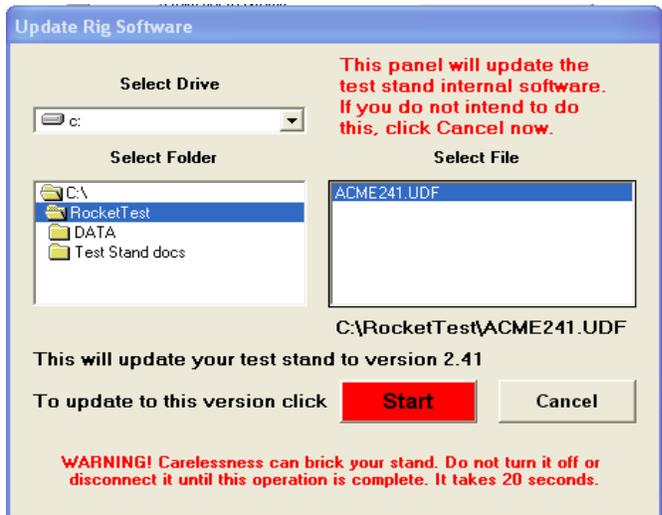


The only files that will appear in the **Select File** window are valid rig update files issued by me. The internal structure of the file is examined to determine this – not just any old file with a UDF extension will show up.

The file doesn't have to be in any particular folder. Depending how you got it, it may be in your **Downloads** folder, or on a flash thumb drive. You can navigate around the computer with the Drive and Folder windows until it shows up.

(Note: you don't have an update file at the moment, so you can't try this yourself.)

When you find and select the file, a red **Start** button shows up. When you click this button, **you are committed**. The rig light will turn blue and its software will be replaced. This takes about 20 seconds. At the end of the process the rig will reset and come back with a green light.



If something goes wrong, the rig's light remains blue. At that point, you call me for help. It's pretty unlikely, but could happen if the download process gets interrupted, such as if you trip over the cable, or the cat walks on your keyboard during the download.

BE CAREFUL WITH THIS FEATURE.

Mechanical Adjustments

There are two, both related to overload protection for the load cell.

The load cell is rated for 100kg, 220 pounds. Its “safe” overload is 120%, ie 120kg, 260lb, and its ultimate overload (beyond which permanent damage may result) is 150%, 150kg, 330lb. There are two adjustable stops in the rig to prevent such overloads.

On the fixture stem is an E-ring, which prevents the stem moving all the way in to the rig. At the bottom of the stem, resting on the load cell, is a set screw and locking nut. This should be adjusted by trial and error such that when a full load of 220 pounds is applied to the stem, the E-ring is resting on the top of the guide tube. This protects the load cell from gross overloads.

There's another failure mode, ballistic overload. This happens in the case of a sudden impact, like a violent CATO. The stem stops on the overload stop, but it has given the load cell a good whack. The load cell then keeps moving, bending under its own inertia, and can go far beyond its safe overload point. To guard against this, underneath the rig is a set screw. This should be screwed in until it just touches the bottom of the load cell under full rated load.

If you have a press, it should not be difficult to set these screws. You can measure the applied force directly from the rig with the **Scale** function. If your only way of applying full load is with a couple of bags of cement, however, it will be more difficult. You can set them with a feeler gauge. There will not be much clearance from either stop at no-load, probably less than 0.005 inch (5 thousandths of an inch), so initially set the no-load clearance somewhat less than this, say 0.003 inches. Then progressively add load to the rig, using the **Scale** function to read the load. If you are able to read it up to full load, adjust the screws to reduce the clearance. If however you can't achieve full load, the stops are preventing it and the screws need to be adjusted to increase the clearance.

A field-expedient feeler gauge is a section cut from the side of an aluminum soda can. These are generally 0.003 to 0.004 thick.

Command Reference

AUTO (no parameters)

Prepare to start logging and fire the ematch after the ematch delay

DELAY n

Set the ematch delay to n seconds – n=0, disable ematch

DUMP (no parameters)

Upload the data currently in RAM in unadjusted format. If you just turned the rig on, it will be all zeros.

FREE n

Release memory n (1..18). FREE 0 releases them all. Note, this does not erase the memories, it just deletes their directory entry and marks them available. Any data in the memory can still be recovered until it is reused and overwritten.

LIST (no parameters)

List the memory contents. Note, this is a directory list. It will display the run numbers of the data in all memories that have not been freed.

LOAD n

Copy the data from memory n (1..18) to RAM

RATE n

Set the sample rate. If n=0 or not supplied, the sample rate is set to 80 per second and the recording time will be 11 seconds. If n=1, the sample rate is reduced to 40 per second and the recording time will be 22 seconds. The default is 80 samples/second but the slow rate may be needed for some long-burning motors.

READ (no parameters)

Read the current load on the rig. In other words, use it as a scale. The resolution is about 2 grams with a 100kg load cell.

SAVE n

Save the current data in RAM to specified memory (n = 1..18). The memory will be written regardless of whether it is marked free or not. This can be used to duplicate a data set.

SEND (no parameters)

Send the contents of the RAM memory in a format suitable for input to Excel.

SPAN n

Calibrate the rig to weight n grams. You must enter this weight in grams, not pounds. This only needs to be done once for a particular load cell. See the section on calibration for details.

START (no parameters)

Prepare to start logging. This is the same as AUTO, but the ematch is disabled and will

never fire.

INFO (no parameters)
Report the test stand settings.

TRIG n
Set the force trigger level to n grams. You must enter this force in grams, not pounds. Logging starts when a force equal or greater than the trigger level is sensed on the load cell.

UNIT x
Select pounds (x=P) or grams (x=G). This only affects the way data is displayed – the rig always uses metric units (grams) internally.

ZERO (no parameters)
Zero the load cell. Functionally, this is the same as turning the rig off and on.

UPLOAD (no parameters)
Upload the data currently in RAM, in Excel format.

FIRE (no parameters)
Fire the e-match

STOP (no parameters)
If the rig is armed, disarm it.

Commands beginning with exclamation point (!) do not echo, and return data in a special human-unfriendly format for the PC program. They can be entered manually, but this is not really necessary. I include them here for completeness.

!MEM ; send list of saved records
!GET ; send data direct from memory N (0 = RAM)
!INF ; return box info
!VAL ; return weight in grams
!CLR ; free memory N (0 = all)
!ZER ; zero the load cell
!TRG ; set trigger level
!DLY ; set ematch delay
!ARM ; auto
!80S ; log 11 seconds at 80 samples/sec
!40S ; log 22 seconds at 40 samples/sec
!CAN ; disarm