Thrust Curve Tool   **ThrustGear.com**

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John@ThrustGear.com

Introduction

The ***Thrust Curve Tool*** was designed to analyze rocket motor thrust data and to produce standard '.eng' files for use with flight simulators such as Wrasp and Rocksim™. The program makes it easy to visualize the thrust curve, determine the motor's specifications, plot the data, and produce an optimal '.eng' file. It's now possible to go from motor test firing to rocket simulation in just a few minutes!

This software tool is useful for both amateur/experimental rocket motor builders and model rocketeers. If you have a test stand and a data acquisition system, you may load the raw output data into the ***Thrust Curve Tool*** in a variety of formats. It will compute the total impulse, peak thrust, average thrust, specific impulse, burn time, and standard NAR/TRA motor designation. You have the options of filtering the data and choosing the number of points for the ".eng" output while interactively generating a "best fit" compact thrust curve.

The "Auto Optimize" feature further automates the curve-fitting process. By selecting this option, the program finds the least number of points needed to reproduce the thrust curve shape while maintaining the original total impulse. In most cases, a simulation program will produce the same flight profile with this minimized '.eng' file as it would with the raw data points. If you wish to override the results, the ***Thrust Curve Tool*** lets you increase the number of points while automatically reshaping the optimized curve and adjusting the total impulse.

The program also reads in existing '.eng' files. This feature is useful if you wish to visualize and plot a rocket motor's thrust curve, or verify any manual modifications you may have made to an 'eng' file. For example, a delay at the beginning of the thrust curve is useful when simulating a cluster with air-started motors.

The interactive display allows you to resize the plot while automatically scaling and labeling the axes. A JPEG image of the graph may be saved to a file or copied to the clipboard and pasted into other programs.

Installing & Running

The program runs on any computer that has the Java runtime environment (JRE) installed. This package is available for free from Sun Microsystems for Windows, Macintosh, and Linux. For people with Mac OS-X, the JRE comes installed from Apple. To download and install Java, go to:
http://www.java.com/en/download/manual.jsp

Copy ThrustCurveTool.jar to a working folder where you'll keep your rocket motor data files. If you downloaded the example data files, save them in this folder as well.

To run the program, double-click on the ThrustCurveTool.jar icon. If Java is installed properly on your computer, the program will open and display the file selector dialog. If it does not run, change the properties of the ThrustCurveTool.jar file to associate it with Java (usually called "Java(TM) 2 Platform Standard Edition" or something similar on Windows).

Or, you can run the program using the TTC.bat batch file on Windows computers. Put this file in the same folder as ThrustCurveTool.jar. You may also create a short-cut to the TTC.bat and place it on your desktop.

For further assistance with installation of the program and configuration of your computer please visit our website at: www.ThrustGear.com .

Overview of Features

All the features of the *Thrust Curve Tool* program are accessible from one window. The major regions of the program window are described below.

There are six **Buttons** along the top that select the major functions:

- **Load**: read an input file and translate it (Dataq™, RDAS™, ASCII, or ENG).
- **Save**: output a standard ".eng" file for use with rocket simulator programs.
- **Redraw**: update the graph using the current input parameters.
- **Image**: generate a *JPEG* image of the graph, to file or clipboard.
- **Help**: a brief description of the program's features.
- **Exit**: quit the application.

The **Graph** area shows the input (blue) and output (green) data plots. When the output graph is generated, it overlays the input graph to show you how well the output curve represents the original thrust data. The time and thrust axes, along with the grid, are labeled & resized automatically when you change the size of the program window. Two features of the graph area include: the burn-time duration marks (vertical red dashed lines), the average thrust level (horizontal red dashed line); the motor designation line (text above the graph); and the motor performance line (text below the graph); all of these features are derived whenever you *Load* a data file or change the burn-time *Min Cutoff percentage*.

The **Input Panel** (on the right side) is where you enter in the motor information for the ENG output. It's also where you choose the number of points to output. For most curves, 32 points are more than enough to produce a good ENG output file. The *smoothing* factor chooses the amount of filtering applied to the input data before producing the output curve. A value of '0' leaves the input data unchanged (this is good for small sets of input data); higher values will remove more of the noise and spikes ('1' is good for most input sources). Too much smoothing could remove significant features of the thrust curve's shape.
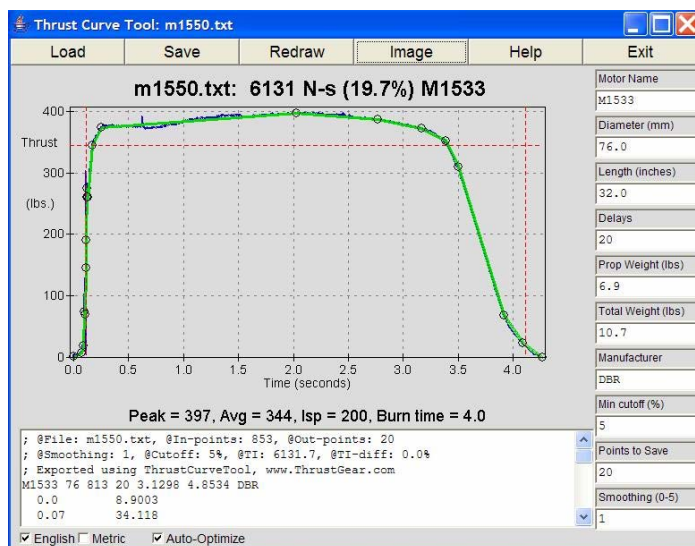
Located near the bottom of the window, the ENG **Text Box** contains the output text. This is an exact copy of what will be written to the '.eng' file when the Save button is used. Each time you change an input parameter or redraw the graph, this information is regenerated. If you add your own comments at the beginning of the Text Box, they will be kept each time the text is updated. In case you forget to add a semi-colon at the beginning of the line, one will be added for you to let simulation programs know it's a comment line.

The **Options** area appears at the far bottom of the window. Click on *English* or *Metric* and the display will convert everything for you. Change back and forth at any time. Note that the motor diameter always stays in millimeters because this is the standard measure for model and high-power rocketry. The Auto-Optimize check box enables the higher-level automation built into the *Thrust Curve Tool* program. When this feature is enabled, it generates an output curve with the least number of points. It uses the current smoothing level and stops when the difference in total impulse between the input curve and output curve is <0.1%. Increasing the *Points to Save* will override the results and cause it to search for the next best curve fit. By disabling the Auto-Optimize function, you can try various numbers of points and smoothing levels while observing the results.

Thrust Curve Tool

Quick Start Examples

Load, Plot, and Save

- o Start the program by double-clicking on the *ThrustCurveTool.jar* icon.
- o Select a ".txt" or ".asc" example data file from the file selector. Click the *Open* button.
- o The **blue** curve shows the original data curve. The motor specs are displayed.
- o Edit the motor information on the right side. This info is used in the ENG output file.
- o Keep the default of 5% for the "*Min Cutoff".* Enter *"Points"* as 32 and *"Smoothing"* as 1.
- o Press the *Enter* key while in one of the input boxes, or click on the *Redraw* button.
- o The **green** curve is a 32-point best-fit approximation of the input data, after smoothing.
- o Add comments at the top of the Text box if you wish to put your own info into the ENG file.
- o Note the "@TI-diff" percentage in the *ENG Text box*. This shows how well the output curve matches the input curve, as measured by the total impulse.
- o Increase the *Points* if needed. Press the *Enter* key or click on the *Redraw* button.
- o Save the ENG file by clicking on the *Save* button. Use ".eng" as the file extension.
- o The resulting ENG file may now be used within your favorite simulator program.

Using Auto-Optimize

- o After Loading a data file, click *Auto-Optimize* on the bottom line of the program window.
- o The program will find the smallest number of points for a total impulse error less than 0.1%.
- o The resulting output curve is automatically adjusted for no error in total impulse.
- o Note the number of points it found. You may override this value for a better fit.
- o Input a value one point larger in the *"Points to Save"* box, press Enter.
- o Note again the number of points found. Repeat if necessary for a desired curve fit.
- o For data files with a lot of 'spikes' and 'noise', increase the *"Smoothing"* factor and repeat.
- o Enter your motor information on the right. *Save* the ENG file.

### Creating an Image of the Thrust Curve

- o Any time after Loading a data file or Redrawing a curve, you may create an Image.
- o Resize the program window to the desired graph size.
- o Click on the *Image* button at the top of the program window.
- o Select the *File* option to create a JPEG image file. View the file in a graphics program.
- – or –
- o Select the *Clipboard* option to copy the graph image to the system's clipboard.
- o Open a program that allows you to use graphics. Paste the clipboard into your document.

Note: using the clipboard will generally produce a sharper image than saving to a file.

Loading Input Files

Using Dataq/Windaq Data Files

The Dataq data acquisition system is a popular low-cost product used by many rocket motor experimenters. The Windaq software package lets you open the Dataq output files, view the waveform, apply calibration, and export the thrust curve data. The following describes how to export the data for use with the *Thrust Curve Tool*.

Open the ".WDQ" file containing your test stand data with the Windaq Waveform Browser. Show the single waveform channel containing the force transducer data. Locate the thrust curve by zooming in on the portion of time where the data was sampled. Under the "Scaling" menu, choose Autoscale, then use the horizontal scroll bar to find the thrust data. (The Page-Up, Page-Down and arrow also scroll and zoom in.) Place a marker line just before the start of the thrust curve by clicking below the graph area and above the scroll bar in Windaq (on the line that shows the time info).
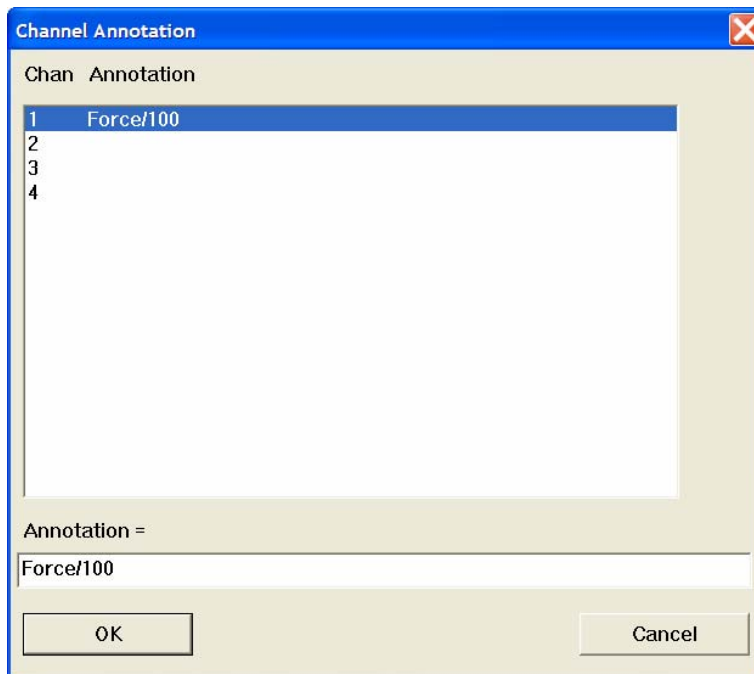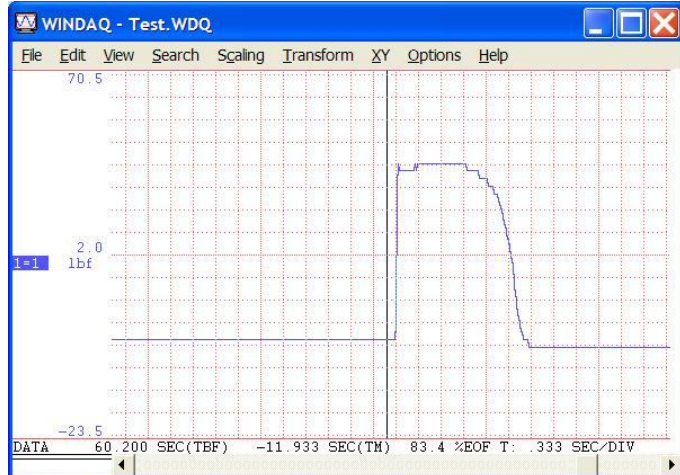
As an option, you may label the Force channel and enter a calibration factor. Go to the "Edit" menu in Windaq and select "User Annotation". Click on the channel number that contains your thrust data and enter the word "Force" at the bottom. If your data is not calibrated in pounds, enter in a scale factor here. For instance, if the sampled data is actually 100 pounds per volt then enter "Force/100". *Thrust Curve Tool* will apply the factor to correct the data (all points will be multiplied by 100 in this example). You may also use this to apply a small calibration factor to your load cell. The offset will be taken care of automatically in the *Thrust Curve Tool* program.

To export the data in a format readable by the Thrust Curve Tool, go the File menu and select "Save As…".   Choose option #5, labeled "Spreadsheet print (CSV)".   Also, check the box labeled "Visible channels only". Make sure no other boxes are selected. Enter a new file name and include the file extension ".asc". Choose the folder where you want to save the file (such as the place where you put the ThrustCurveTool.jar program). Click on the Save button.
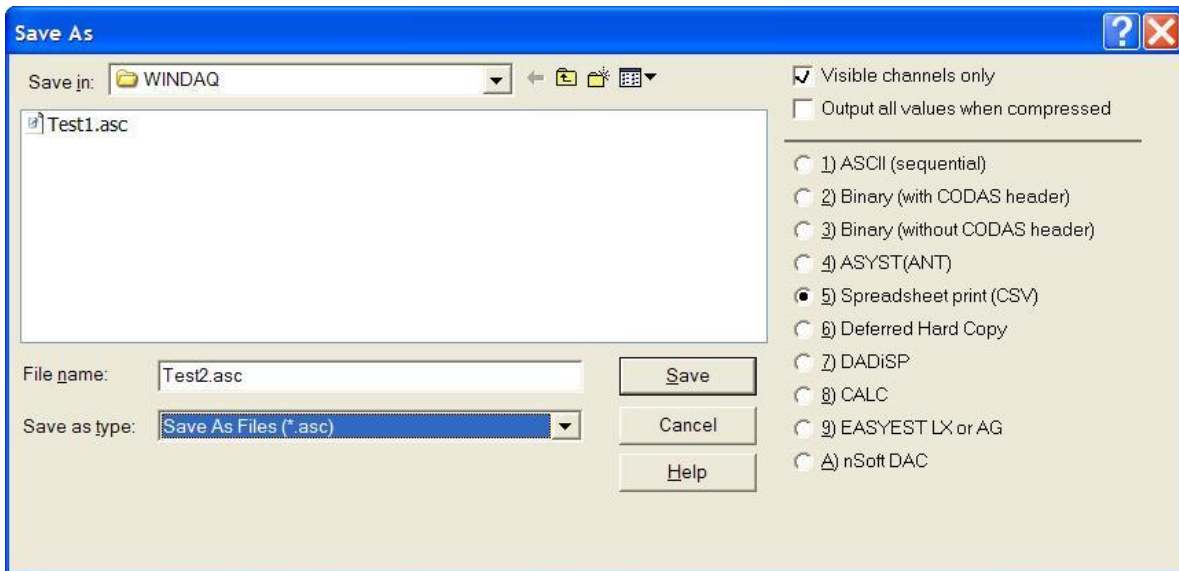
The "Spreadsheet Comments" dialog will appear in Windaq after you click the Save button. Make sure you have ONLY the following boxes checked: "Comments", "User Annotation", and "Relative Time".   Click on the OK button and your file will be exported and ready to load into *Thrust Curve Tool*.
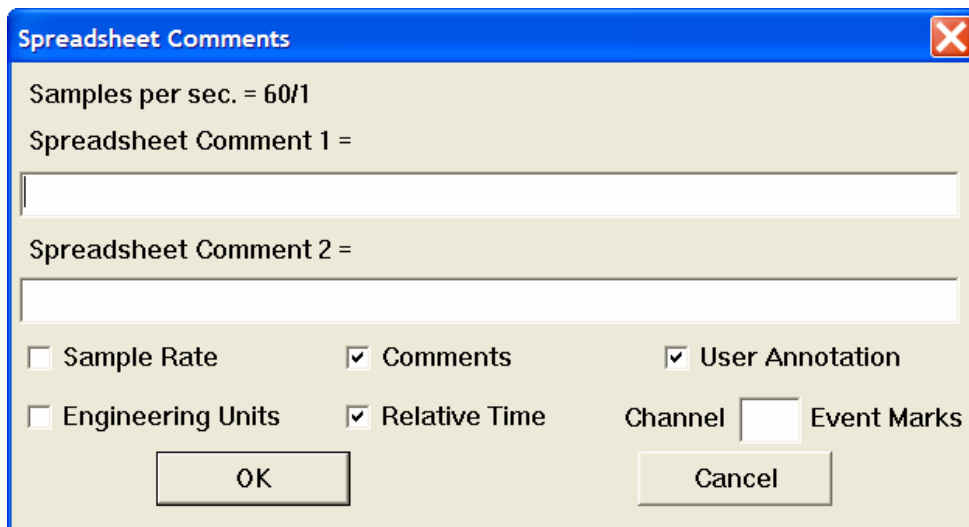
General Notes about Input Files

DATA OFFSET
   If there is an offset in your Windaq data, it will be removed when the file is Loaded into the Thrust Curve Tool. The **first** value in the exported data file will be used as the "zero" level. If you wish to change this value, open the ".asc" exported file in a text editor (such as Notepad), change the first value at the beginning of the file, and save the file as the same name.

LEADING and TRAILING ZEROS
   You will probably have many zero-level values at the end of the active thrust portion of the data. When you first generate the output curve in the Thrust Curve Tool, you will be asked if you wish to truncate the trailing zeros. However, if there are leading zeroes (before time=0, or ignition), they will be retained in the file. Typically, it is a good idea to remove these extra data points by edited the file with Notepad, etc. Remember that you will be asked to remove extra trailing zeros only once after loading a data file; if you change your mind, just *Load* the original data again and hit *Redraw*.
   It may be desirable in special circumstances to leave in the leading zeros to simulate an ignition delay (for delayed ignition in clusters, for example).

DATA FILE SIZE LIMIT
   The maximum number of data points allowed in any input file is 30,000. The time increments for each point does not need to be consistent (gaps in time are allowed).

(NEW) DELAY TIME AUTO-LOCATOR: If the data file contains an additional spike after the end of the actual thrust curve, this point in time will be used to determine the motors ejection delay time. The time is calculated from the "Min cutoff %" time and the end of the curve to the 'spike', per NFPA 1125. A vertical green line is drawn at the ejection point.
   The characteristics of the spike must be: 1) at least ½ sec from the point were thrust goes to zero; 2) the value of the mark must be above the noise level which is set as 0.005 pounds in this version; and 3) must be the LARGEST spike in the 'tail' to the end of the motor data file. If your file does not fit these limitation, it must be edited by hand to get TCT to pick the delay time. A common problem is noise at the beginning of the file. Another problem is that the thrust doesn't go to zero during the 'tail' of the motor burn to the end of the file. Insert a zero level (same value as the first point in the data) somewhere before the ejection spike.

Using Excel Spreadsheet (CSV) Data Files

   The "Comma Separated Value" format (CSV) is standard to many programs. Choose this file format when exporting data from Excel or Windaq. This format may have extra columns, a field header, and a calibration value. For example, here is the beginning of a CSV file exported from Windaq:

```
"Time","Force","Volts","",""
.000, 1.9531E+00, 2.4414E+00, 2.4414E+00, 2.4609E+00
.017, 1.7578E+01, 2.4609E+00, 2.4414E+00, 2.4609E+00
.033, 2.9297E+01, 2.4609E+00, 2.4609E+00, 2.4609E+00
[etc.]
```

 The first line contains labels for each of the 5 columns in this input file. Only two columns are required. *NOTE: the first column must be the time values!* If the thrust values are not in the second column, label the appropriate column as "Force". All other columns will be ignored if each has at least a pair of empty quotes. The thrust may be regular decimal numbers or in exponential format (as shown).   A calibration factor may be inserted anywhere in the first line within a label. For example, the first line above could look like this:

```
"Time","Force/49.778","Volts","",""
```

The '/49.778' would cause every thrust value to be <u>multiplied</u> by the factor 49.778 . In other words, the input data represents pounds thrust divided by this factor. This is useful if the input values are in units other than pounds (such as volts). The above example would apply the calibration of about 50 pounds per volt. The * (multiply) symbol is also allowed. "Force*4.45" would convert data in Newtons to Pounds. This feature may also be used to apply a calibration adjustment after the motor was fired and the data were saved. If there is an offset, make sure the average offset is the **<u>first</u>** thrust value in the file.

Using RDAS Data Files or Raw A-to-D Data

The analog-to-digital file format contains up to 16 columns of data with a special header added. The first column must be the time, but any other column may contain thrust data. The thrust values are raw analog-to-digital levels from 0 to 1023 (10 bits). These values are converted to volts by default, with 5 volts being full scale. To apply a scaling factor, the first line of the file must begin with the '#' symbol. For example, here is the first 4 lines of an RDAS export, plus 2 new header lines:

```
#200.0
@5/6
37.270  528  924   18    24  591
37.275  527  923   18   321  591
37.280  532  923   18   285  591
37.285  526  923   18   274  591
[etc.]
```

After exporting from the RDAS software, all of the non-numeric text was removed from the file (using a text editor). Next, all of the extra data lines were removed before and after the thrust data. Remember that the first line of actual data in the file will be used as the zero thrust offset. Two new lines were added to the top of the file to choose the following:

- o   The first line beginning with '#' is the scale factor in 'pounds per volt' (assumes 10 bits).
- o   The next line beginning with '@' selects column 5 for thrust with 6 columns total.
- o   The default is 5/6 but any column greater than 1 may be used for thrust, up to 16 total.
- o   Note: for other than 10-bit values and 5V max, change the scale factor accordingly.

Up to 30,000 lines are allowed in any input file. Extra spaces and tabs are ignores. Other non-numeric characters are not allowed in the raw a-to-d data file.

(NEW) **SPECIAL CASE (NAR S&T):**   If a single column of data is contained in the file, with no header, it is assumed to be thrust in Newtons and the sample rate is assumed to be 500 Hz (or 0.002 sec per sample).

Using Existing ENG Files

The Thrust Curve Tool will read in a standard ".eng" motor file. Currently, if the file contains multiple motors, it will read in the first motor description in the file. If you would like to read in some other motor than the first one, read the multi-motor ENG file into a text editor (such as Notepad) and cut/paste the motor description into a new text file.

If redundant data is found in an existing ENG file, points are removed when it is saved. You may also set the "Points to Save" to a smaller value to create a new ENG file that approximates the original.

There is no limit to the total impulse, thrust level, and burn time of the motor.

GRAPH AREA DETAILS

Input graph:
The input graph is shown in blue. The input data is left unchanged as a reference.
The time and thrust axes, along with the grid, are labeled & resized automatically
when you change the size of the program window.

Output graph:
The output graph is shown in green and depends on the 'Points to Save' and 'Smoothing'.
It is redrawn whenever an input field is changed (then press Enter) or click the Redraw
button.
The output graph is drawn over the input graph to visualize the current approximation.

Motor Designation line (top):
The motor's total impulse and standard designation are displayed above the graph.
The total impulse percentage helps compare motors within the same letter class.
The average thrust (in newtons) follows the letter in the standard designation.

Motor Performance line (bottom):
The peak thrust, average thrust, and burn duration are displayed below the graph.
The thrust values are shown in the selected units of measure (pounds or newtons).
If the propellant weight is entered, the I_{SP} is inserted here before the burn time.\n");
The I_{SP} (specific impulse) is the Newton-secs per weight (propellant efficiency).

Burn-time Duration marks:
The burn time begins when the thrust exceeds a set percentage of the peak thrust
and ends when the thrust falls below this value. The standard is 5% of peak thrust.
These points in time are shown as red vertical dashed lines on the graph.

Average Thrust level:
The average thrust is calculated by dividing the total impulse by the burn time.
A red horizontal dashed line indicates the average thrust level on the graph.

Thrust & Time axes:
The grid lines and labels are optimized to fit the chosen size of the graph.
Re-size the window (with the mouse, etc.) to increase or decrease the resolution.

INPUT PANEL DETAILS

Motor Name:
 The 'Motor Name' is the standard NAR/TRA designator.
 If you leave this blank, it will be inserted automatically.

Diameter:
 Enter the outside diameter of the motor in millimeters.
 This is the only field that does not change with English/Metric.

Length:
 Enter the overall length of the rocket motor casing.
 This field and those that follow use the English/Metric option.

Delays:
 Enter the ejection charge delays available, seperated by the '-' sign.
 For 'plugged' motors, enter a value beyond the maximum apogee time.

Prop Weight (Mass):
 Enter the weight (pounds) of the propellant when in English units.
 Enter the mass (kilograms) of the propellant when in Metric units.

Total Weight (Mass):
 Enter the loaded weight (pounds) of the motor when in English units.
 Enter the loaded mass (kilograms) of the motor when in Metric units.

Manufacturer:
 Enter an abbreviation for the motor manufacturer.
 Some simulation programs may not like non-alphanumeric characters.

OUTPUT OPTIONS

Min cutoff:
 Enter the percentage of max thrust used to determine burn time.
 The standard is 5%. This will also affect the average thrust.

Points to Save:
 Enter the desired number of points to use in the ENG output file.
 Press 'Enter' or click Redraw to update the graph.
 The program locates the best points for minimum error.

Smoothing:
 A value of 0 through 5 chooses the smoothing applied to the input.
 Enter 0 for no filtering. Use a higher value for 'noisy' data.
 Smoothing is reset to '0' when a file with less than 50 point is loaded.\n");
 A smoothing value of '1' is good for typical test-stand data with low noise.\n");

English/Metric:
 Select either type of measurement units at any time.
 The Input panel and the Graph information will change automatically.

Auto-Optimize:
 After loading a file, the Auto-Optimize feature is turned off. Click on the check box to enable/disable this feature. By enabling Auto-Optimize, the program will find a 'best fit' output. It finds the least points needed for an error <0.1% in total impulse. After that, it applies an overall scaling to reduce the error to zero. The next higher 'fit' is found by manually increasing the 'Points' by one.

ENG Output File Format Details

ENG FILE EXAMPLE:

This is an L1240, about 4000 N-sec, with a 3.2 sec burn time. It has 19 points generated to approximate the 650-point input file. It was created by applying a smoothing factor = 1, with the standard thrust cut-off percentage = 5%. The output curve has zero error in total impulse compared to the raw input data (AutoOptimize was used).

The ENG header details are as follows:
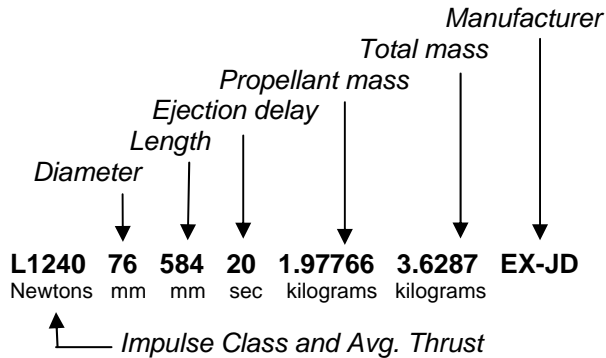
```
; 4-grain 76mm Purple Punch, John DeMar, 7/4/2005
; @File: pp4gr76jd.eng, @In-points: 650, @Out-points: 19
; @Smoothing: 1, @Cutoff: 5%, @TI: 3968, @TI-diff: 0.0%
; Exported using ThrustCurveTool, www.ThrustGear.com
L1240 76 584 20 1.97766 3.6287 EX-JD
 0.0010    1083.42
 0.212     1154.75
 0.419     1216.9
 0.612     1267.15
 0.803     1308.74
 0.991     1341.09
 1.168     1363.28
 1.351     1377.47
 1.537     1382.53
 1.715     1378.47
 1.892     1365.86
 2.066     1345.29
 2.252     1314.69
 2.614     1231.49
 3.019     1106.73
 3.051     877.35
 3.133     398.27
 3.164     187.21
 3.22      0.0
```

Manufacturer
Total mass
Propellant mass
Ejection delay
Length
Diameter

L1240   76   584   20   1.97766   3.6287   EX-JD
Newtons   mm   mm   sec   kilograms   kilograms

Impulse Class and Avg. Thrust

Comments:
Any line that begins with a semicolon ';' is a comment line.
Add your own comments at the beginning of the ENG Text box.
Your comments will be kept when the output is Redrawn or Saved.
@File:
A few parameters within ThrustCurveTool are saved within the comments.
The original filename of the input data is noted after the '@File' label.
NOTE: Any comments you add after this line will not be saved!
@In-points:
This is a note showing the number of points loaded from the input file.
Most data acquisition systems record 100's of samples per second.
@Out-points:
This is a note showing the number of points in the output data.
If a zero was removed, there may be one less here than entered in 'Points'.
@Sm:
This is a note of the Smoothing level applied when producing the output.
@CO:
This is a note of the Cutoff percentage applied when computing burn time.
@TI:
This is the Total Impulse for the estimated data in the ENG file.
@TIa:
This is the truncated Total Impulse using to find average thrust during burn time.
@TI-e:
This is the 'Total Impulse Percent Error' between the input and output data.
@ThMax, @ThAvg:
These are the maximum thrust and average thrust in the ENG file data.
@Tb:
This is the burn time in the ENG file data.
ENG header & data:
The motor info entered into the Input Panel is used to generate this header.
The header is generated automatically whenever the graph is changed.
Simulation programs use this to determine all the motor parameters.