



LogWorks 2 User Manual

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1 Overview

LogWorks is a software application that interfaces with the Innovate Modular Tuning System products. It enables easy analysis and manipulation of engine data acquired by MTS components and also allows to view engine data in real-time on the on-screen virtual gauges.

This manual describes the basics of data logging with the Innovate Modular Tuning System and how to use the LogWorks 2.0 Program.

In addition this manual shows how you can extend the capabilities of the MTS with some basic electronic skills.

1.1 Specifications

Computer requirements

Operating System	Windows 98 or later
Computer speed	500MHz Pentium 1 or faster
RAM	Min. 48 Mbyte
Hard Disk space	Min. 100 Mbyte free space
Display	Thousands of colors, 800 x 600 Min.
Other	1 free serial port or USB to serial adapter

LM-1

Firmware version required	1.1 (1.33b or later recommended)
LM-1 Input Impedance	> 1 MOhm (- 0.5 to + 5.5V input range) < 10 kOhm (< - 0.5V or > 5.5V input range)
LM-1 Dynamic Input Impedance	Low pass filter 10 kOhm / 4700 pF
Data logging rate	12.21 times/second for all inputs concurrently Equivalent to 81.92 msec per data set
LM-1 Max. Logging time internally	44 minutes
LM-1 Max number of sessions intern.	1024

LogWorks limits

Max. Session Size	1 hr 45 minutes
Max. Number of sessions per log	1024
Max. Number of logs open	32 open concurrently

2 Logging engine data

2.1 Data logging 101

Data logging is basically the recording of engine data. Engine data is measured with various sensors. Two types of logging are common.

- a. Time based logging
- b. RPM based logging

In time based logging the sensor data is read in fixed time intervals. This is similar to how a movie projector or a TV works. In a movie, a snapshot of the camera scene is taken 24 times per second. Because of the limited speed of the human eye, these snapshots, when viewed at the same sample rate of 24 snapshots per second, seem like continuous motion to the human eye.

Time based data logging works the same way. A snapshot of the engine state is recorded at fixed time intervals.

RPM based logging is mainly used in conjunction with chassis- or engine-dynamometers. Their purpose is to measure power and torque curves of an engine in relation to RPM. Typical RPM interval is every 50 RPM. Although this serves its purpose, time-dependent dynamic effects can't be analyzed with this logging method.

A time based recording can be converted into an RPM based recording (LogWorks has that capability), but an RPM based recording can't be converted back into a time based recording.

2.1.1 Definitions

Channel

A channel is the data from a single sensor, like AFR or RPM.

Sample

A snapshot of the engine state is called a sample. A sample can contain the data of many channels, but they are all measured ideally at the same time.

Sample Rate

The sample rate is the number of samples (snapshots) of engine data taken per second.

Channel Rate

The channel rate is the number of total channel measurements taken per second. It is the number of sensors measured for each sample multiplied by the sample rate.

2.1.2 Logging speed

The data logging speed (samples per second) is dependent on what data is to be logged. When logging engine data, 99% of the data changes no faster than about 5 times per second (one state to another and back).

The engine state is ultimately controlled by the driver's right foot. The fastest external muscle in humans is the eye-lid muscle. It goes through one blink-cycle in about 100 milliseconds.

A mathematician named Harry Nyquist found out (in 1928), that for anything that you want to record, you only need to record at twice the maximum frequency contained in the recorded signal. So, for the human eye-lid, the required minimum logging speed is 20 times/second. The human foot, controlling a gas pedal, is much slower. Remember, the frequency is not measured from idle to WOT, but from idle to WOT and back.

The second parameter determining the logging speed is the statistical nature of the combustion process itself. No two combustion events in an engine are identical. Therefore, to get meaningful data, multiple combustion events must be averaged to see the overall effects. If each combustion event is analyzed and recorded, meaningful tuning data can't be seen in most cases. At 6000 RPM an engine goes through 50 engine cycles per second (a 4-stroke engine cycle requires two rotations per cycle). At a logging speed of 12.5 samples per second this would mean that the resulting data is the average of 4 engine cycles.

The above means that data logging engine data needs to be done at 10-15 samples per second. Anything more creates only more data points which do not contain any additional information, but are harder to analyze.

The Innovate Modular Tuning System samples engine data at 12.2 samples/second.

NOTE:

This sample rate is the rate for a sample containing multiple sensor data, each sampled at the same time instance, NOT the total channel rate.

When evaluating data-logging products be very aware of the difference between channel rate and sample rate. Many manufacturers specify the channel rate, but claim it as sample rate.

For example if a data logging system records 30 data channels, but reads each in turn only once per second, the channel rate is 30 per second, but the sample rate is only 1 per second.

This is especially problematic if the channels are not sampled at the same instance in time, but at whenever it is the turn for this channel to be read. The channel data, when taken and interpreted as sample, do not correlate anymore, because each reflect the engine state at up to 1 second apart and there is no way to correlate them.

Many OBDII based systems log this way because of the limited speed of OBDII, but some of the manufacturers claim 30 samples or more per second.

Higher logging speeds

There are situations when higher logging speeds are needed. To analyze engine data on a crank degree basis at a resolution of 1 crank degree, requires measuring at 72000 times per second at 6000 RPM ($6000 * 360 \text{ degrees} * 2 \text{ [Nyquist]} / 60$). The applications for this are very specialized. An example is to analyze the point (in crank degrees) where flywheel acceleration is fastest. With the availability of fast and cheap microprocessors today this data can be analyzed on the fly and then the results logged (for example as max. acceleration point) at a much lower speed of 10-15 samples per second.

Another application for higher logging speeds is suspension analysis. There typically the shock velocity needs to be known under various conditions. Measuring rates of 1000-2000 times/second are required to calculate shock velocity and travel amplitude. But again, this data can be processed on the fly and then get logged at lower speeds by modern microprocessors.

2.1.3 Logging resolution

Logging most channels involves interpreting voltages. Typically for most of today's sensors the voltage range is 0..5V. When a data logger reads these voltages they are converted into a number that is represented digitally. Converting the voltage to that number is the task of an analog-to-digital converter (abbreviated A/D or ADC). The highest number a A/D can represent conforms to the max. voltage it can read and also determines the finest resolution it can read. The number of 'bits' of the ADC specifies that highest number. For example for an 8 bit A/D the highest number is 255 (2 to the power of 8 minus 1). It could resolve the input voltage into 5/256 Volts. For a 10 bit A/D the highest number is 1023 and the resolution is 5/1024 Volts. So the resolution for any sensor is:

Range / (2 to the power of [number_of_bits]) or Range / 2^N,

Where N is the number of bits of the ADC.

Most MTS devices that read external voltages or internal sensors use 10 bit resolution A/D's. The exception is the AFR/Lambda data.

Even though the Lambda range goes from 0.5 to infinite, it is limited for logging purposes to 0.5 to 1.523 Lambda, or possibly 0.5 to 4.595 Lambda.

In the first case it is then still a 10 bit range with a resolution of 0.001 Lambda. In the second case it is a 10 bit range with a resolution of 0.004 Lambda.

The LMA-3 internally digitizes with a 16 bit ADC. It then uses the extra resolution to filter out noise and finally reduce the resulting resolution to 10 bit for the MTS data stream.

NOTE:

LogWorks always stores all channel data in the 10 bit raw format as digitized. How the numbers are interpreted for the user display depends on the user settable channel configuration. But the raw stored 10 bit numbers will not get changed when the interpretation changes.

2.2 Sensors and the Modular Tuning System

The Innovate modular tuning system (MTS) consists of various devices to measure, digitize and record various engine parameters. Typically these parameters are sensed by different sensors built either into the engine itself or into MTS components. These sensors measure for example temperatures, pressures, air-flow, air-fuel ratio and so on. Sensors convert the measured quantity into an electrical signal, typically a voltage between 0 and 5V, which can be logged or displayed by the MTS components. The sensors can be categorized generally into four different groups, depending on the output they produce:

a. Voltage output sensors with external supply

These sensors have mostly 3 pins. One for the supply voltage (typically 5V), one for the output signal, and one ground. Sometimes the ground pin is omitted and the sensor is grounded through its metallic body to the engine. Typical examples are Throttle Position sensors (TPS), Manifold Absolute Pressure sensors (MAP), and Mass Air Flow Sensors (MAF). The output voltage has a typical range of 0..5V and varies for most sensors linearly with the measured quantity.

b. Voltage generating sensors

These sensors generate a (small) voltage more or less proportional to the measured quantity. Typical examples are Thermocouples and (Narrow-Band) O₂ sensors. Thermocouples output a very small voltage (in the microvolt range) that requires a special amplifier to make the signal readable and loggable. The LMA-3 Auxbox has such an amplifier built in. Narrow-Band O₂ sensors output a voltage in the milliVolt range (up to 1000mV). Their voltage output has a jump from low (~100mV) to high (700mV to 1000mV) when the AFR of the exhaust gas changes from lean of stoichiometric to rich of stoichiometric. They act more like switches than actual sensors. Basically they can indicate lean, rich and stoichiometric.

c. Resistive sensors

These sensors change their electrical resistance with the measured quantity. Very often the relationship between resistance change and the measured parameter is non-linear. Typical examples are Intake Air Temperature Sensors (IAT), coolant temperature sensors (CT) and some oil-pressure/fuel pressure sensors. Typically these sensors have 2 pins. One is ground, the other is connected to a load resistor. Often the ground pin is omitted and the sensor is grounded through its body to the engine. The other end of the load resistor is connected to a voltage supply (typically 5V). The purpose of the load resistor is to form a voltage divider with the sensor. At the connection between load resistor and sensor a voltage is formed that is dependent on the resistance change of the sensor according to this formula:

$$V_{out} = V_{supply} * R_s / (R_s + R_L)$$

Where V_{out} is the output voltage, V_{supply} is the supply voltage, R_s is the sensor resistance and R_L is the load resistor. For maximum sensitivity, R_L is typically chosen to be equal to R_s at the typical operating point.

A sensor that falls between resistive sensors and voltage output sensors with external supply is the throttle position sensor. Although it is a resistor with a movable tap, it behaves and interfaces exactly like a voltage output sensors with external supply.

d. Frequency sensors

These sensors output a signal that varies in frequency (oscillating voltage) with the measured quantity. Examples are some MAF sensors, the tach signal that measures engine RPMs and the vehicle speed signal generated by drive-shaft or wheel sensors.

The LMA-3 (Auxbox) has the capability to convert these frequencies into a digital or analog signal that can be interpreted and logged.

The MTS components convert the sensor data to a digital number between 0 and 1023 or a total of 1024 steps incl. 0. This is equivalent of a 10 bit resolution ($2^{10} = 1024$). The resulting resolution for a 0.5V signal is therefore about 4.9 mV. Any signal variations smaller than that cannot be resolved.

LogWorks has capabilities to convert the logged number back to the original quantity, provided the characteristics of the original sensors are known. This means that LogWorks needs to know how to convert the voltage output of the original sensor to the measured quantity equivalent.

The Air-Fuel-Ratio signal of the MTS components is not digitized from an external analog voltage. Instead it is internally calculated. For logging purposes this signal is internally always stored as Lambda with a resolution of 10 bits (1024 steps). To create the Air-Fuel-Ratio, the Lambda value is multiplied with the stoichiometric ratio for the given fuel (like 14.7 for gasoline) by the LogWorks software.

The datalog range for Lambda is 0.5 to 1.523, equivalent to 1024 steps with a resolution of 0.001 Lambda (for gasoline this is equivalent to a 0.0147 AFR with a range of 7.4 to 22.4 AFR). This range is more than sufficient for spark ignited internal combustion engines. AFR/Lambda ranges outside of the logging range are pegged at the minimum or maximum point respectively.

See the manual for the MTS device you are using for details on how to connect various sensors.

2.3 Sensor Hookup

Almost any sensor requires a ground connection. The voltage output of the sensor is referenced to that ground. If the device measuring the sensor is connected to a different ground, the voltage difference between the grounds can shift the sensor output voltage relative to the measuring device. Some measuring devices, like the LMA-3, have differential inputs to compensate for that offset. The negative side of a differential input is NOT a ground. It is intended to be connected to the same ground as the sensor. A measuring device with a differential input measures the difference between its own ground and the sensor's ground on the negative input and subtracts the difference from the measured voltage on the positive input to compensate for the ground offsets. The hookup from a differential input requires two wires. One for the signal itself and one for the ground reference. The ground reference input (typically named CHx-) goes to the grounding point of the sensor.

Ground offsets are especially problematic for resistive and voltage output sensors. They are not so important for frequency or duty cycle based sensors.

For a measuring device with common ground, like the LMA-2, it is best to ground all sensors at the same point where the measuring device itself is grounded.

Ground offsets can also affect frequency or duty cycle based sensors. Typically when measuring a frequency, the signal is measured as 'high' or 'low' depending on the measurement device's high-low threshold. In the LMA-2 or LMA-3 the threshold is 1V for the LMA-2 or 2.5V for the LMA-3. Ground offsets of 1V or 2.5V will not allow the device to measure correctly.

Another problem can be 'ground bounce'. If the signal generating device (for example an ignition system) creates very high current pulses, its ground can momentarily 'jump' over the threshold of the measuring device because of the high current. These 'ground-bounce' pulses are measured as false frequencies and can interfere with the measurement.

Another problem in sensor hookup is called 'induced noise'. In an engine compartment very high current pulses are routed many different places. These current pulses can come from the injectors, ignition system or alternator. Any (changing) current flowing through a conductor creates a changing magnetic field. A changing magnetic field intersecting another conductor (for example the sensor wires) will create a voltage along that conductor. This voltage is added as noise to the sensor signal. This is how an antenna for radio signals works as well.

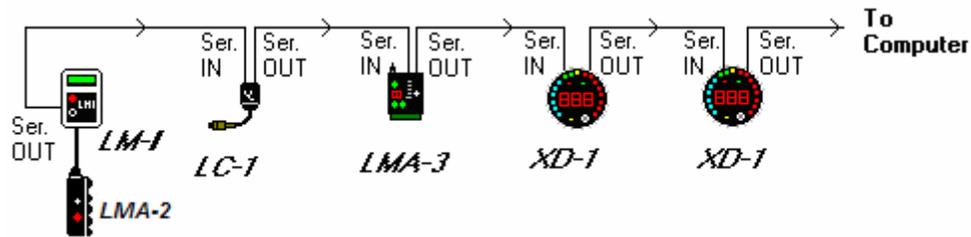
By twisting the sensor output and sensor ground wire together, that induced noise can be minimized. Each twist creates a wire loop acting as small antenna to pick up the induced noise. BUT, the noise induced in each loop changes polarity from loop to loop. This way each twist-loop cancels out the noise from the previous loop. The tighter the twist, the more cancellation can be achieved.

2.4 The Innovate Log-Chain concept

LogWorks 2.0 has the capability to log, display and analyze up to 32 engine parameters. Most users will use less though. Each of the MTS components reads between 1 and 6 (as of 6/1/05) engine parameters. To interface a multitude of MTS components to LogWorks with a single connection, the Innovate LogChain concept was introduced.

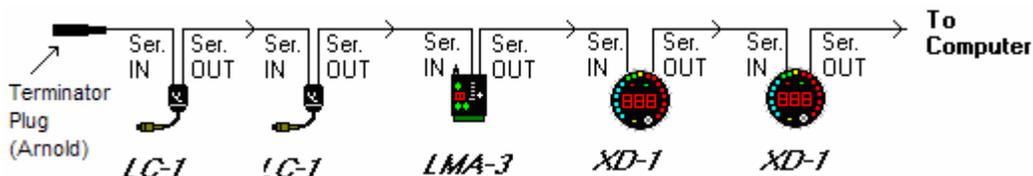
Each of the MTS components has two serial ports (except the LM-1, which has only one). One serial port is designated as IN-port, the other as OUT port. The OUT-port of one device is connected to the IN-port of the next device and so on. This way devices can be 'daisy-chained' to build a log-chain for up to 32 channels total. The OUT-port of the last device is connected to the computer for logging or downloading of logged data.

The following diagram shows how to connect multiple MTS devices to form a log-chain. The example chain consists of a LM-1/LMA-2, a LC-1, a LMA-3 and 2 XD-1's. In this case the chain has 12 channels (6 from LM-1, 1 from LC-1 and 5 from LMA-3).



Devices attached to the LM-1's analog input count as being part of the LM-1's 6 channels. They don't count extra. XD-1's do not contribute any channels, so you can add as many as needed.

Another Example Log Chain (7 channels with 2 AFR channels):



The device that's first in the chain is special. It determines the logging sample rate. The first device in the chain sends a data packet containing its channel data (a sample) to the next device (downstream, left to right in the diagram) every 81.92 milliseconds. The next device appends its data to that packet and hands that packet to the next device downstream and so on. At each device the packet grows in length. The devices in the chain synchronize their sampling of the engine parameters to the packets, so that all the channels in a packet together represent the same instance in time. At the downstream end of the log chain (OUT-port of the last device) a computer or external logger can be connected to store or display the stream data. The XD-1 display is such a device.

This also means that the complete channel data set is ONLY available at the end of the log-chain. A datalogger capable of recording the log-chain data-stream therefore MUST be placed at the end of the log-chain. This includes lap-top computers or other loggers.

Commands for individual devices are sent 'upstream'. A device (incl. a computer or an XD-1) can send commands to the devices upstream of itself, but not downstream. Commands can include start-stop recording, calibration/configuration commands and so on. Only the device directly upstream of the command originator of course will receive the command. This device then decides, depending on the command, whether to execute the command and whether to pass it on. An example of a case where the command is executed but not passed on is the start-stop record command. The first upstream device capable of logging internally will execute the command, but not pass it on.

As said before, the first device is special because it is the synchronization source for the entire chain. By plugging its IN-port with the supplied terminator connector, a device can detect that requirement when it powers up. The terminator connector just connects the transmit and receive line of the IN-port together. Each device sends a special command out on its IN port when it powers up. This command is ignored and not passed on by any device if received on its OUT port. If the sending device immediately receives that command on its IN-port again, because the terminator is plugged in, it assumes it is the first and special device in the chain. The LM-1, having only one serial port, is ALWAYS a special device and MUST be connected to the beginning of the chain.

2.5 Identifying devices and Channels

To easily identify which channel is representing which engine parameter, the channels must be given a name. Use short names to not use up a lot of screen real-estate.

USE ONLY NUMBERS AND LETTERS IN A CHANNEL NAME. THE ONLY SPECIAL CHARACTER ALLOWED IS THE UNDERLINE CHARACTER _ . A CHANNEL NAME MUST START WITH A LETTER.

LogWorks allows you to configure each channel. Part of the configuration is the name. Also the color in which the channel is displayed is programmable in LogWorks as well.

To further easily identify the channels each MTS device **MUST** be given a name. This name can be up to 8 characters long and is programmed into the device. Use the LM Programmer application to change the name of a device. This is especially important when multiple devices of the same type are used.

When LogWorks start up, it will identify the devices in the LogChain. If new devices have been added or devices removed, LogWorks will automatically change its channel configuration to reflect the new log-chain configuration. Channels associated with a device previously will stay associated with that device, even if the device has been moved to a different location in the chain, provided it has been given a unique name.

For details on channel configuration see chapter 3.3.

2.6 Logs and Sessions

Different to other data logging products, LogWorks organizes the acquired data in logs and sessions. A session is a contiguous data set. This means there is no interruption in the data stream and all data points are spaced equally in time (81.92ms apart). Each time you start logging, a new session is created and the session ends when the logging stream is stopped.

A log is a collection of sessions. In a typical qualifying race or tuning session multiple runs are made, and each run is data logged. LogWorks conveniently organizes these runs into a common log. The sessions in a log are numbered from 1 through x. Typically they are sequential in time, starting with the oldest session as session 1 and so on. Each log can be stored in a separate file on the computer. Each session can be renamed so it does reflect something more meaningful than just a numbered sequence.

In addition each log contains the information on how to convert the digitized numbers (see [Logging engine data](#)) into the original quantities. These so called channel settings apply to all sessions in a log.

LogWorks distinguishes three different kinds of logs:

a) Real-time log

This is a log created by connecting a computer to the MTS log-chain and recording the real-time data stream from the MTS devices to the computers hard drive. New sessions can be added at any time by starting to record the serial stream. Only one real-time log can be open at any time. The current real-time input settings apply to the real-time log.

b) LM-1 log

This is a log created by downloading log data from the LM-1's internal memory, but not yet stored in a file. Only one LM-1 log can be open at any time. The current real-time input settings apply to LM-1 log.

NOTE: The LM-1 has to be the first device in a log-chain. Therefore the only channels it can see are its own AFR channel and the 5 channels on its Aux input. The LM-1 can NOT record any other channels downstream in the log-chain.

c) File logs

File logs are data files created by LogWorks when saving a real-time log or a LM-1 log. Up to 30 such logs can be opened by LogWorks concurrently. LogWorks stores logs in either of two file formats:

Log files (file extension .log)

Or

DIF files (file extension .dif)

The .log file format is native to LogWorks. It stores the original data in a very compact format and also stores additional information like measurement points, filter parameters and all input settings. This allows to change and manipulate the data later more conveniently than the DIF file format.

The DIF file format is used to allow importing the log data into spreadsheet program like Microsoft Excel.

The DIF format stores the data as manipulated by LogWorks and already converted into the real engine quantities. Because of that, information can be lost when reloading a DIF file for further manipulation.

The DIF format should only be used when the log data is to be processed by external software like Excel.

NOTE:

LogWorks 2.0 LOG files (file extension .log) are different from log files created by an earlier version of LogWorks. Although LogWorks 2.0 can read the earlier files, an earlier version of LogWorks can't read the new file format.

2.7 LogWorks Files

LogWorks uses the following files. These are installed in the same directory or folder where the LogWorks program file (LogWorks.exe) is installed.

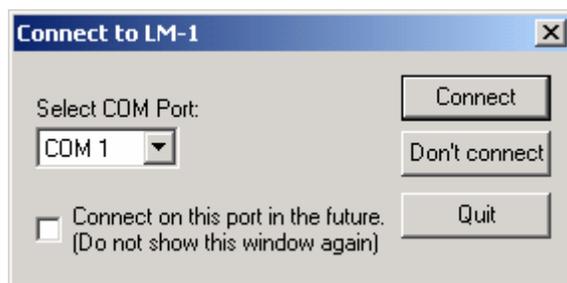
- a. **LogWorks.exe** (the main LogWorks Program)
- b. **Mts.dll** (the MTS serial protocol manager – includes plug-ins for LM-1, LC-1, and LMA-2)
- c. **Conversions.txt** (text file containing formulas for unit conversions. See section x)
- d. **MathlibSI.txt** (text file containing mathematical formulas in international units [MKS system] for channel calculations)
- e. **MathlibUS.txt** (text file containing mathematical formulas in US units [pounds, degF and so on] for channel calculations)
- f. **ChartMathlib.txt** (text file containing mathematical formulas for 3D-chart calculations.
- g. **Searchlib.txt** (text file containing formulas for frequently used searches)

3 Using LogWorks

3.1 Starting up LogWorks

Connect OUT port of the last device in the Log-Chain to a free serial port on your computer and start the LogWorks program. If an LM-1 is used, the LM-1 can either be currently operating in the car or can be connected (running from its internal battery) to the computer. Real-time logging can of course only be done when running the Log-Chain (can be as small as just an LM-1) in the car.

The following dialog box will appear:



Select the serial port (COM Port) to which the Log-Chain is connected. Then press the Connect button.

To quit here and don't start LogWorks press the Quit button.

If you do not wish to connect to the chain (or don't have it connected), Press the "Don't connect" button.

Check the "Connect on this port in the future" checkbox if you want to auto-connect on the selected port always in the future (you can change that later on if you wish).

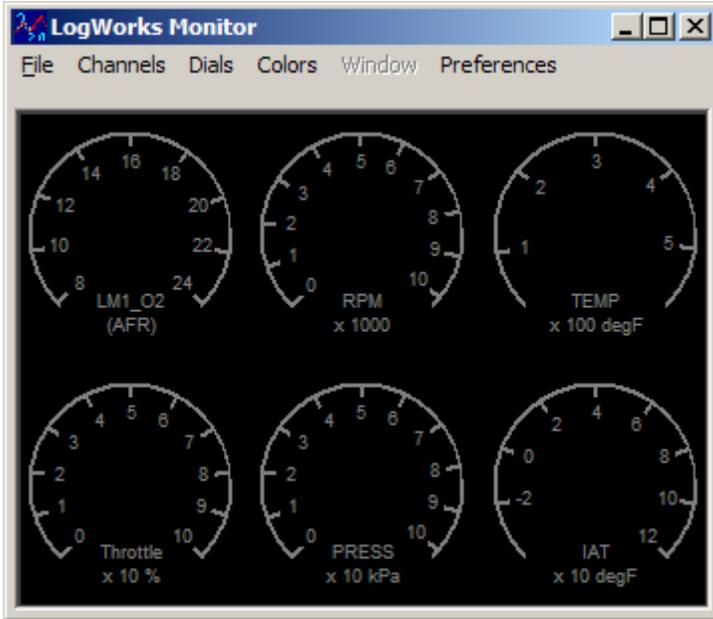
LogWorks can also be started by dragging one or more log files on the LogWorks icon (if you installed one on the desktop). In this case the log files will be opened automatically.



Make sure no other program (including LM Programmer or LM-1 Manager) is using the selected serial port.

3.2 The LogWorks Main Window

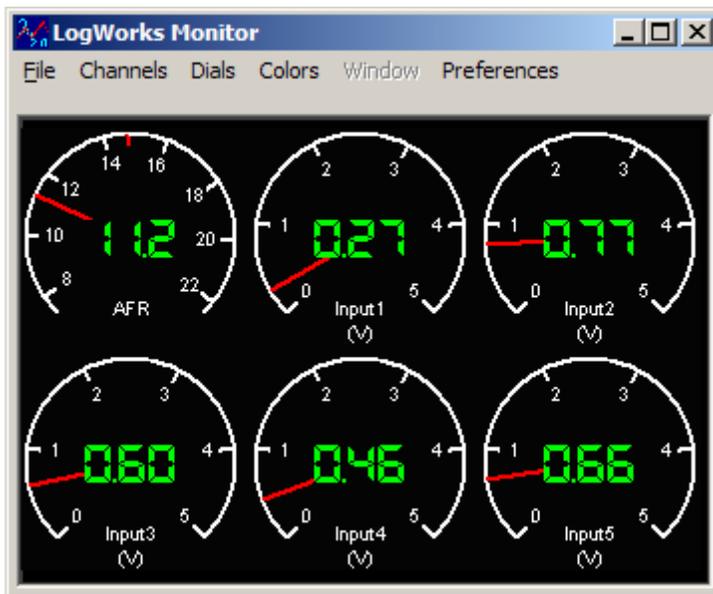
After this the main window of LogWorks, the LogWorks Monitor, appears:



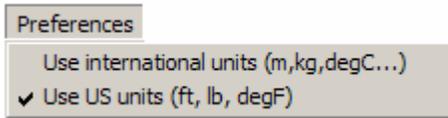
This window is resizable by grabbing on the lower edge of the window. All gauges are grayed out until:

- a) LogWorks is connected to the Log Chain
- b) A valid serial data stream is detected on the serial port
- c) The appropriate input is enabled.

When this happens the window might look like this:



3.2.1 Changing the preferences for units



This menu allows you to set your preferences for unit calculations and for displaying channels. A lot of calculations are different when US units vs. international units are used. To make it easier to find the correct calculations, the math libraries are divided, so that the number of duplicate entries is minimized.

3.2.2 Manipulating the gauges

LogWorks can display three different gauge types: Round, vertical bar and number.



Round gauge (default) vertical bar number gauge

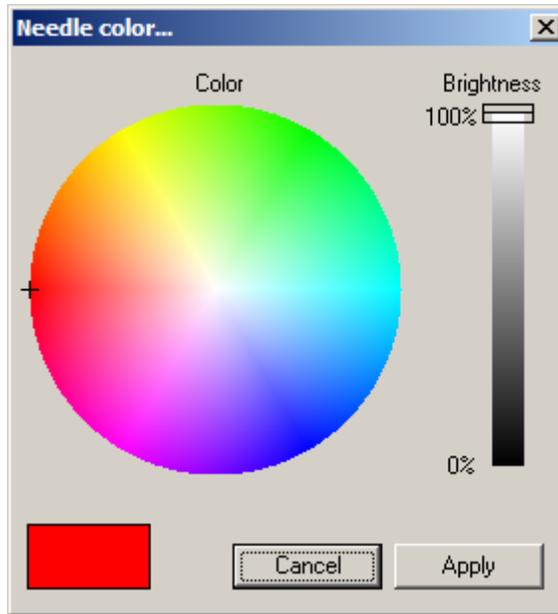
To change the size or position of a gauge, click on the gauge. The gauge will be shown with a selection rectangle like this:



A gauge selected like this can be dragged in the window to any position. Grabbing the gauge with the cursor at any of the corners allows you to resize the gauge. Multiple gauges can be selected by holding down the Control key (Ctrl) while clicking on the next gauge.

Changing gauge colors

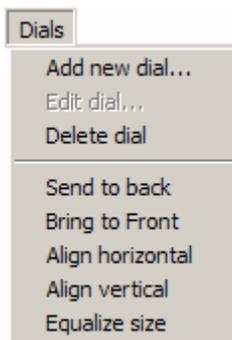
The different colors used in the gauge display can be manipulated with the Colors menu. When either of the items (like needle color) is selected, the following color dialog box will appear:



Click anywhere on the color circle to change the hue or saturation of the color. Saturation is how 'intense' the color is; hue is the color itself (red, yellow, green and so on). Grays have a saturation of zero and are located in the center of the circle. The distance from the center is a measure of the saturation. The slider on the right of the window determines the brightness of the color (in % of the max brightness achievable for the selected hue and saturation).

Changing gauge depth position relative to other gauges

Use the **Dials** menu to change the gauge relative position and other positioning aspects:



Send to back

Puts the gauge in the background behind other gauges if gauges overlap. This is useful when for example using vertical bar gauges to show for example multiple AFR or EGT channels. By positioning the bar gauges such that the next gauge to its left overlaps the gauges scale, a multi-bar gauge can be constructed with minimum screen real-estate usage. In this case you would use **Send to back** successively on the gauges from left to right. This way the rightmost gauge would be furthest back.

Bring to front

This is the opposite of **Send to back**. It brings the gauge all the way in front of other gauges if gauges overlap.

Align horizontal

If multiple gauges are selected, LogWorks calculates the average vertical center position of all selected gauges and moves the selected gauges such that their centers align on the same horizontal line positioned at the average vertical center position of the selected gauges.

Align vertical

Same as Align horizontal, but the selected gauges are aligned vertically.

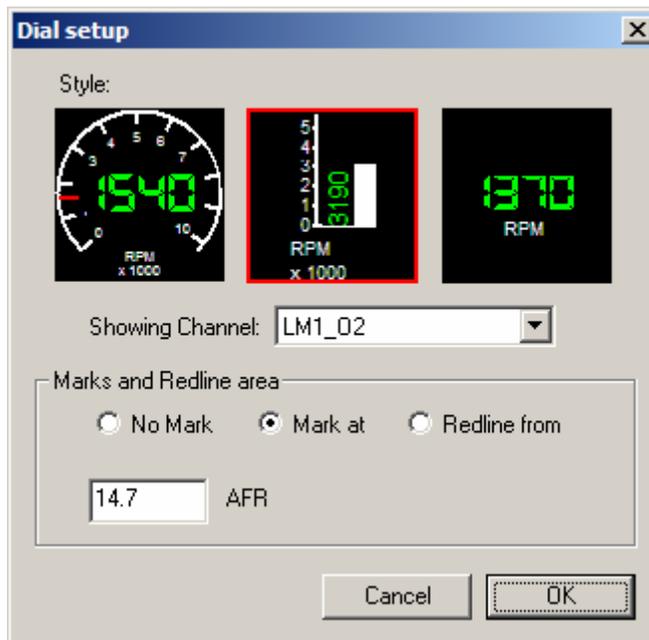
Equalize Size

The average size of the selected gauges is calculated and the selected gauges are sized to the average size.

Adding and Editing gauges

You can add as many gauges as you have logging channels. To add a new gauge (or change an existing gauge) select **Add new dial...** or **Edit dial...** in the dials menu. The following dialog box allows you to change the gauge type and the associated channel.

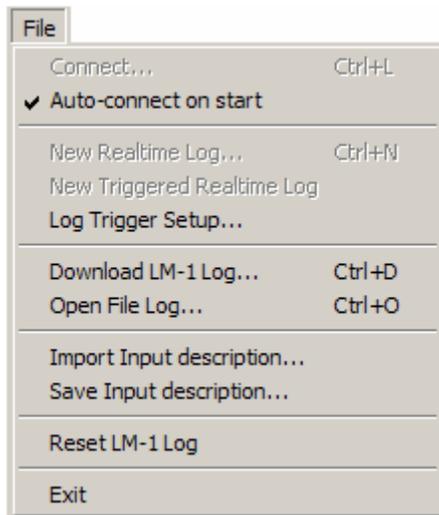
You can also specify if the gauge has a mark or a redline area at a specific scale location.



Note:

Double-clicking on a gauge also brings up this dialog box.

3.2.3 LogWorks Main File Menu



Connect...

Allows the connection of Log Chain on the serial port if LogWorks was started without connecting.

Auto-connect on start

Allows auto connecting at LogWorks start to be switched off or on.

New Real-time Log...

Starts a new real-time log or brings the real-time log window to the front if it is already open.

New Triggered Realtime Log

Starts a Triggered Log. See section **2.4 Triggered Realtime Logs** for details

Log Trigger Setup

See Section **2.4 Triggered Realtime Logs** for details.

Download LM-1 Log...

Creates a new LM-1 log by downloading data internally logged in the LM-1. During downloading the car may not be running (engine off) because the WB sensor's heater is switched off during downloads. After a download completes, the LM-1 is automatically restarted (heater runs again).

Open File Log...

Opens a saved log for further inspection and manipulation.

Import Input description...

Extracts the input settings data from an existing log file. Note that .dif files do not contain the entire input description data.

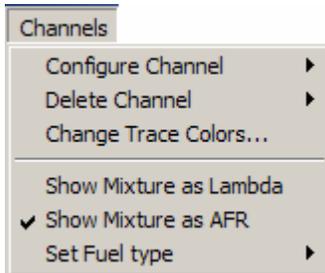
Save Input description...

Saves the current input settings (see [Configuring the Inputs](#)) in a .log file. This log file will contain only the input settings, no session data. Trying to open it as a file log results in an error.

Reset LM-1 Log

Resets the log memory in the LM-1. This works only in LM-1 firmware version 1.33b or later.

3.2.4 LogWorks Channel Menu



Configure Channel

Select the channel to configure. See Section **2.3 Manipulating the Channels** for details.

Show Mixture as Lambda

The Mixture data from the Wideband Controllers in the Log-Chain is shown as Lambda.

Show Mixture as AFR

The Mixture data from the Wideband Controllers in the Log-Chain is shown as air-fuel-ratio (AFR).

Delete Channel

Deletes the realtime channel

Set Fuel Type

This menu item is only important when the mixture data is shown as air-fuel-ratio. You can select the fuel type independent of what the Wideband Controller settings are. Normally LogWorks uses the device settings of the first Wideband controller in the Log Chain to calculate the air-fuel-ratio settings.

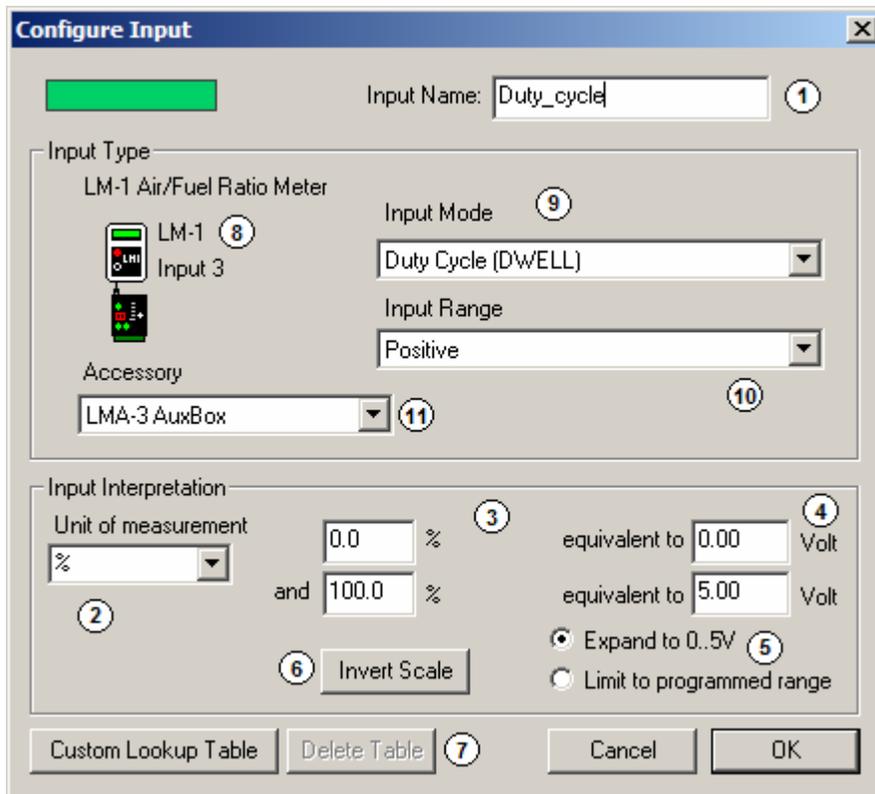
3.2.5 LogWorks Main Window Menu

Use this menu to quickly switch between open logs.

3.3 Manipulating the Channels

3.3.1 Configuring the Channels

The Configure Menu of the main window allows configuring the LM-1 inputs. The AFR/Lambda input can't be configured. You can only switch it between displaying Lambda or AFR. To configure an input, select the appropriate input from the Configure menu or double-click on the appropriate instrument. The following dialog box appears:



This dialog box contains up to 11 fields.

Field 1.

In field one you can specify a name for the input for easy identification. The left side of this field shows a colored box. This color is the trace color of this input in the logs.

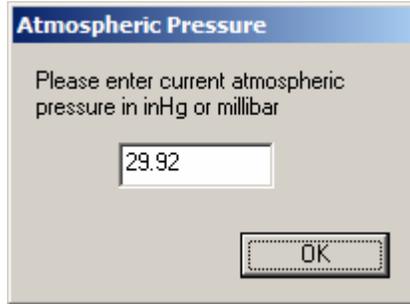
Use a unique name.

Only letters, numbers and the underline character _ are allowed in an input name.

Field 2.

Select or enter the unit to be used for that channel. This drop-down list shows all units that are preprogrammed into LogWorks. For details about using units and unit conversions see chapter 8.

Units typically belong to a unit family. A unit family consists of different units for the same measured quantity. For example you can measure pressure in PSI, inHg, kPascal and so on. Conversion formulas describe how to convert between different units of the same family. In the drop-down list the units belonging to the same family as the current unit are shown in **bold face**. When converting between absolute pressure and gauge pressure LogWorks will ask you to enter the current atmospheric air pressure:



You can enter this in either in inches of mercury (inHg) or millibar. LogWorks decides from the number entered which unit is used. This is asked only once after LogWorks has started and will not be asked again if that conversion is executed again. For details see chapter 8.1.2.

Field 3, 4 and 5

Specify two voltages (0 and 5V in the above example) in field 4 and the equivalent measurement quantity (0 and 101.3 kPa respectively in the example). If voltages different than 0 and 5V are specified, the range will be automatically expanded to 0..5V if the radio button "Expand to 0..5V" in Field 5 is selected, even if the sensor is not capable to produce 0..5V (the measured signal will stay within the range the sensor produces).

If the "Limit to programmed range" radio button is selected, the input is limited to the programmed range in field 3. Input values outside the range will be clipped to the entered range.

To easily enter the correct voltage values when LogWorks is connected realtime to a Logchain, you can also right-click on one of the voltage fields.

TPS Example:

To calibrate a TPS sensor, connect the sensor to for example an LMA-2 or LMA-3, switch the ignition on but don't start the car. Enter % as the unit and enter 0 in the upper box of field 3. Then right-click on the upper box of field 4. A menu will show up that allows you to paste in the current voltage of the TPS sensor into the upper box of field 4.

Next enter 100 in the lower box of field 3, depress the gas pedal fully and right-click in the lower box of field 4. Paste in the full throttle voltage.

Field 6.

Clicking on the "Invert Scale" exchanges the upper and lower boxes of field 3. This is useful for example for duty-cycle measurement. Normally the LMA-3 will measure positive duty cycle. This means that 100% duty cycle happens when the input is at full voltage and 0% when the input is a 0Volt. A typical fuel injector and also ignition points show full voltage when off and 0V when on. This is a negative duty cycle. By inverting the scale you can measure this duty cycle correctly where 0V means 100% and full voltage means 0%.

Field 7.

Adds or deletes custom lookup tables. See chapter 3.3.2 for details

Field 8.

This field shows the name, type and icon of the device where this input is from. If a device allows the connection of optional accessories, the accessory selected is also shown. The example shows a LMA-3 Auxbox connected to the LM-1.

Field 9.

This indicates the input mode selected for this input, dependent on the device. LogWorks interrogates all devices connected to the serial LogChain during connection and downloads their settings. If the settings have changed since the last time LogWorks started, LogWorks will change the current input to the current settings of the input, using defaults for the unit and range. If a device is connected to the Aux-In port of the LM-1, it can't be interrogated by LogWorks. In this case you have to manually select the function and, if necessary, fill out the fields for range and unit. See the manual for the appropriate device for details.

Field 10.

Allows you to select sub-functions for the selected main function as selected in field 9. This field will only be shown when sub-functions are selectable.

Field 11.

This field is present only for devices that allow connection of accessory devices. For example the LM-1 allows to select LMA-3 and LMA-2 or home-made connections. Select the appropriate device as accessory.

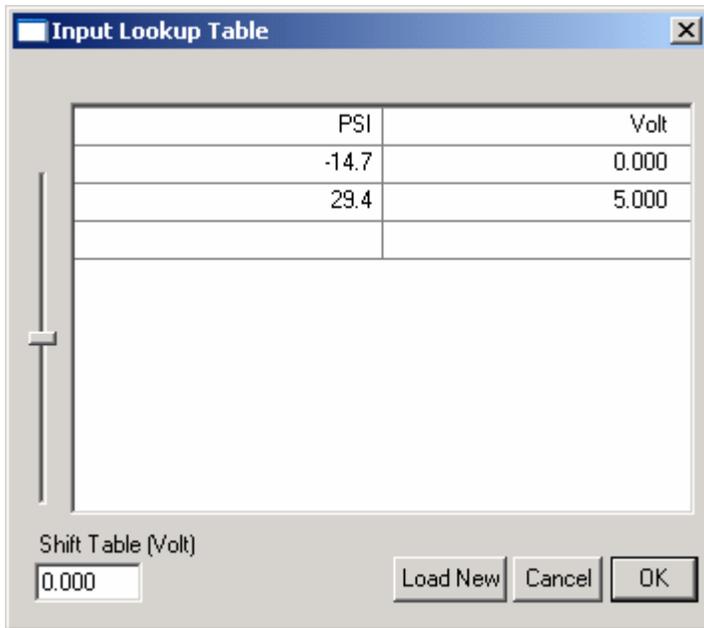
Note:

LogWorks will maintain the channel configuration for each device, even if the device has been moved to a different position in the LogChain. This is NOT true for display devices like the XD-1. The XD-1 is sensitive to the position of its programmed input in the LogChain. This means that if you moved for example an LMA-3 from the first position in the LogChain to the second position, and have the XD-1 programmed to display or use (hold or waring) an XD-1 channel, you need to reprogram the XD-1.

3.3.2 Custom Input Lookup Tables

Many sensors used in cars have a non-linear response curve. This means that their output voltage does not follow the measured quantity linearly but with some sensor dependent curve. LogWorks allows you to enter points of that sensor curve (as many as 1024, the more, the better) to convert the sensor output voltage back into the measured quantity directly. LogWorks interpolates the sensor measurements between entered points.

Press the Load/Edit Table button in **field 7**, and you will be presented with the following dialog box:



Double click on any field in the table to modify it. Click on a field to select it. To delete an entry, select it and hit the delete key.

If you make changes by editing, click anywhere in the table to make the changes permanent.

You can import a new lookup table from a text file (extension .txt) or a DIF file created by a spreadsheet program (extension .dif). A text table must have two columns, separated by spaces or tabs.

The first line contains in the left column the unit of the measured quantity (PSI in our example). The right column, first line must contain the word "Volt".

Underneath that first line listed are the individual equivalents of the lookup table. Left column contains the measured quantity and the right the equivalent voltage.

Note:

The slider on the left of the window shifts the entire table voltages up or down to compensate for ground differences between the MTS device ground and the measurement sensor. This should NOT be used with the LMA-3. It automatically compensates for ground differences when connecting the CHx- input to the sensor's ground.

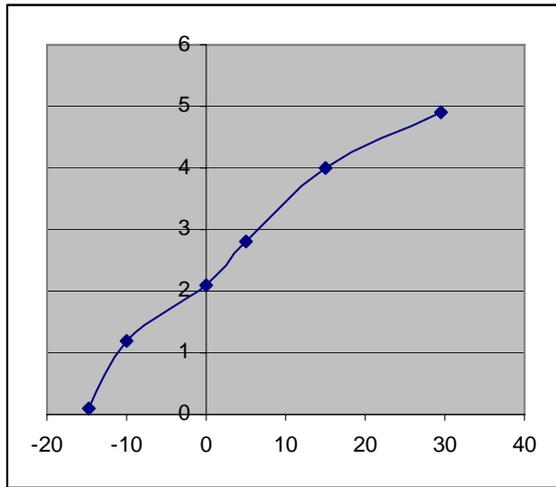
The following is an example of an input lookup table:

PSI	Volt
-14.7	0.1
-10.0	1.2
0	2.1
5	2.8
15	4
29.4	4.9

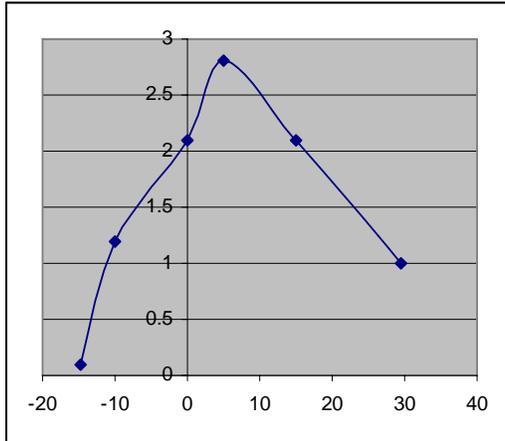
A DIF file must be organized similarly. The top left entry in the spreadsheet (field A1) must contain the measured unit. The second entry (field B1) MUST contain the word "Volt". The rest of the 'A' column contains the measured quantity equivalents and the rest of the 'B' column contains the equivalent voltages.

When loading the table LogWorks sorts it in ascending order by voltage. LogWorks then creates a custom lookup table for all 1024 possible input values by interpolating between table points using what's called cubic splines (Not the right place here to explain what they are). The table must be monotone rising or falling. If the difference between the second quantity and the first quantity is positive, the quantities must be always rising (third bigger than second and so on. If the difference is negative, the quantities must be always falling (third smaller than second and so on). If this were not the case, the same voltage could mean different measured quantities.

Example of monotone lookup table (x in PSI, y in Volt):



An example of a wrong table:



Note that 2.1 V could either mean 0 PSI or 15 PSI.

Note1:

Different than the custom setting in Field 3. and 4. of the Input Settings dialog box, the lookup table will NOT be automatically expanded to 0..5V. Instead the resulting log is clipped to the minimum and maximum of the table entries.

Note2:

If this dialog box was started from the LogWorks main window, double-clicking on one of the voltage fields, then right clicking on it will show a menu that allows you to paste the current input voltage of this input.

3.4 Triggered Realtime Logs

Sometimes it is convenient to start/stop a log not by hand, but automatically when certain conditions are met.

The **New Triggered Realtime Log** and **Log Trigger Setup** menu items in the Main window file menu allow you to do that.

Examples are in drag racing, where a run needs to be logged, but there's no time to select the appropriate menu while waiting in the staging area. Another use is to track down random problems. The trigger condition can be set up to start a session when the problem condition happens. It can then also pre-record a programmable time before the condition happened so one can see what led up to the problem without searching through long sessions. Pre-record includes the programmed number of seconds of data **before** the start condition happened. When waiting for a trigger LogWorks continuously records data, but keeps only the last pre-record seconds and throws older data away. When the trigger happens, the current data buffer is first inserted in the session, followed by the recording.

When selecting the **Log Trigger Setup** menu item the following dialog box will show up:

Realtime Log Trigger

Channel Comparison and/or

Log Trigger Start when

(Throttle > 50) AND (RPM > 3000)

and condition persists for : 0.00 sec. Pre-Record: 60 sec.

Log stops when

and condition persists for : 0.00 sec. Post-Record: 0.00 sec.

Cancel OK

3.4.1 Trigger Start Condition Setup

In the Log Trigger Start field you enter the session start condition. In the above example the session starts when the Throttle channel indicates more than 50% and RPMs are greater than 3000. Use parenthesis () liberally to indicate conditions.

DO NOT ENTER THE UNITS in the condition equations.

For example DO NOT enter: Throttle > 50%. LogWorks knows the units already from the channel name (Throttle in this case) and does not need to be told.

The persist field allows you to specify a length of time for the condition to persist before the recording is started. This allows eliminating false starts due to for example spikes or glitches.

The Pre-Record field allows you to set a time that LogWorks records before the start condition happened. If set to 60 seconds as in the example, LogWorks will include in the session the last 60 seconds before the start condition happened. Pre-Record times of up to 300 seconds can be programmed. If a persist time is used, the persist time is included in the pre-record time.

3.4.2 Trigger Stop Condition Setup

Once a recording session has started, it will only stop if the following things happen:

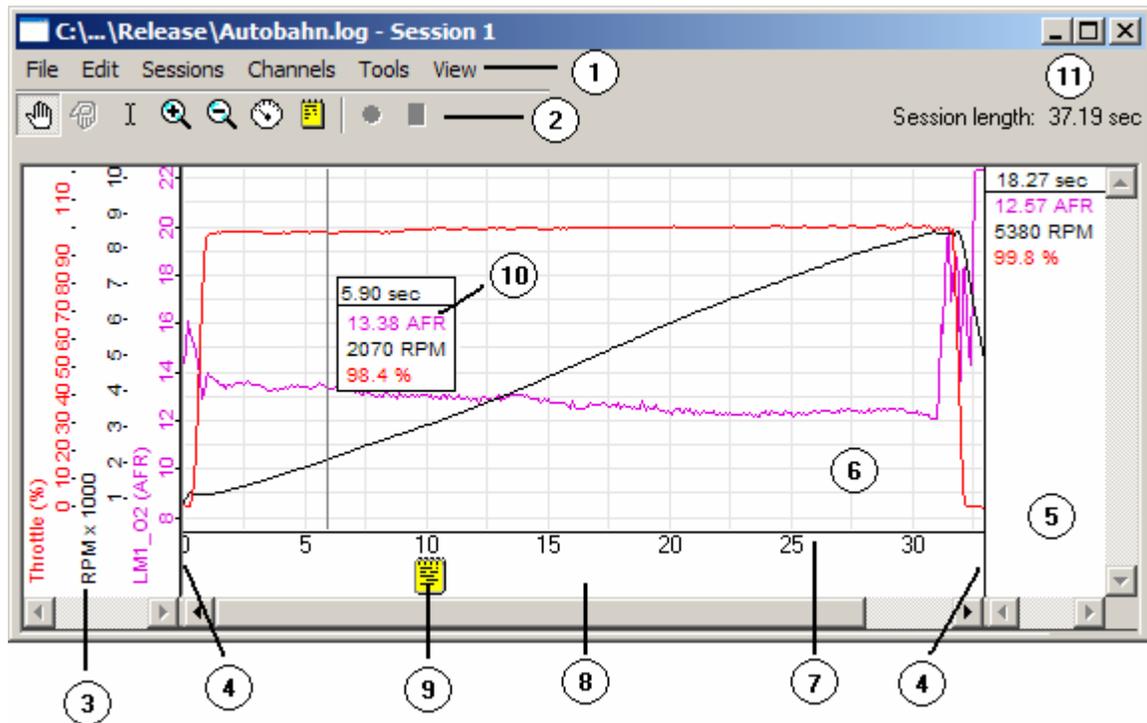
- a. The user stops recording with the stop button in the Log Window
- b. A stop recording condition has been specified and the condition happened.

In the Log Trigger Stop field you can specify a stop condition. This is done exactly the same way as for a start condition, including the capability to program a persistence time to avoid stopping a log on short glitches and spikes.

In the post-record field you can specify also a time (up to 300 seconds) for which LogWorks will continue to record **after** the stop condition happened.

4 Working with Logs and Sessions

4.1 The Log Window



The Log window can be resized to any size. It is divided into different areas and has three different panes:

The scale pane (3) shows the vertical scale, the graph pane (6) shows the time traces for the channels and the measurement pane (5) shows the values at the cursor position if the cursor is in the graph pane. Here's a short description of the parts of the Log Window.

1. Menu area

Contains the Log menus.

2. Tool area.

Allows selecting the various tools and functions to manipulate the log.

3. Vertical scale Pane

Shows the vertical scale of the graph for the various channels.

4. Pane Dividers (Mullions)

Grab the pane dividers with the cursor to resize the panes.

5. Measurement pane

Shows the current values of channels under the cursor if the cursor is moved in the graph pane. Moving the cursor over a text note icon shows the content of the text note in the pane.

If an overlay session is used, the overlay values are shown in parenthesis () and italics like this: *(overlay)*

6. Graph Pane

Shows the graphs of the active channels color coded. Moving the cursor over a channel highlights the channel (trace shown in double thickness). Right-clicking on the highlighted channel brings up a menu to manipulate different aspects of the channel. Leaving the cursor on the highlighted channel for a second will show the name of the channel.

7. Time scale area

8. Note area

In this area notes can be placed to comment events at that point in the session. Notes are indicated by an icon . Moving the cursor over a note will show the note contents in the Measurement Pane. Double-click on the note icon to edit the note text. You can also move the note in the note area by clicking and dragging. Some MTS logging devices can record audio comments while logging. If an audio comment is inserted, an audio note icon  will be shown at the audio comment point. Double-click on the icon to play the audio comment.

To delete a note, drag the note outside the note area.

9. Text Note

Indicates a text note at that point.

10. Measurement point

Any number of measurement points can be inserted in a graph. The measurement points scroll with the graph. A measurement point shows the values of all active inputs at that particular point in time.

11. Session length info

Shows the total length of the session.

4.2 Log Window Tools

Select the tool by clicking on it. You can also switch between tools using a keyboard shortcut.

4.2.1 Hand Tool (Shortcut Ctrl-H)

Scroll the graph left and right. If a channel trace is vertically magnified (see magnification tools) also scrolls the trace up or down. To scroll, click in the graph (left mouse button) and drag the graph left or right.

If a real-time session is currently recording, the graph will automatically scroll to show the latest data. Scrolling with the hand-tool or the horizontal scroll bar to an earlier time in the recording will stop the auto scrolling. To restart auto scrolling, scroll the graph to the rightmost end.

4.2.2 Overlay scroll tool

When an overlay is pasted onto a session, this tool moves the overlay relative to the underlying graph. To scroll, click in the graph (left mouse button) and drag the overlay left or right.

4.2.3 Selection Tool

Allows selecting a portion of a session. To select a portion, click in the graph (left mouse button) and drag the mouse left or right. Whenever you click (without any other keys held down), the current selection is removed. Holding down the shift key while clicking extends the selection from the first click to the new click.

Holding down the Ctrl key while clicking allows selecting multiple areas without removing the previous selection.

4.2.4 Magnification Tools

The  tool is used to magnify, the  tool is used to reduce a magnification. To magnify or reduce a channel vertically, click on the channel trace with the tool. To magnify/reduce the time scale, click on the time scale with the tool. Holding down the Ctrl-key will select the opposite of the current tool. For example if you selected the magnify  tool it will change into the reduce  and vice versa.

4.2.5 Measurement tool (Shortcut Ctrl-M)

Use this tool to add measurement points in the graph as shown in item 10 of the window. Click anywhere in the graph to add a measurement point. Click in the measurement window (rectangular area showing the measurement results) to remove a measurement point. Click and drag to fine-position a measurement point. Any number of measurement points can be added. When holding down the Ctrl-key while releasing the mouse button, the measurement point is considered temporary and will be removed.

4.2.6 Text Note Tool

Select this tool and click anywhere in the note area (area 8 in the window) to place a new note there. Once placed, a dialog box will show up that allows you to enter the text for the note.

To delete a note, drag it outside the note area.

4.2.7 Real-time Logging Start button (Shortcut Ctrl-N)

This button is only active in the real-time session window. Clicking this button starts a new real-time session.

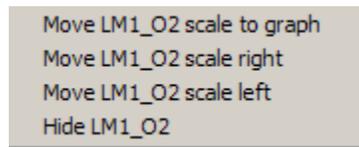
4.2.8 Stop button (Shortcut Ctrl-Spacebar)

Clicking this button stops recording a real-time session.

4.3 Manipulating the vertical scale pane

If a channel trace is vertically magnified, you can scroll that trace up or down by clicking and dragging on the scale for that trace.

Right click on a vertical scale for a trace and the following menu will show up:

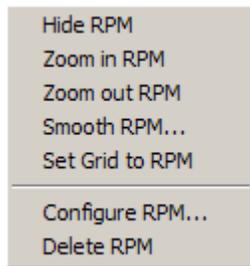


With this menu you can hide a trace and manipulate the order of the channel scales in the vertical scale pane.

The grid in the graph pane is adjusted to the scale that is next to the graph pane.

4.4 Manipulating traces in the graph pane

Right-click on a trace in the graph pane and the following menu will show up:



4.4.1 Hide Channel

Hides the channel trace and its associated vertical scale. The measurement pane will still show the values of the hidden channel though.

4.4.2 Zoom in Channel

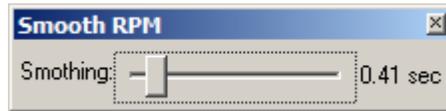
Increases the vertical magnification of the channel

4.4.3 Zoom out Channel

Decreases the vertical magnification of a channel

4.4.4 Smooth channel

When selected, the following dialog box will appear:



This allows you to 'smooth' a channel. The smoothing slider allows smoothing a trace by replacing each data point with the running average of its neighbors and itself. The position of the slider determines how many of the neighbors are included in the running average (0 to 32 neighbors on each side).

Smoothing can be used to better see trends and is necessary for some calculations (specially those involving calculating slopes). Smoothing should NOT be used to get rid of excessive noise in a channel, for example spikes caused by ignition misses. Because smoothing is an averaging operation, the lean-spikes caused by ign. misses would be included in the AFR values and would bias them towards leaner values.

4.4.5 Set Grid to channel

Can be used to set the graph-pane grid to the selected channel without moving the vertical scale next to the graph.

4.4.6 Configure channel

Brings up the channel configuration dialog box as described in Section 3.3 Configuring the channels.

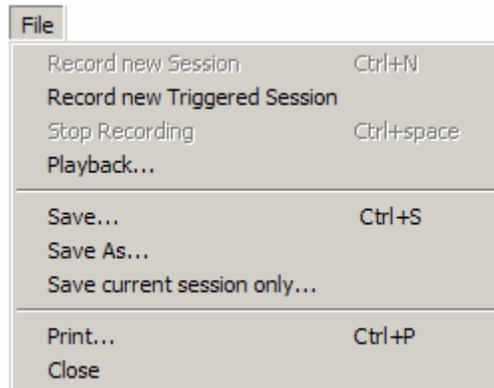
Input configuration changes performed in the real-time log window also apply to the LogWorks main window and vice versa. The same is true for the LM-1 log window.

File log input changes only affect the current file log.

4.4.7 Delete channel

Deletes the channel trace from all sessions in the log.

4.5 Log Window File Menu



4.5.1 Record new Session

Starts a real-time session. Same as Real-time Session Start button.

4.5.2 Record new Triggered Session

Starts waiting for a trigger to start a new triggered session. To stop while waiting for a trigger, select Stop Recording.

4.5.3 Stop Recording

Stops the current recording session. Same as the Stop Recording button. You can also stop while waiting for a trigger to interrupt the wait.

4.5.4 Playback...

Brings up the Play Window.



The gauges in the playback window can be manipulated the same way as described in section 2.2.2 Manipulating the gauges. The position, type and colors of the gauges and of the playback window is saved in the log file when log file is saved.

In addition you can play, single-step forward and back and loop on an area. If areas in a session are selected, only the selected areas are played. When playing back while a 3D chart/graph is open (see section 5) the play position is also indicated in the chart/graph.

4.5.5 Save...

Saves the log into a log file. Either as .log or as .dif file. .dif files can be opened by many programs, including Excel. To open a .dif file in Excel, select "Data Interchange Format" as the file format in Excel.

4.5.6 Save As...

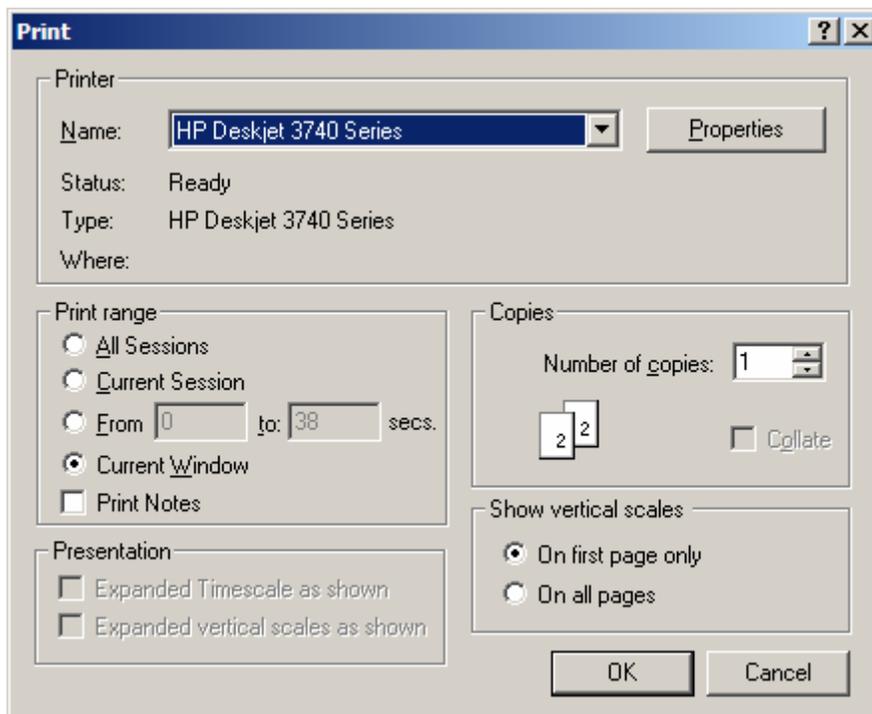
Saves the log under a different file name.

4.5.7 Save current session only...

With this menu item you can save the currently displayed session in a separate log file (or .dif file).

4.5.8 Print...

Prints the log or current session. A print dialog box like below appears:



This dialog is divided into four sections:

In the 'Printer' section select the printer to use. Usually you do not need to touch this section.

The 'Print range' section allows you to select the time range you want to print. Also selects whether you want to print the content of all the text notes as well.

The 'Presentation' section allows you to select if you want to show the time-scale or vertical scales for each input expanded as in the window or at their normal 1:1 scale.

The 'Show vertical scales' section allows you to select if you want to show the vertical scales on the left of the graph on every page or only on the first one. Showing it only on the first page allows you to glue the pages of a long session together as a strip-chart.

4.5.9 Close

Closes the log window.

4.6 Log Window Edit Menu

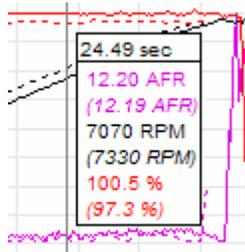
Edit	
Copy	Ctrl+C
Paste as Overlay	Ctrl+V
Paste as new Session	Ins
<hr/>	
Remove Overlay	Alt+O
<hr/>	
Autoselect...	Ctrl+F
Search Library...	
Go to next selection	Ctrl+G
Select whole Session	Ctrl+A
Delete Selection	Del
Invert Selection	
Invert Selection in all Sessions	

4.6.1 Copy

Copies a selection (see Selection Tool) into the LogWorks internal clipboard.

4.6.2 Paste as Overlay

Pastes the clipboard content on top of the current session as overlay. The traces of the overlay are shown as dashed instead of solid as in the example below:



Using the overlay scroll tool you can move the overlay left and right. If a measurement point overlaps an overlay trace, the overlay measurements at this point are shown in brackets () and *italic*. The hand tool or horizontal scroll bar moves underlying graph and overlay together. Overlays are not saved with a log.

4.6.3 Paste as new session

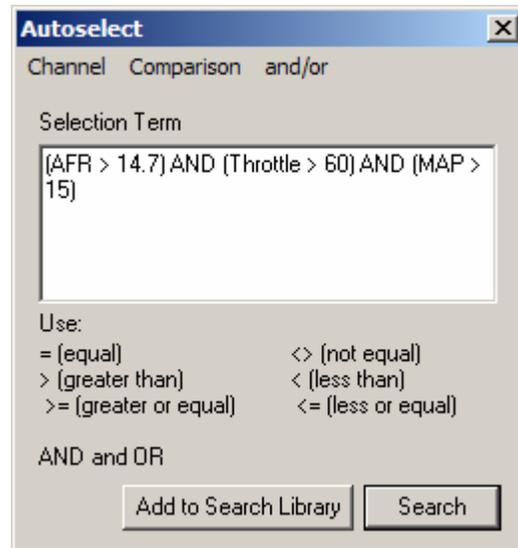
You can only paste a session or part of a session into an existing log from another log. The input definitions of the source and destination logs have to match.

4.6.4 Remove Overlay

Removes the overlay.

4.6.5 Autoselect...

Autoselect is a very powerful tool to select areas of interest in a session. Selecting this item brings up the following dialog box:



In the window of this dialog box you can specify search terms like “AFR > 14.7” and so on. You can then connect these terms with ‘AND’ or ‘OR’. LogWorks will process the entire session and select those areas which satisfy the search criteria. In the above example all lean spots leaner than 14.7 AFR are selected where the engine is under boost and the throttle position is bigger than 60%.

Do not specify a unit (like % after 60% or PSI after 0 PSI).

Note that the input names are case sensitive. Afr would be different than AFR. Make sure you type the input name correctly. Click on the ‘Add to Search Library’ button to add the search term to a search library. The search library holds frequently used searches. When clicking the button a dialog will show up that will allow you to specify the name, category and comment for the library entry. See section 7 LogWorks Libraries for details.

4.6.6 Search Library

Brings up a list of stored searches. See section 7 LogWorks Libraries for details.

4.6.7 Go to next selection

This menu item (equivalent to a search function) jumps directly to the beginning of the next selection created by for example the Autoselect function. It also puts a temporary measurement point at that point.

4.6.8 Select whole session

Equivalent to the select all function of other programs. Selects the entire session.

4.6.9 Delete Selection

Deletes the selected area from a session.

Note:

Only areas at the beginning or end of a session can be deleted. Deleting in the middle would cause a non-contiguous data area and is therefore not allowed.

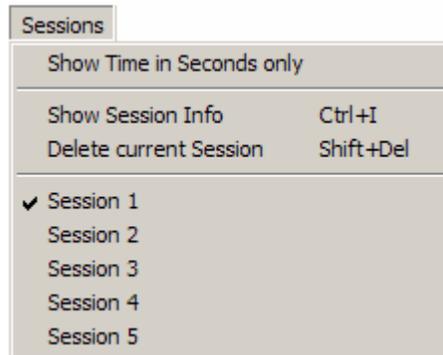
4.6.10 Invert Selection

All areas in the session that are selected will be unselected. All areas that were unselected, will be selected.

4.6.11 Invert Selection in all sessions

Same as Invert Selection above, but the process will be applied to all sessions in the log.

4.7 Log Window Session Menu

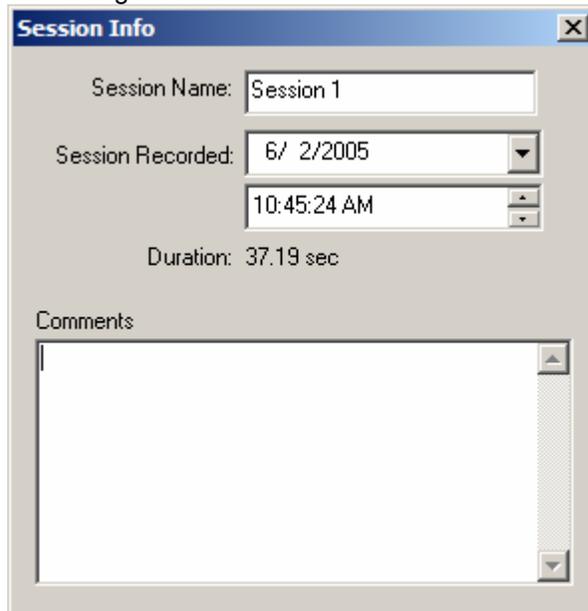


4.7.1 Show Time in Seconds only

Normally the time in the time scale are is shown in minutes and seconds. With this menu item the time can be shown alternatively in seconds only.

4.7.2 Show Session Info

Brings up this dialog box that shows information about the current session:



- Session name,
- Session length (in minutes and seconds),
- Record start time and date,
- And a comment added to a session.

If the record time and date is unknown (for example for a session recorded in an LM-1), the current time and date is shown. You can change the time and date for a session by editing the appropriate field.

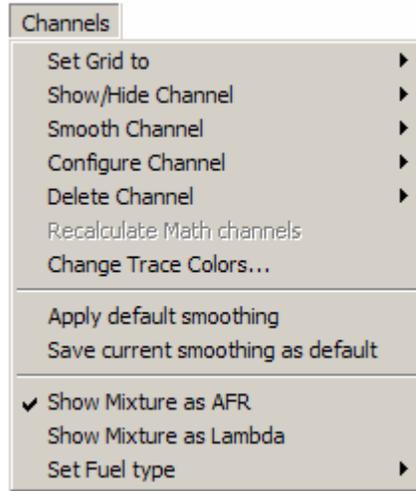
4.7.3 Delete current session

Deletes the current session from the log. If only one session is left, it cannot be deleted (logs can't be empty).

4.7.4 Session selection

Select which session you want to view/manipulate.

4.8 Log Window Channel Menu



4.8.1 Set Grid to

This submenu allows you to change the graph pane grid to the selected channel without moving the vertical scale next to the graph pane.

4.8.2 Show/Hide Channel

Hides/Shows a channel trace and scale. Same as described in section 2.8.1 Hide Channel.

4.8.3 Smooth Channel

Same as described in section 2.8.4 Smooth Channel.

4.8.4 Configure Channel

Brings up the channel configuration dialog box as described in Section 2.3.1 Configuring the channels for the selected channel.

Input configuration changes performed in the real-time log window also apply to the LogWorks main window and vice versa. The same is true for the LM-1 log window.

File log input changes only affect the current file log.

4.8.5 Delete Channel

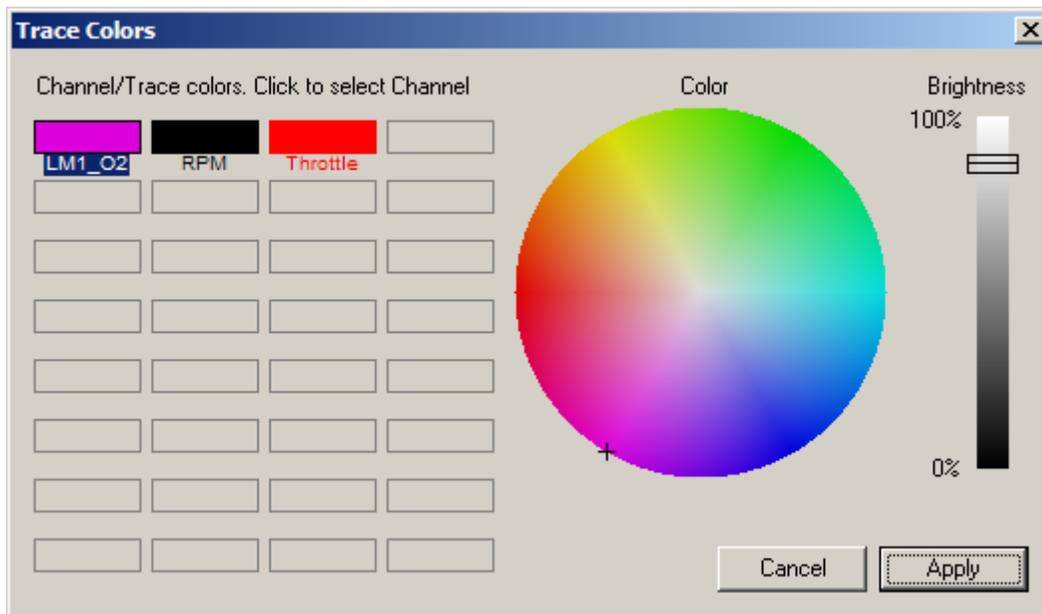
Deletes the channel trace from all sessions in the log.

4.8.6 Recalculate Math Channels

Recalculates all new channel traces created with the Math trace calculator. This might be necessary if various aspects like smoothing, or the configuration of channels used to calculate the Math traces changed. See chapter 6: Math Trace Calculator for details about calculated channels.

4.8.7 Change Trace colors

Brings up a dialog box to change the colors of the channel traces:



On the left side of the dialog box, select the channel whose color needs to be changed. Click anywhere on the color circle to change the hue or saturation of the color. Saturation is how 'intense' the color is. Gray scale colors have a saturation of zero and are located in the center of the circle. The distance from the center is a measure of the saturation. The slider on the right of the window determines the brightness of the color (in % of the max brightness achievable for the selected hue and saturation).

4.8.8 Apply default smoothing

If the current smoothing values for a channels are saved, this applies the saved smoothing values to all channels in the session.

4.8.9 Save current smoothing as default

Saves to smoothing values for all channels of the current session as default values to be used later.

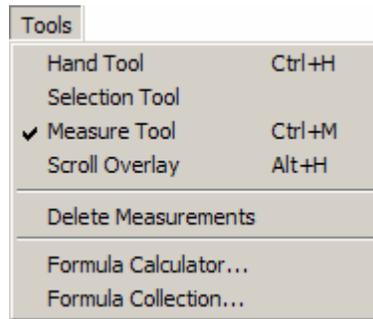
4.8.10 Show Mixture as AFR or Lambda

Allows you how to show the Mixture channels in either AFR or Lambda.

4.8.11 Set Fuel Type

Allows you to manipulate the AFR multiplier (stoichiometric ratio of fuel used) for all Mixture channels in the log. This has only an effect if the mixture for the mixture channels (WB –O2 channels) is shown as AFR.

4.9 Log Window Tools Menu



4.9.1 Tool Selections

The Hand Tool, Selection Tool, Measure Tool and Scroll Overlay selections are the same as described in the [Log Window Tools](#) chapter.

4.9.2 Delete Measurements

Deletes all measurement points in the current session.

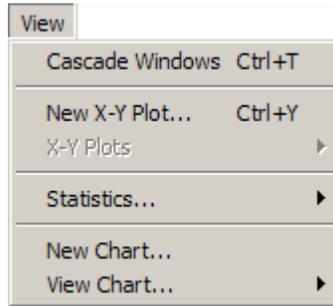
4.9.3 Formula Calculator

Brings up the trace calculator window. See Section 6 Math Calculator for details.

4.9.4 Formula Collection

Brings up the trace calculator Library. See section 7 LogWorks Libraries for details on how to use the various libraries LogWorks uses.

4.10 Log Window View Menu

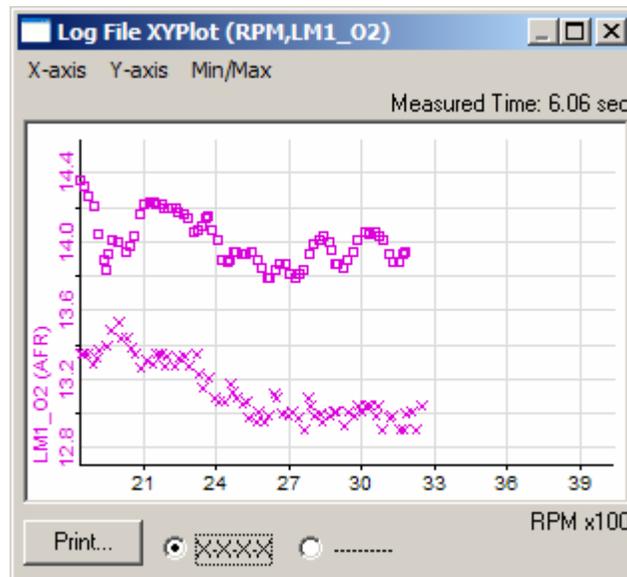


4.10.1 Cascade Windows

This item causes all auxiliary views of the session (Statistics Window or X-Y Plot Window, see below) to be stacked in the top left corner of your screen.

4.10.2 New X-Y Plot...

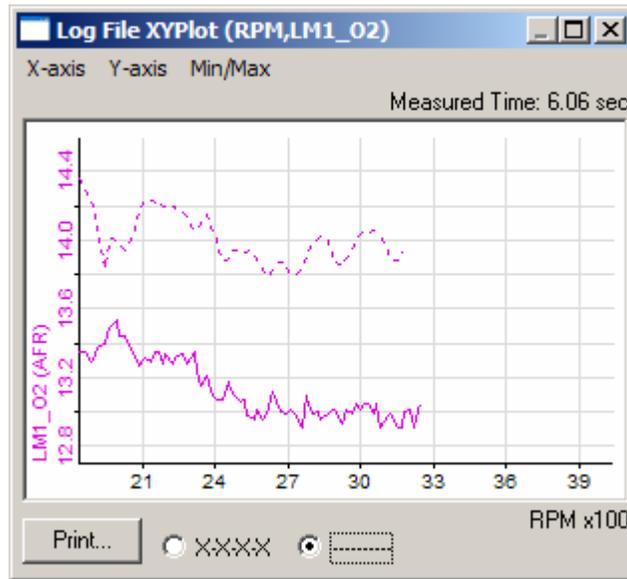
This opens a new X-Y Plot window. An X-Y plot window shows the data of any two inputs in a two-dimensional graph like this:



In this case the Y-axis is AFR and the X-axis is RPM. You can select any two inputs as either of the X or Y axis. If nothing in the graph is selected, the X-Y Plot represents the data of the entire session. If a part of the session is selected (Selection Tool), only the data of the selected areas is represented. If **overlays** are in the selected area, the overlay data points are shown as rectangles, the original as crosses.

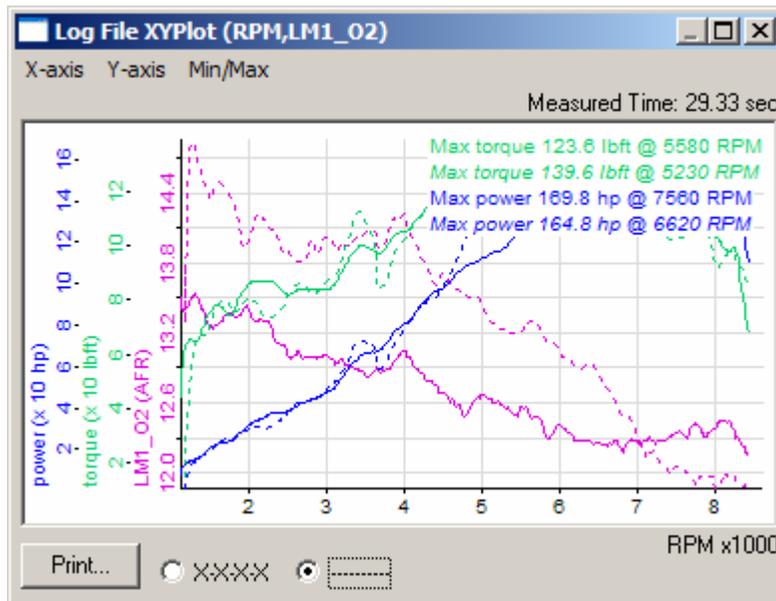
For example if you are only interested in the AFR over RPM curve for wide open throttle (WOT), you can either hand-select these areas or use the [Autoselect](#) tool if you have a throttle position input connected to the LM-1.

As shown above the individual data points are shown as small "x"s. Clicking the '----' button shows the data points connected with lines as in this:



The X and Y axis are automatically scaled to the range of input values for the respective axis. Manipulating the session data with the smoothing filter, changing selection or adding/deleting measurement points will be automatically represented in the X-Y Plot.

Multiple channels can be shown at the same time in the plot. The Y-axis menu allows selecting which channels are shown. In addition the Min and Max points for each of the channels shown on the Y axis can be indicated as in this example:



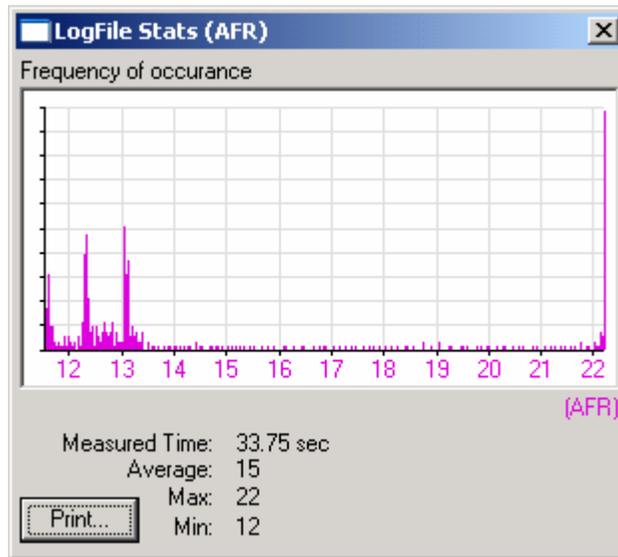
The Min/Max values of the overlay channels are shown in *italic* font.

4.10.3 X-Y Plots

This submenu lists all open X-Y Plot windows and allows you to quickly bring one to the top.

4.10.4 Statistics...

This submenu opens a statistics window for the selected input. A statistics window looks like this:



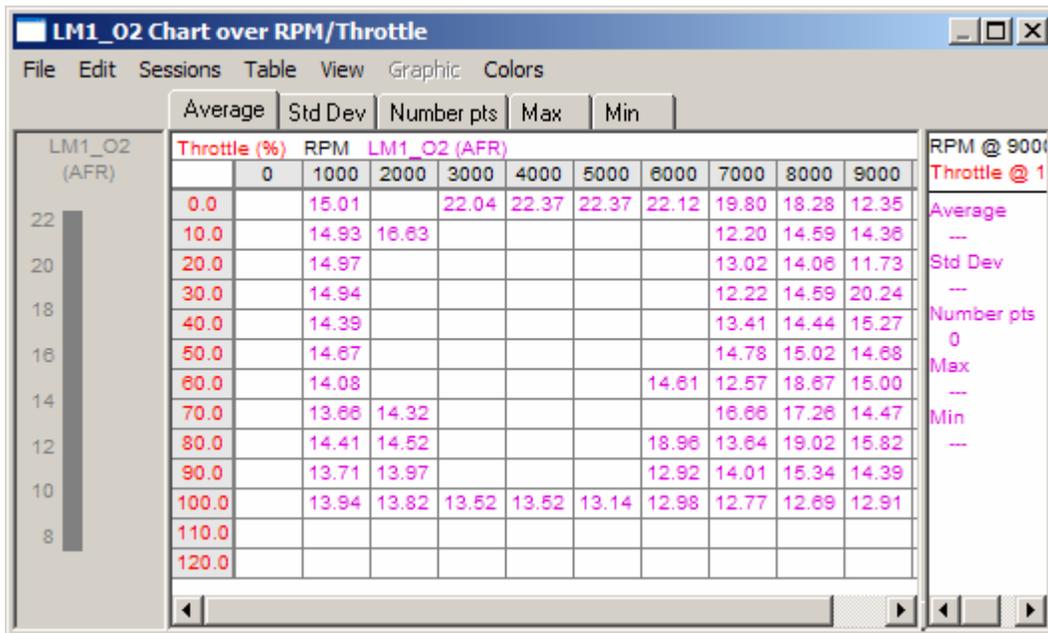
This window shows how often a certain input value happened during a session or partial session. If nothing in the graph is selected, the Statistics window represents the data of the entire session. If a part of the session is selected (Selection Tool), only the data of the selected areas is represented.

The vertical axis is automatically scaled relative to the highest occurrence. The horizontal axis is automatically scaled to the range of the input with the session or selection. In addition the window shows how many data points (time) are represented, the average of the selected data and the minimum and maximum points in the selected data range or entire session.

Manipulating the session data with the smoothing filter, changing selection or adding/deleting measurement points will be automatically represented in the statistics.

4.10.5 New Chart...

With this item a new 3D chart can be specified. A 3D chart is a table (or graph) that shows the contents of a channel as dependent on two other channels as in this example:

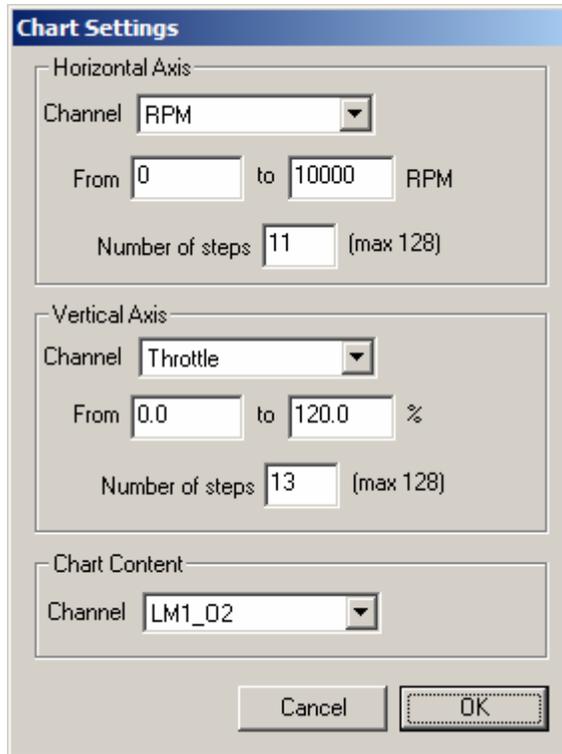


This example shows average AFR over throttle position and RPM.

The fuel map or ignition map of an electronic fuel injection system is a typical example for such a map.

For further details see chapter 4. 3D charts and graphs

When this menu item is selected, the following dialog box will show up:



The image shows a 'Chart Settings' dialog box with three sections: 'Horizontal Axis', 'Vertical Axis', and 'Chart Content'. Each section has a 'Channel' dropdown menu, a 'From' and 'to' range input, and a 'Number of steps' input. The 'Horizontal Axis' section is set to 'RPM' with a range from 0 to 10000 and 11 steps. The 'Vertical Axis' section is set to 'Throttle' with a range from 0.0 to 120.0 % and 13 steps. The 'Chart Content' section is set to 'LM1_02'. At the bottom are 'Cancel' and 'OK' buttons.

Section	Channel	From	To	Unit	Number of steps	Max steps
Horizontal Axis	RPM	0	10000	RPM	11	128
Vertical Axis	Throttle	0.0	120.0	%	13	128
Chart Content	LM1_02					

This allows you to select the x- and y channels, the content channel and the range and number of steps for the initial chart settings. Don't fret on the number of channels and range though. Once the chart is created, you can always manipulate the spacing and number of the columns and rows of the chart.

4.10.6 View Chart...

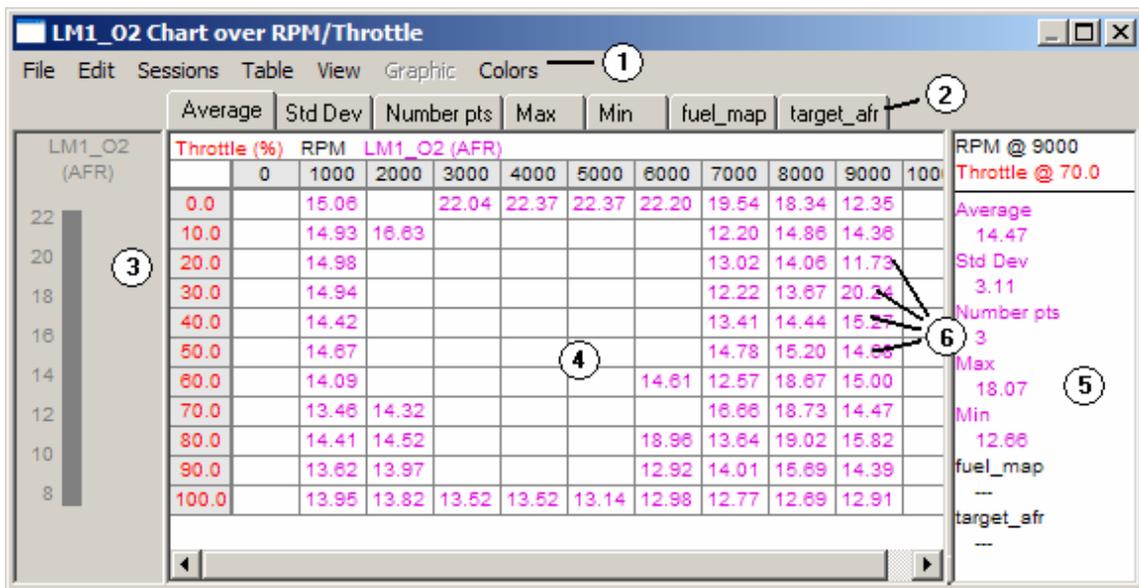
You can select from the last four chart settings used (also up to four charts can be open at the same time). LogWorks stores the chart settings in the log file when the log file is saved.

5 3D charts and graphs

3D charts are tables or graphs showing the dependency of a selected channel (content channel) in relation to two independent other channels.

The independent channels (x and y axis) are divided into variably sized sections. The values of the content channel are sorted into 'bins' dependent on the content of the x-y channels. The average value, standard deviation, number of datapoints contributing and the max and min for each bin are calculated.

5.1 The 3D chart window



The Chart window can be resized to any size. It is divided into different areas and has three different panes:

The colorizing pane (3) allows selecting the color range if colorizing is selected, the chart/graph pane (4) shows the values of the selected sub-chart and the measurement pane (5) shows the values at the point of the cursor when the cursor is in the chart/graph pane. Here's a short description of the parts of the Chart Window.

1. Menu area

Contains the Chart menus.

2. Chart Selection Tabs

Allows switching between displaying the sub-charts. Just click on the tab. The standard sub-charts that are always generated are:

- Average (average value for the bin)
- Standard Deviation (statistical standard deviation for the bin). A bin where the standard deviation can't be calculated (Number of datapoints less than 2) will be shown as ---.
- Number pts: Number of datapoints in that bin
- Max: the maximum value of all datapoints in the bin
- Min: the minimum value of all datapoints in the bin

In addition the example window shows two user sub-charts: fuel_map and target_afr. More on that later.

3. Colorizing pane

Allows colorizing the chart according to different values. See 5.4 Colorizing charts and graphs for details

4. Chart/Graph pane

Shows the values of the bins of the selected sub-chart.

5. Measurement pane

Shows the values of all sub-charts of the bin over which the cursor currently is. Resize the measurement pane by grabbing its left border.

6. Chart bins

5.2 Selecting data to base the chart on

In the Sessions menu you can select which sessions the chart is calculated from. You can also specify to base the chart on only the selected areas in the sessions. For details about selections, see section 4.9 Selection Tool.

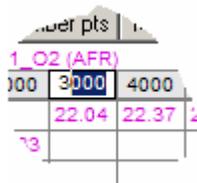
5.3 Manipulating the chart settings

5.3.1 Adding a column or row

To add another row or column in the chart, click on the column or row header where you want to insert a new row or column. Then select in the **Edit** menu **New column left** or **right** if you want to add a column, or **New row above** or **below** if you want to add a new row. The bin value of the row/column is initially the average of the neighboring rows or columns.

5.3.2 Changing row or column values

To change the value of a column or row header, double-click on the column or row header. The column/row entry will become editable:



The image shows a portion of a data table. The header row contains '1_Q2 (AFR)'. Below it, there are three columns with values 1000, 3000, and 4000. The row below these has values 22.04 and 22.37. A blue selection box highlights the '3000' cell, and a small '2' is visible to its right, indicating it is in edit mode.

1_Q2 (AFR)			
1000	3000	4000	
	22.04	22.37	2

When you are done entering a new value, hit the 'Enter' key to make the change permanent. The row/column will be inserted at the right place in ascending order.

5.3.3 Copying/pasting row and column settings

To copy row and column settings, select the column/row headers you want to copy by clicking and dragging over the header. Then select in the **Edit** menu **Copy Selection**.

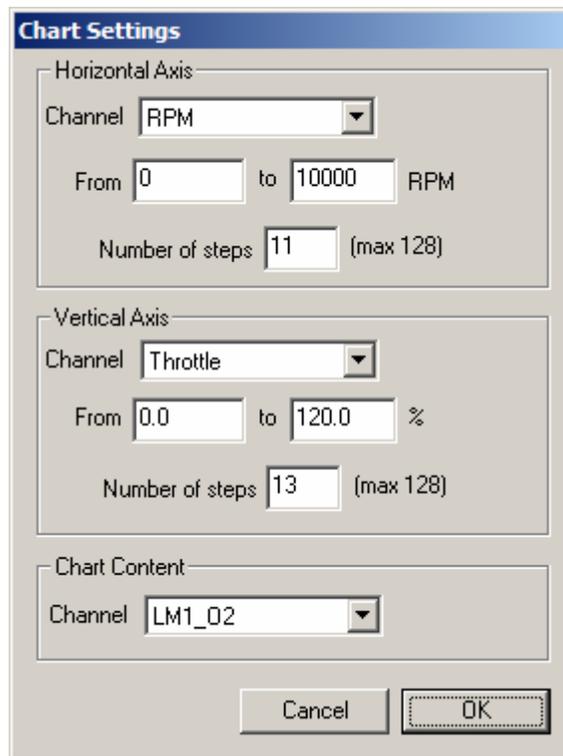
To paste new values in the row and column headers, select the rows or columns which you want to replace with the copied settings. Then select in the **Edit** Menu **Paste Settings**.

NOTE:

You can also paste in settings created by other programs like Excel as long as these programs put the values as tab-delimited text on the clip-board of the computer.

5.3.4 Changing the Chart channels

In the **Table** menu, select **Table Setup...** the following dialog box appears:



The image shows a dialog box titled "Chart Settings" with three sections: "Horizontal Axis", "Vertical Axis", and "Chart Content". Each section has a "Channel" dropdown menu, "From" and "to" input fields, and a "Number of steps" input field. The "Horizontal Axis" section has "RPM" as the channel, "From 0" and "to 10000 RPM", and "Number of steps 11 (max 128)". The "Vertical Axis" section has "Throttle" as the channel, "From 0.0" and "to 120.0 %", and "Number of steps 13 (max 128)". The "Chart Content" section has "LM1_02" as the channel. At the bottom are "Cancel" and "OK" buttons.

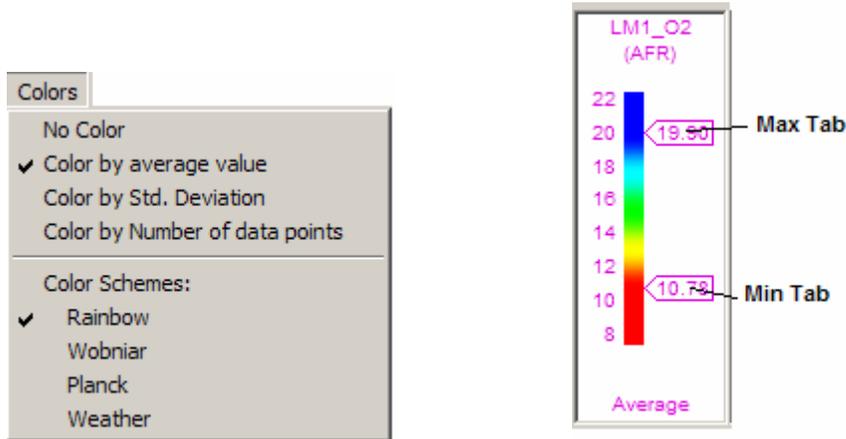
If you just change the content channel, the current row and column settings of the chart will stay untouched. If you change either of the axis channels, the settings for that axis (rows or columns) will change to be equally spaced with the number of steps and end values specified in this dialog box.

5.3.5 Deleting rows or columns

Select the rows or columns to delete, then in the **Edit** menu select **Delete Selection**.

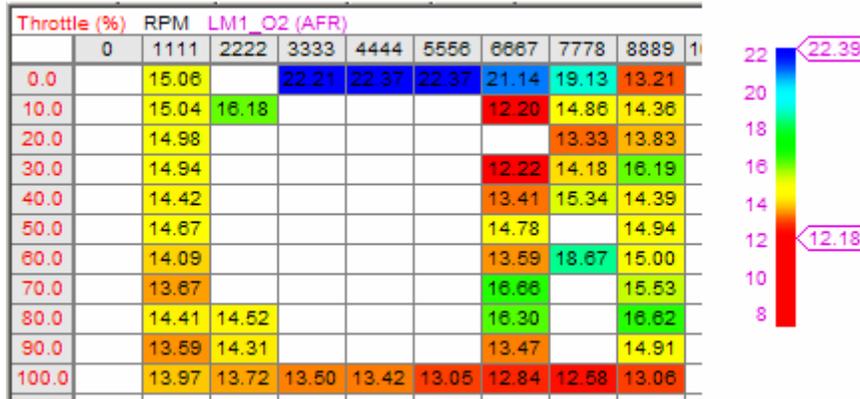
5.4 Colorizing a chart

Select the Colors menu.



You can color a chart by average value, Standard Deviation or Number of data points. You can also choose between 4 different color schemes. The Colorize pane will become active as shown above.

By moving the Max and Min tabs you can limit the colorization to the value range you are interested in. The range can be limited to as small as 10% of the total range of the channel. If colorizing by Number of datapoints the scale for the colors is logarithmic. Example of a colorized chart:



5.5 User sub-charts

User sub-charts are sub-charts that contain user entered or calculated values. **User chart contents are saved when the log file is saved.**

5.5.1 Creating a user sub-chart

To create a new user sub-chart manually, In the **File** menu select **New user chart...**

A new empty user chart with a default name will be created. You can change the name of the user chart by selecting it with its tab and then, in the **Table** menu select **Change user chart name...**

USE ONLY NUMBERS AND LETTERS IN A SUB-CHART NAME. THE ONLY SPECIAL CHARACTER ALLOWED IS THE UNDERLINE CHARACTER _ . A SUB-CHART NAME MUST START WITH A LETTER.

User charts can also be created by the Chart Calculator (see section 6.8).

5.5.2 Entering data in a user sub-chart

To enter data in a field in the user sub-chart, double click on a bin. The bin becomes editable and you can enter values manually.

5.6 Exchanging chart data with other programs

There are several ways in which chart data can be interchanged between LogWorks and other programs.

5.6.1 Saving charts

Use the **Save Chart menu** item in the **File** menu. The entire chart, including all sub-charts, are saved in a .dif file. DIF files (Data Interchange Format) can be opened by many programs, including Excel.

5.6.2 Copying and pasting chart data

To copy the chart data to the clip-board, select the data by clicking and dragging. Then, in the **Edit** menu, select **Copy Selection**. The chart data will be put on the computers clip-board as tab delimited text, which can be understood and pasted in by many programs.

To copy the entire current sub-chart, including the column and row headers, select in the **Edit** menu the item **Copy current view**.

You can paste data from other programs into user sub-charts, but not into the standard sub-charts. The other program must be capable of putting the data as tab-delimited text onto the clip-board.

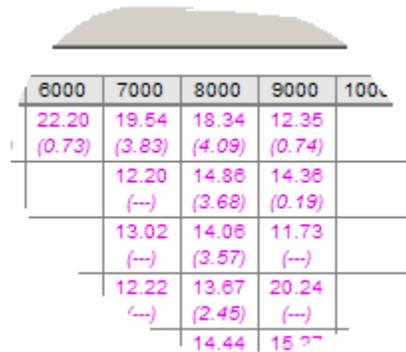
To paste the data in the user sub-chart, select the top-left bin of the area where you want to paste the data. Then, in the **Edit** menu, select **Paste Data**. The current view in the chart/graph pane must be a user sub-chart.

5.7 Overlaying charts

You can overlay one sub-chart over another so you can view both at the same time. In the **View** menu, select the sub-chart from the **Overlay on current view** sub-menu.

To switch off overlays, in the **View** menu, select **Overlay view off**.

An overlay view looks like this:



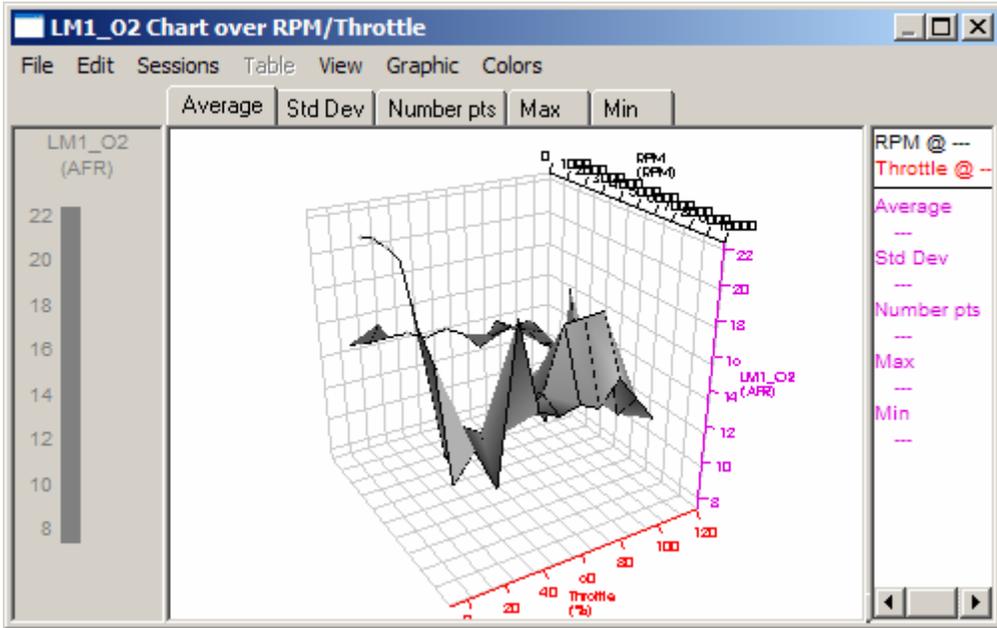
6000	7000	8000	9000	1000
22.20 <i>(0.73)</i>	19.54 <i>(3.83)</i>	18.34 <i>(4.09)</i>	12.35 <i>(0.74)</i>	
	12.20 <i>(--)</i>	14.86 <i>(3.68)</i>	14.36 <i>(0.19)</i>	
	13.02 <i>(--)</i>	14.08 <i>(3.57)</i>	11.73 <i>(--)</i>	
	12.22 <i>(--)</i>	13.67 <i>(2.45)</i>	20.24 <i>(--)</i>	
		14.44 <i>(--)</i>	15.27 <i>(--)</i>	

The overlaid sub-chart is shown in the bins in *italic* and parenthesis (*)*.

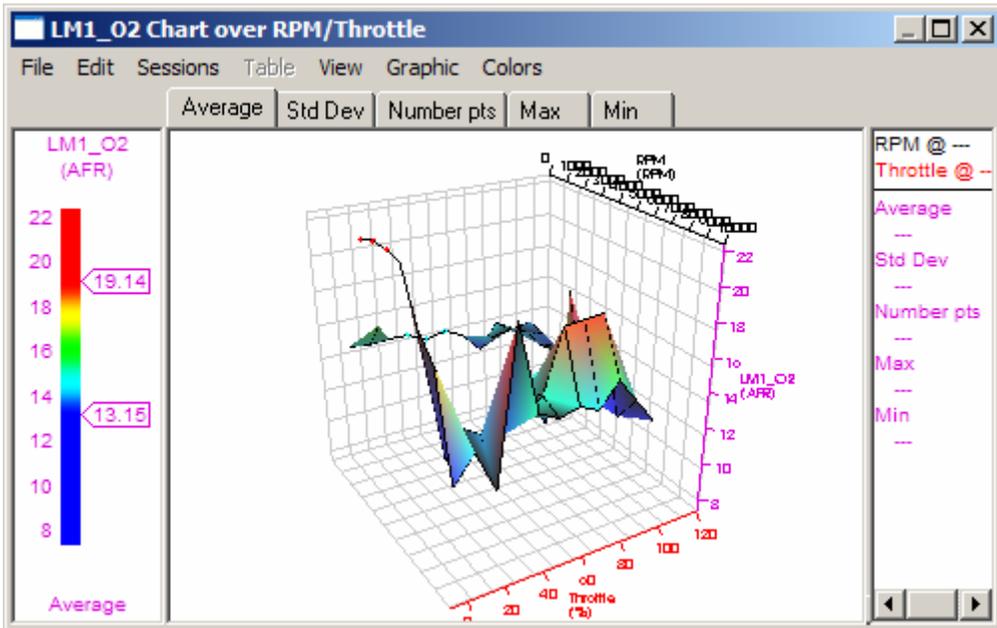
5.8 Viewing a sub-chart as 3D-graph

In the **View** menu, select **View as graph**.

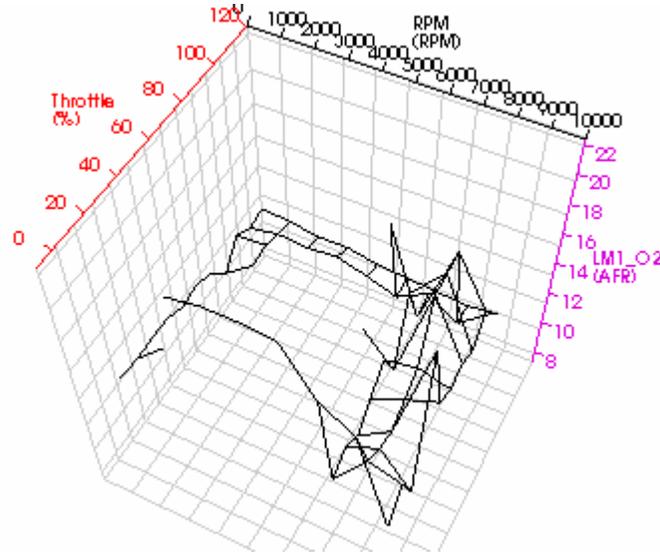
The 3D chart window changes to look like this:



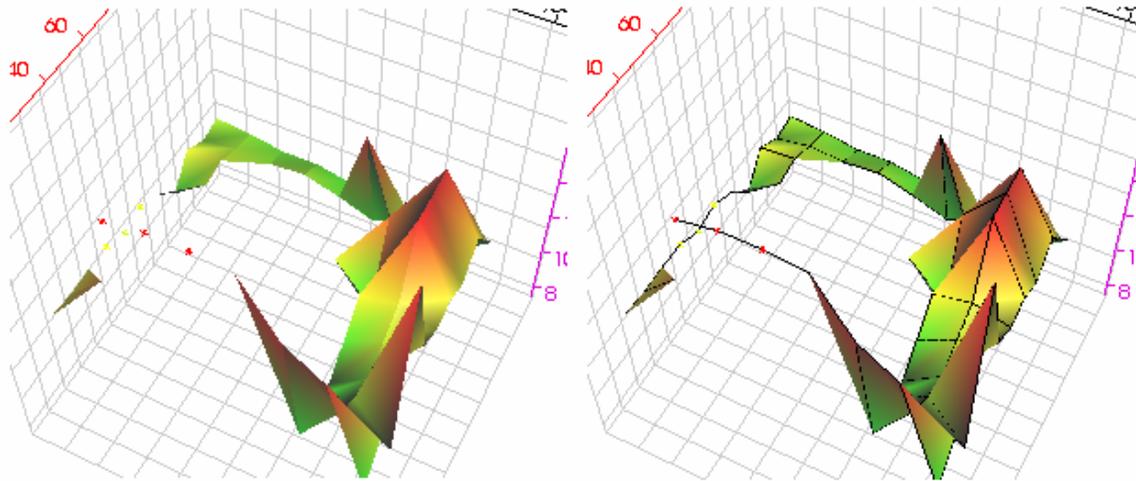
Or, if colorizing is switched on, like this:



The 3D surface represents the content data of the currently selected sub-chart. The x and y axis are the independent channels, the content channel is the z-axis. The grid lines represent the spacing of the columns and rows. But the scales are equally spaced for easier readability. The graph view can be selected to be either surface, mesh or both (see Graphic menu). A mesh view looks like this:



In a mesh view, neighboring data points in the table are connected by black lines. But only neighbors above/below or left/right are connected, not diagonal neighbors. A surface only view (colorized) looks like this (without and with mesh):



The surface is constructed according to the following rules. If a datapoint has 2 or more neighbors (incl. diagonal) a triangle is drawn on the surface. Otherwise the datapoint is shown as 3D cross.

5.8.1 Manipulating the graph view

The graph is basically a 3D surface representing the dependency of the content channel from the x and y channels. The 3D surface (including the measurement grid and scales) is projected onto the chart/graph pane as if it were photographed by a camera. When changing the camera view the grids are always positioned such that they are 'behind' the surface or mesh as seen from the camera position. The scales are also moved to the edge of the grid that projects with the longest line on the pane so that the scale numbers overlap as little as possible.

You can manipulate the camera position and zoom with the following user actions:

a. Camera view angle

Click on the graph with the left mouse button and move the mouse. Moving the mouse left and right rotates the camera around the graph left or right, but leaves the focal point (where the camera is pointed to) the same. Moving the mouse up and down rotates the camera vertically around the focal point.

b. Camera pan

Hold down the Ctrl button while clicking and dragging the mouse. This moves the camera focal point and effectively moves the graph in the window.

c. Camera zoom

Click on the graph with the right mouse button and move the mouse up and down. Moving the mouse up zooms in closer, moving the mouse down zooms away.

When the mouse is moved (without a mouse button pressed) over the graph, LogWorks effectively shoots a ray into the picture (like shooting a gun from the camera position). If that ray hits the graph, the closest bin-point is calculated and the values of all the sub-charts at that position are shown in the measurement pane.

If you get lost zooming and panning, the camera angle and zoom value can be reset at any time by selecting in the **Graphic** menu: **Reset Camera Position**.

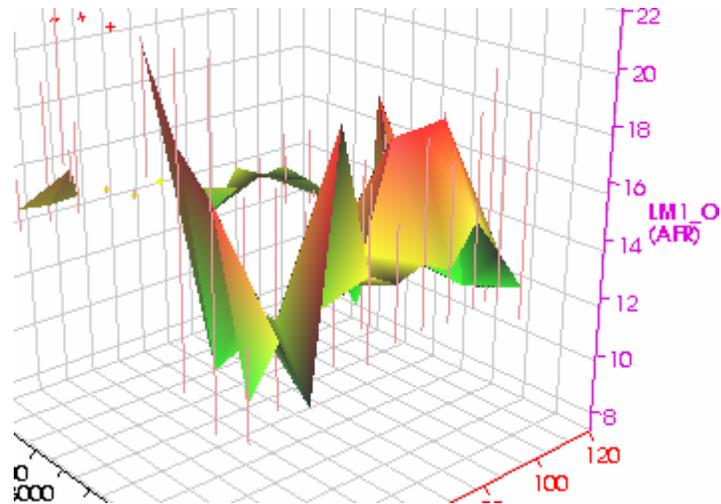
5.8.2 Glyphs

Glyphs are in computer visualization indicators of additional data drawn on a visualized view. LogWorks can show the Standard Deviation or the Min/Max points of each bin as glyphs. In the Graphic menu select Indicate Std. Dev. or Indicate Min/Max Values to show the glyphs for Std. Deviation or Min/Max. The glyphs are indicated as vertical lines emanating above and below a data point. The end-points of the lines indicate the Min or Max values or the deviation inside the bin from the average value.

NOTE:

Glyphs can be added only when the current view shows the average values of the bins.

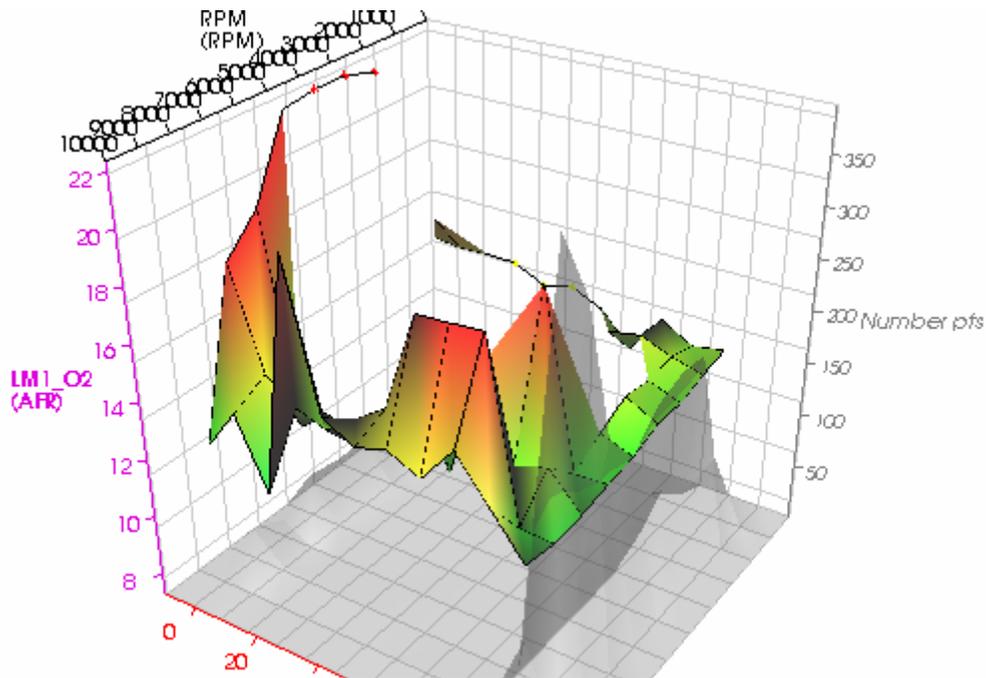
Here's a view of a Min/Max glyphed surface:



5.8.3 Overlays on 3D graphs

Just as you can in the table view of the charts, you can overlay another sub-chart in the graph view as well. Select which sub-chart you want to overlay in the **View** menu.

Overlays are shown in gray, half transparent as in this view:



Here the number of datapoints sub-chart is overlaid on the colored average view. As the sessions included in this chart are mostly at WOT, most of the datapoints are located at the WOT line.

5.9 Calculations with charts

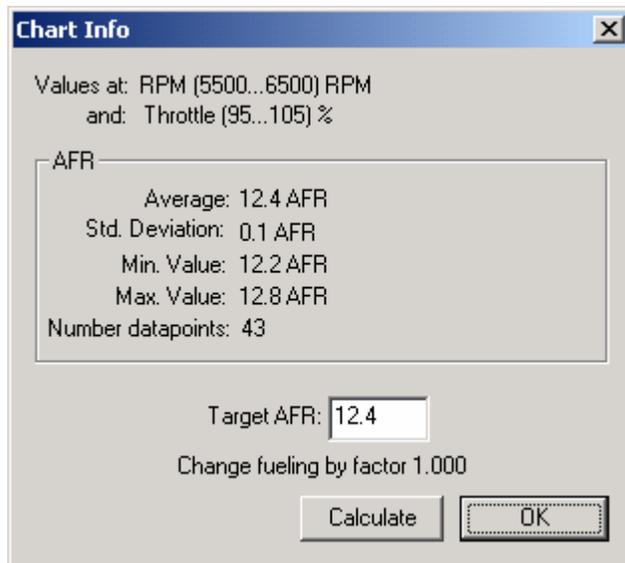
You can use the Math calculator built into LogWorks with charts as well. It is then called Chart Calculator. To call up the chart calculator select in the **Table** menu the item **Chart Calculator...** See section 6 Math Trace Calculator and section 6.8 Chart Calculator for details on how to use the calculators.

Calculation results can be stored in a user chart. If a user chart is created with the Chart calculator, it can be recalculated (for example if it's source data changed) by selecting **Recalculate Math Charts** in the **Table** menu.

Frequently used chart calculations can be stored in a chart calculator library. The library is a text file named **ChartMathlib.txt**. The library can be called up by selecting **Chart Calculator Library...** in the **Table** menu.

Details on how to use the Math libraries can be found in section 7, LogWorks Libraries.

A simple very often used calculation is built into the charts function without using the calculator. When viewing one of the standard sub-charts, double-click on a bin. The following dialog box will show up:



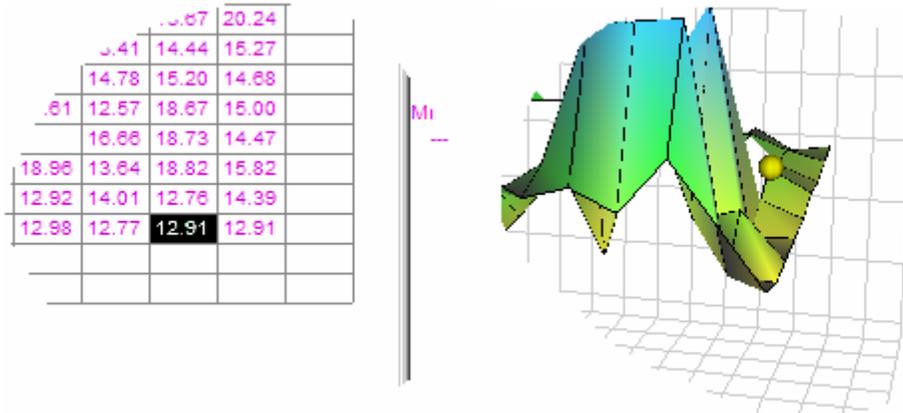
This shows the current values of the clicked field. The target AFR or Lambda calculation functions are only available if the field content is AFR or Lambda. The fueling change calculation is based on fuel flow control where higher numbers represent more fuel.

The fueling factor is calculated by dividing the actual average AFR by the target AFR. If for example your EFI is set by injector timing, just multiply the timing setting by the suggested number.

This number is a suggested value only, different EFI systems will react differently.

5.10 Realtime indication in the chart and graph

If the chart is opened for a realtime log while recording, or while playing back a log, the current engine state (the bin it is running in) is indicated in the chart (table) view by highlighting the appropriate bin as in this:



Or as a 'bouncing yellow ball' in the 3D graph as in the example on the right.

Note:

In the graph view the position of the ball shows the real current values the engine is running, not just the bin it is running in.

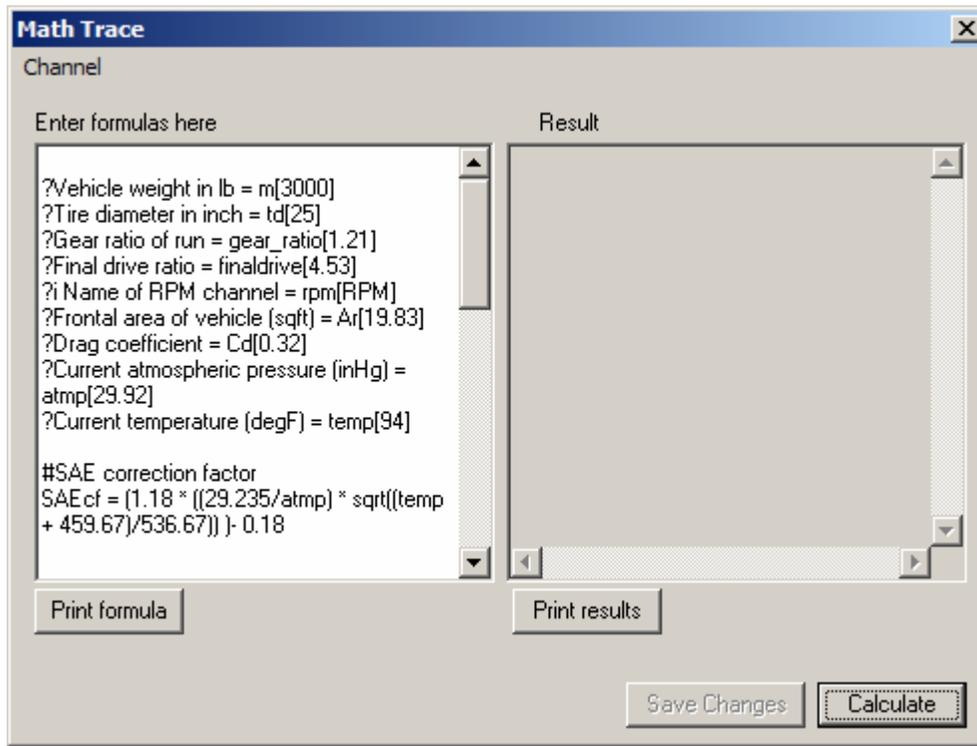
Do not use the realtime view of the 3D graph unless your computer is at least a 800MHz Pentium II and has a graphics system with 3D acceleration. The 3D graph updates and warps in realtime as the data becomes available. The processing requirements for that are very intense.

5.11 Some tips on working with charts

You have to be careful when using the chart for tuning the main fuel map of your EFI system. The chart reflects what's in the log, including transition points and so on. So acceleration enrichment and possible warm-up enrichment are reflected in the averages as well. The best way to create a chart is to create an as long log as possible with steady load points. This way the effects of transitions are minimized. The fewer data points are represented, the less reliable the data. This is reflected as well in the standard deviation.

Acceleration runs in low gears are not ideal for calculating the load points. The same problem as in inertial dynos exists. The acceleration enrichment might still be active and reliable load point data can't be extracted from only a few data points.

6 Math Trace Calculator



In the left window pane of the calculator you enter your calculations. The right side pane shows the results (incl. intermediate results) of that calculation.

You can cut and paste in the left window pane using the standard Window cut and paste shortcuts like Ctrl-X for cut, Ctrl-C for copy and Ctrl-V for paste. Right-clicking in the pane brings up a standard Window edit menu that can also be used for cut-n-paste.

With the **Channel** menu you can insert a channel name in the current cursor location without having to type in the name carefully and correctly.

NOTE:

Trace calculations can't be executed in realtime, while recording.

6.1 Calculator basics

You can write formulas however you want to create new channels from existing data or calculate stuff.

There are certain rules you need to follow.

The following examples show how to use the Calculator: Formulas and calculations can be entered as described in the examples.

By right-clicking in the formula window you can also cut and paste formulas in as text from any program.

Comments can be added in the calculation by putting a '#' as the first character in a line.

Example 1: Calculate Force (in lb force) from car mass (lb) and acceleration (in g)

(Thanks, Isaac N.)

```
#m is vehicle weight in lb  
m = 3000
```

```
#a is acceleration in g  
a = 0.4  
F = m * a
```

In this example acceleration a is 0.4 g and vehicle mass is 3000 lb. The result window shows the acceleration force. Enter the text (or copy it from this manual) and press the **Calculate** button

In the LogWorks Calculator, multiple variables used for a built-in function are separated by semicolons, not commas as is usual for most programming languages. Example:

avrg(a;b;c) calculates the average of the variable a, b and c.

The reason is that in some languages, German for example, a comma is used instead of the decimal point as is usual in English speaking countries. Using a semicolon allows stored calculations to be used in either case without re-writing. For every formula used, the math calculator converts numbers with decimals into the respectively used format before doing a calculation. So in English speaking countries, commas in the text will be converted into colons, or in countries that use decimal commas, colons are replaced by commas. Calculation formulas can so be interchanged internationally.

You can also change the formula so the user is asked for the car weight. To ask the user a question you put a question mark at the beginning of the line, followed by a space. Then type in the question, followed by an equal sign '=' and then the name of the calculation variable you want to assign the answer to.

6.2 Asking for user data

Example 2: Calculate Force (in lb force) from car mass (lb) and acceleration (in g)

```
? Enter vehicle weight in lb = m
? Enter acceleration in g = a
```

```
F = m * a
```

When you press the calculate button here, a dialog box will pop up that allows the user to enter the values for his application.

If you want to suggest default values for a question, enter the default value in [] after the variable name in the question line as in this example:

```
? Enter vehicle weight in lb = m[3000]
```

The formula calculator libraries (see chapter 7) always store the last entered user values in the appropriate library entry so they don't have to be entered every time they are used.

Formula Calculator allows to use as many intermediate results as you want to make the calculations clearer. The following example shows how.

Example 3: Calculate torque and horsepower from vehicle weight, acceleration, gear ratios, tire diameter and rpm

```
#m is vehicle weight in lb
m = 3000

#a is acceleration in g
a = 0.4
F = m * a

#dia is tire diameter in inches
dia = 25

r = dia/(2*12) #calculate radius in feet

#final (differential) ratio
finaldrive = 4.53

#gear ratio of the gear in which the acceleration is measured
gear_ratio = 0.82

#and finally rpm
rpm = 4500

torque = F * r / (gear_ratio * finaldrive)
hp = torque * rpm / 5252
```

Or this time without fixed values, but a questionnaire that has to be filled out by the user

```

? Enter vehicle weight in lb = m
? Enter acceleration in g = a

F = m * a

? Enter tire diameter in inches = dia

r = dia/(2*12) #calculate radius in feet

? Enter final drive ratio = finaldrive
? Enter gear ratio = gear_ratio
? Enter rpm = rpm

torque = F * r / (gear_ratio * finaldrive)
hp = torque * rpm / 5252

```

LogWorks collects up to 10 questions into a questionnaire dialog box, so that only a minimum of dialog boxes pop up. If more than 10 questions are asked, the questions are asked with multiple sequential dialog boxes of 10 questions each.

6.3 Restrictions on variable names

There are certain restrictions on variable names so that the Formula Calculator can correctly distinguish between what is an operator like + - * / and a variable or constant.

1. Variable names **MUST** start with a letter, not a number or special character.
2. Variable **CAN ONLY** contain letters and numbers, no special characters, with one exception.
3. The underline character `_` is allowed.

6.4 Using LogWorks channels

Suppose you don't want to enter the values manually, but use data collected in a LogWorks channel. You can use LogWorks channels as variables just as if you had defined them. For a simple calculation with only one value as above, the formula calculator chooses the value to use according to the following rules:

If an area in the visible window is selected, get the first selected datapoint in the window (from left to right).

Otherwise choose the first selected datapoint in the session

If nothing is selected, use the first (leftmost) datapoint in the visible window.

Example 4: Calculate torque and horsepower from vehicle weight, acceleration channel, gear ratios, tire diameter and rpm

```

? Enter vehicle weight in lb = m
F = m * ACCEL
#ACCEL is the acceleration channel from the LMA-3

```

? Enter tire diameter in inches = dia

r = dia/(2*12) #calculate radius in feet

? Enter final drive ratio = finaldrive

? Enter gear ratio = gear_ratio

? Enter rpm = rpm

torque = F * r / (gear_ratio * finaldrive)

hp = torque * rpm / 5252

If the channel name is not known initially because the user might have assigned a different name to it, you can ask for the acceleration channel as in this example:

?i Enter your acceleration channel name = a

The Formula Calculator knows from the i following the question mark that a channel name is requested, not a number.

6.5 Calculating new LogWorks channels

Suppose you want to create a new channel from existing data. This channel can be used then just like any other channel in LogWorks. The LogWorks restriction of 32 channels includes calculated channels.

NOTE:

The restrictions on variable names also apply to channel names used in the calculations.

Example 5: Calculate torque and horsepower channels from vehicle weight, acceleration channel, gear ratios, tire diameter and rpm channel

```
? Enter vehicle weight in lb = m
F = m * ACCEL #ACCEL is the acceleration channel from the LMA-3

? Enter tire diameter in inches = dia

r = dia/(2*12) #calculate radius in feet

? Enter final drive ratio = finaldrive
? Enter gear ratio = gear_ratio

trq = F * r / (gear_ratio * finaldrive)
MC(power;hp) = trq * RPM / 5252 #RPM is the RPM channel
```

MC() indicates that a new channel is to be created (Make Channel). The first word after the parenthesis ('power' in the example) is the name of the new channel. The second word, separated from the first by a semicolon, is the unit assigned to the channel.

The format of the MC command is:

MC(channel_name; channel_unit; minimum_bound; maximum_bound)

The channel unit, minimum_bound and maximum_bound are optional. See below.

LogWorks channels also have 'bounds'. The bounds are there to limit what is shown on the main session window to the interesting region. Input channels are naturally bounded by the input capability of the LM-1, LMA-3 or other data collection devices, typically 0..5V. Calculated channels have no such natural limits. When no bounds are specified, the MC command calculates the minimum and maximum of the bounds automatically by looking at the minimum and maximum of the calculated trace in all sessions. This can lead to too large a range because calculations are always performed on all sessions in a log.

To limit the min and max bounds select the areas in each session you are interested in calculating. When areas are selected, the formula calculator will only use the selected areas for the bounds calculations.

You can also set fixed bounds by adding the bounds to the MC command like this:

```
MC(power;hp;0;500) = trq * RPM / 5252 #RPM is the RPM channel
```

This will now create a channel with bounds of minimum 0 hp and maximum 500 hp. This eliminates for example negative hp values created during braking.

If you want to set the minimum bound only, just leave out the maximum as in this:

```
MC(power;hp;0) = trq * RPM / 5252 #RPM is the RPM channel
```

If you want to set the maximum bound only, just leave out the minimum, but use 2 semicolons as in this:

```
MC(power;hp;;500) = trq * RPM / 5252 #RPM is the RPM channel
```

Note:

LogWorks stores the data in 10 bit words. This means that the results are stored with a resolution of about 0.1%. Therefore calculated channels should not be used in further calculations. Calculate one channel at a time.

For example:

```
MC(trq;lbft) = F * r / (gear_ratio * finaldrive)
MC(power;hp) = trq * RPM / 5252 #RPM is the RPM channel
```

Would work, but can create wrong results because trq is stored with 10 bit resolution and then used in the hp calculation.

Instead recalculate or assign the torque channel as in this:

```
trq = F * r / (gear_ratio * finaldrive)
MC(torque;lbft) = trq
MC(power;hp) = trq * RPM / 5252 #RPM is the RPM channel
```

6.6 Dealing with units

Sometimes a channel used for a calculation is in a different unit as required for the calculation. For example if the user set **ft/sec^2** as acceleration metric, but the calculation requires g's. You can force an automatic unit conversion by using the unit converter operator.

Example 6: Automatic unit conversions

? Enter vehicle weight in lb = m

F = m * ACCEL{g}

The curly braces { } around the desired unit after a channel name recalculates that channel temporarily to the new unit.

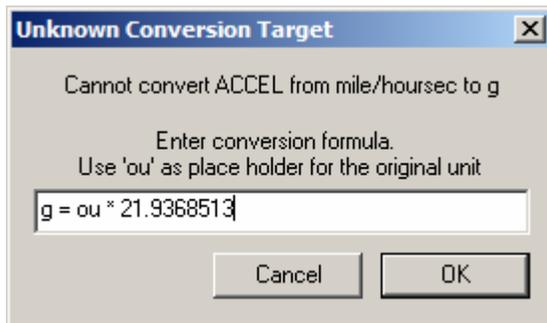
Once a channel is converted, you can't convert it again in the same calculation. The converted channel will be used for the rest of the calculation and further {}'s after a channel name will be ignored.

If a question for a channel name is asked from the user, the automatic unit conversion can also be automatically invoked to make sure the channel is correct for the calculation.

?i Enter your acceleration channel = a{g}

This recalculates the acceleration channel into gs temporarily.

If the unit conversion requested is unknown to LogWorks, a dialog box will pop up that asks how to convert the unit:



The formula uses 'ou' as placeholder for the original unit.

Enter the formula and the calculation will proceed.

For details on the unit conversion, see chapter 8 How LogWorks unit conversions work.

6.7 Formula Calculator Functions

Rules:

- If a function uses multiple arguments, like `floor(x;10)`, the arguments are separated by semicolons.

The Formula Calculator has the following built-in functions, operators, constants and values

Pre-assigned constants and values

e	2.71828182846
pi	3.14159265359
t	time in seconds from begin of session

Math Operators

+	Addition
-	Subtraction
*	Multiplication
/	Division
^	Power of, as in x^2 would square x

Boolean Operators

Boolean operations result in just one of 2 possible results: 1 or 0, equivalent to true or false. The following Boolean operators are built into the Math Calculator:

&	AND, as in $a \& b$. Result is 1 if both, a and b, are 1.
	OR, as in $a b$. Result is 1 if either a or b are 1.
!	NOT as in $!a$. Result is 0 if a is not 0. Result is 1 if a is 0.
==	EQUAL as in $a == b$. Result is 1 if a is equal to b. Otherwise result is 0.
!=	UNEQUAL as in $a != b$. Result is 0 if a is equal to b. Otherwise result is 1.
>	GREATER THAN as in $a > b$. Result is 1 if a is bigger than b.
<	SMALLER THAN as in $a < b$. Result is 1 if a is smaller than b.
>=	GREATER OR EQUAL as in $a >= b$. Result is 1 if a is bigger or equal to b.
<=	SMALLER OR EQUAL as in $a <= b$. Result is 1 if a is smaller or equal to b.

Regular Math Functions

abs	Calculates absolute value ($-x$ turns into x)
acos	Calculates arc-cosine as in $\text{acos}(x)$
asin	Calculates arc-sine as in $\text{asin}(x)$
atan	Calculates arc-tan as in $\text{atan}(x)$
avrg	Calculates the average of multiple values as in $\text{avrg}(a;b;c;d)$
ceil	Limits value to a maximum as in $\text{ceil}(x; 10)$ would limit x to a maximum of 10
cos	Calculates cosine as in $\text{cos}(x)$
cosh	Calculates hyperbolic cosine as in $\text{cosh}(x)$
fact	Calculates the factorial of x as in $\text{fact}(x)$ calculated as $x*(x-1)*(x-2)*...*(x-x+1)$
floor	Limits value to a minimum as in $\text{floor}(x; 2)$ would limit x to a minimum of 2

max	Returns the largest of a set of variables as in <i>max(a;b;c;d)</i>
min	Returns the smallest of a set of variables as in <i>min(a;b;c;d)</i>
ln	Calculates the natural logarithm (base e) of x as in <i>ln(x)</i>
log10	Calculates the base 10 logarithm of x as in <i>log10(x)</i>
sin	Calculates sine as in <i>sin(x)</i>
sinh	Calculates hyperbolic sine as in <i>sinh(x)</i>
sqrt	Calculates square root as in <i>sqrt(x)</i>
sum	Calculates the sum of multiple values as in <i>sum(a;b;c;d)</i>
tan	Calculates tan as in <i>tan(x)</i>
tanh	Calculates hyperbolic tan as in <i>tanh(x)</i>

Note:

Trigonometric functions (sin, cos...) use radians arguments, not degrees.

Special channel functions

slope	Calculates the slope (or differential) of a channel as in <i>slope(channel)</i> .
area	Calculates area under the channel curve or partial integral (or area) as in <i>area(channel; t0; t1)</i> where t0 and t1 are constants in seconds in the session. Can also be used as in <i>area(channel; t-10; t+10)</i> to calculate running area (integral).

Note1:

The slope functions will only take a channel name as argument, not an evaluated function as in `slope(channel * x + y)`.

The automatic unit conversion operator can be applied though.

Note2:

Slope calculations are very sensitive to noise on the channel. To minimize noise it is better to smooth the channel before applying the calculations. As a rule, smoothing of 0.25 to 1 second is enough in most cases (reasonably smooth data to begin with). Experiment with the right smoothing value for your application.

6.8 Chart Calculator

The chart calculator usage is exactly the same as for the Math Trace Calculator. With the following differences:

- **Channel names CANNOT be used as variables**
- **Sub-chart names can be used as variables.**
- **The special math functions slope and area cannot be used.**
- **The MC special function stands here for “Make Chart”.**
The additional variables for the MC function, like unit and limits, are ignored. MC creates a new user chart.
- **The ‘t’ variable for time is not available**
- **Standard sub-charts can be modified**

Because sub-chart names can be used as variables, the same restrictions as for general variable names applies here too. See section 5.3, Restrictions on variable names for details.

6.8.1 Pre-assigned names for the standard sub-charts:

chart_avg	The “average value” sub-chart.
chart_num	The “number of datapoints” sub-chart
chart_stddev	The “standard deviation” sub-chart
chart_min	The “minimum value” sub-chart
chart_max	The “maximum value” sub-chart
chart_X	The horizontal value (column header) of the bin used
chart_Y	The vertical value (row header) of the bin used

6.8.2 Using the Chart Calculator

Here are a few examples on how to use the chart calculator:

Example 1: Filtering the chart so that only values with more than 50 datapoints are used:

```
chart_num = (chart_num > 50) * chart_num
```

In this case, the number of datapoints is reset to 0 (empty) if it has less than 51 datapoints in it. The term $(\text{chart_num} > 50)$ evaluates to 1 if the number of datapoints in the bin is more than 50, otherwise to 0. So, chart_num stays either the same ($\text{chart_num} * 1 = \text{chart_num}$) or becomes 0 ($\text{chart_num} * 0 = 0$).

Example 2: Calculating a horsepower sub-chart from a chart containing torque:

For this example the chart_average view contains the engine torque in lbft, the column headers (horizontal axis of the chart) are in RPM.

$$\text{MC(power)} = \text{chart_avrg} * \text{chart_x} / 5252$$

Example 3: Calculate a new fuel map based on an existing fuel map sub-chart and a target AFR sub chart:

Requirements:

- a. The chart_average view contains the measured AFR over RPM and MAP/MAF or Throttle position.
- b. There is a sub-chart named current_map that contains the current fuel map
- c. There is a sub_chart named target_afr that contains the target AFRs for each bin
- d. The fuel map is linearly related to the injector duty cycle, where 0 means no fuel and some max value means 100% injector duty cycle.

$$\text{MC(new_map)} = \text{current_map} * \text{chart_avrg} / \text{target_afr}$$

7 LogWorks Libraries

LogWorks has multiple libraries. These libraries are used to store frequently used searches or calculations. When using the LogWorks Log Window, the Trace Libraries or the search Library is used. When using the 3D chart, the Chart Library is used.

Each library entry or formula has a name under which it can be easily identified, and (optionally) a category to which it belongs to further simplify and find calculations or searches.

So that distracting duplicate entries are avoided, the Trace Library is divided into two parts. One part is in US units, the other in international units. You select which Library is used by selecting the appropriate Preferences in the LogWorks Main Window menu.

Libraries are plain text files. So they can be opened and edited by any text editing program, even the simple Notepad program built into Windows. In practice, this is rarely necessary because the Library editor built into LogWorks can accomplish all Library management tasks. For details on the file format of Library text files, see chapter 7.4 Library formats.

The library files must be in the same folder as the LogWorks.exe program for LogWorks to find them.

7.1 Using the Libraries

7.1.1 Basic usage

Log Window:

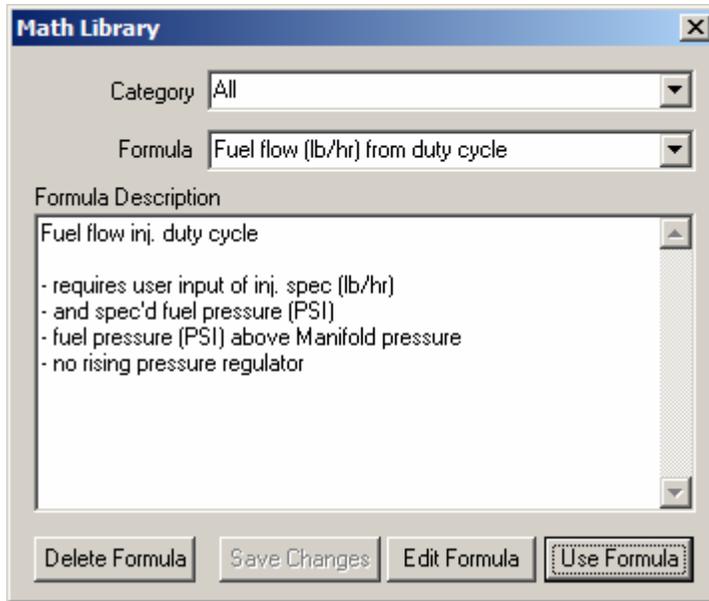
Select **Formula Collection...** in the **Tools** menu for trace calculations.

Select **Search Library...** in the **Edit** menu for frequently used searches.

3D chart window:

Select **Chart Calculator Library...** in the **Table** menu for chart calculations.

The following dialog box will appear:



With the uppermost field, you can select or edit the category the calculation belongs to. In the middle field you select or edit the formula name. The lowest field shows and allows you to edit a short description of the formula.

To delete the formula from the library, click on the **Delete Formula** button. To save possible changes you made to the name, category or description, click on the **Save Changes** button.

To change the formula itself, click on the **Edit Formula** button. The Trace Calculator dialog box will show up and allow you to change the formula.

To execute the selected formula, click on the **Use Formula** button.

Note:

When entering user values in a formula during use, the entered values are stored in the library as defaults, so that they don't have to be entered every time the formula is used.

For a tuner that tunes multiple cars it would be of advantage to copy the libraries to a different (customer specific) folder as the libraries contain the last default values. Then copy the libraries to the LogWorks Folder when the customer car is retuned. This way the customer's last calculation values are restored as defaults.

7.1.2 Adding a new formula to a library

If you entered a new formula in either the Trace calculator, Chart calculator or Auto-search window, you can make it a new library entry by clicking the Add to Library button in the calculator or search window. The same dialog box as above will show up. Enter the name of the new formula in the middle field. Enter a short description in the bottom field. Select a category or enter a new one in the uppermost field.

7.2 LogWorks built-in Trace calculations

These are the calculations built into LogWorks for calculating new channels or traces. Check on the Innovatemotorsports web site (www.Innovatemotorsports.com) for additional calculations as they become available.

To understand the calculations a few things must be known by the user:

- a. Every calculation is only as good as the data used as basis for the calculation. This is especially true for horsepower and torque calculations.
- b. Many time based calculations are based on an engine cycle. A 4-stroke engine cycle requires 2 engine revolutions.

7.2.1 Category: Fuel Calculations

Fuel flow (lb/hr) from duty cycle (US) or (cc/min) for Internat.

Requires you to enter the specs of the injectors used (lb/hr) or (cc/min), their rated pressure in PSI (US) or kPa (int.), the injector duty cycle channel name (easy if you have an LMA-3), the fuel pressure the regulator is set to, and the total number of injectors. Creates a fuel flow channel in lb/hr or cc/min total for the engine.

Note: Specifying injectors in lb/hr is actually a misleading metric. Injectors flow a certain volume in a specified time. Because most fuels have very similar viscosity, but very different specific mass, an injector rated for example for 10 lb/hr will flow 10lb per hour of the test gasoline, but a very different number of lbs for example for methanol.

7.2.2 Density and VE

Intake air density

Calculates an air density channel in lb/cuft (US) or kg/m³ (Internat.) from intake air temperature and absolute intake air pressure (MAP) channels.

7.2.3 Power calculations

These calculations result in two channels, one for torque and one for power. The US version of the calculations result in a torque channel in lbft and a horsepower channel in hp. The International versions result in a torque channel in Nm and a power channel in kW. You can easily change the formulas to get the results in the units you want.

Because these calculations are based on the acceleration of the vehicle, the speed of the vehicle must be known. It is assumed the test runs are done in a single gear (3rd gear for example). Because vehicle speed is calculated from gear ratios and tire diameter, the calculations will be unreliable for an automatic transmission vehicle below the converter lockup rpms. They will be correct at rpm levels above converter lockup. Because a vehicle does not accelerate any more at top speed, for calculations based solely on acceleration alone, the torque (and therefore horsepower) would be zero there. That's of course not the case. The calculations therefore also require to put in the frontal area and Cd value of the car to calculate aerodynamic resistance

force. As this force is speed dependent and acts against the acceleration force, it must be accounted for. The frontal area and Cd value for many cars can be found here:

<http://www.mayfco.com/tbls.htm>

The resulting values are corrected for different meteorological conditions as well as using standard SAE correction.

To use the power calculations correctly, use the selection tool to select ONLY the areas of full throttle at the correct gear.

The results should not be relied upon in the areas at the edges of the selected areas. Rounding of the signal by smoothing will effect the calculated results at about 1 second from the edges if a smooth value of 1 second is used. Smoothing is required for calculations involving slopes because slope calculations will vastly exaggerate any noise or digitizing artifacts in the signal. These artifacts show up as oscillations on top of the calculated channel.

The required data to be entered must be as accurate as possible. The vehicle weight entered is the weight as tested, incl. fuel, liquids and driver, not the dry weight.

The aerodynamic force calculations are based on dry air. The published numbers by the manufacturers might be on the low side of actual, even for an unmodified vehicle. Addition of aerodynamic devices like wings, splitters, side-skirts and so on can drastically change the cd-value and frontal area. The same is true for wider tires, lowering and so on.

NOTE:

These calculations should be used to compare the results of modifications made to fueling and/or timing and their relative effects on power and torque. They are NOT intended as replacement for dyno time if the actual power and torque numbers are needed.

Torque/power from Accel/RPM

This calculation uses primarily the acceleration channel from the LMA-3 and RPM to calculate torque and power. It also uses the tire diameter and gear ratios to calculate speed for the aerodynamic force calculations.

Torque/Power from speed and acceleration signal

This calculation uses a speed signal input and acceleration signal from the LMA-3 to calculate torque and power.

7.3 LogWorks built-in chart calculations

These are the calculations built into LogWorks for calculating with charts. Check on the Innovate Motorsports web site (www.innovatemotorsports.com) for additional calculations as they become available.

7.3.1 Fueling calculations

Fuel map from measured AFR and target AFR

Requires a current fuel map as input chart (user sub-chart) and a target AFR sub-chart. The current fuel map values are assumed to increase linearly with injector timing, where 0 means no injection (injector cut off).

7.4 Library file format

If you feel the need to edit the libraries directly with a text editor, this section shows the file format. All libraries have the same basic format. Irrespective if it is a chart library, trace library or search library.

The library managers use special comments in the formulas to identify individual formula entries. These special library comments use a double comment marker (##) at the beginning of a text line, followed by the text.

7.4.1 Name comment

Format:

##Nformulaname

The comment starts with ##N, followed immediately by the name of the formula. This is a required comment. The Library managers identify formulas as the text between formula name comments. This means a formula entry starts with the formula name and ends at the beginning of the next formula name or the end of the text file.

7.4.2 Category comment

Format:

##Cformulacategory

This comment is optional and, if used, follows the Name comment. The comment starts with ##C, followed immediately by the category used for the formula.

7.4.3 Description comment

Format:

```
##[  
Multiple lines of comment text  
##]
```

This comment is optional and, if used, follows the category comment. If no category comment is used, it follows the name comment.

The library manager strips out any text between the ##[and ##] description markers before handing a formula to the calculator.

8 How LogWorks unit conversions work

To automatically convert units, LogWorks uses a special library file named **Conversions.txt**. This file must be located in the same folder as the LogWorks.exe file. You can manually extend the number of conversions LogWorks understands by editing this file.

Additional conversions for many units can be found here:

www.onlineconversion.com

NOTE:

Avoid multiple conversions back and forth. A computer has a limited resolution for numbers which creates rounding effects, and these rounding effects add up after a few conversions and will create inaccurate data.

8.1 Conventions on unit names

For LogWorks to understand a conversion, certain conventions must be followed:

8.1.1 Temperature conventions

Temperature measurements are in degrees Celsius, degrees Fahrenheit or degrees Kelvin.

Celsius units are named **degC**
Fahrenheit units are named **degF**
Kelvin units are named **degK**

8.1.2 Pressure conventions

Pressures used in engine diagnostics are either in gauge pressure or absolute pressure.

Gauge pressure is typically what a boost or vacuum gauge measures. It is actually the pressure difference to the current atmospheric pressure, not the actual pressure itself.

Absolute pressure is the pressure above absolute vacuum. This is what most MAP sensors measure. MAP stands for **M**anifold **A**bsolute **P**ressure, not Manifold Air Pressure as a lot of people think.

The fueling or AFR value of an engine is a measure of the ratio of the mass of air entering the engine divided by the mass of fuel. The mass of fuel, being a liquid, changes little with pressure or temperature. Air, being a gas, changes dramatically. Doubling the absolute pressure with no change in temperature, will double the mass of air entering and therefore would also require double the fuel for the same AFR. The air mass is dependent on ABSOLUTE pressure in the manifold, not gauge pressure and is also dependent on temperature.

Pressures are mainly measured in PSI (US, pounds-per-square-inch) or kPa (international, kilo-Pascal). The kPa value is by convention an absolute pressure value.

To distinguish between gauge pressure and absolute pressure it is common to add a 'g' at the end of a gauge pressure unit and an 'a' at the end of an absolute pressure unit. If the 'a' is omitted, absolute pressure is assumed. Sometimes also a 'vacc' is added instead of a 'g' to denote a vacuum measurement. This is typically used for carburetor tuning and is done in the US as inches of vacuum. This is a gauge pressure unit and indicates again the pressure difference to atmospheric pressure. InHgVacc is a typical unit for vacuum measure. It means how high (in inches) the given vacuum could suck up a column of mercury (chem. sign Hg). In reality the mercury is not sucked up, but pushed up by atmospheric pressure. Another vacuum measurement unit is mmHg. It's the same as InHg, but expressed in millimeters, not inches.

When converting between absolute pressure units and gauge pressure units the LogWorks built-in unit calculator will ask you for the current atmospheric pressure. You can enter the atmospheric pressure either in millibar or inches of mercury. Any barometer or weather station/radio will give you the atmospheric pressure in one of those two units. LogWorks will store the entered value in memory.

8.2 The Conversions.txt format

You can add comments in the file by preceding a line of text with a #. All text in the line behind the # is ignored by the unit calculator.

To reduce the number of conversion formulas required, LogWorks uses a two-step approach to the conversions.

First the source unit (the one you are starting out with) is converted into a master unit. You can use any unit as master unit, but make sure all units of the same family are using the same master unit. For example for pressure the master unit is kPa. A unit family is a group of units measuring the same quantity, like pressure or temperature.

In the second step the converted value (converted to the master unit) is converted to the target unit (the one you want to convert to).

Example to convert PSI (absolute) into bar (absolute):

PSIa (absolute pressure in PSI) is converted first into kPa. Then the kPa value is converted to bar.

In the formulas for the conversion the name 'ou' stands for original unit.

A typical example for is the conversion formula for converting PSIa to kPa:

PSIa > kPa = ou * 6.8947573

This means to LogWorks:

To convert PSIa to kPa, multiply the original unit (PSIa) by 6.8947573

Another pre-programmed variable name used by the unit calculator is **ATMP**. ATMP stands for atmospheric pressure. Internally LogWorks stores the current atmospheric pressure in kPa. When you enter the current atmospheric pressure, LogWorks decides what unit (inHg or millibar) was used by looking at the number. If the number is above 100, it's in millibar, otherwise its inHg. It then converts that number to kPa for internal storage. Initially, when LogWorks starts up, the value of ATMP is 0. As air-breathing internal combustion engines are

rarely used in space, LogWorks knows to ask when the current ATMP is required, but its current value is equivalent to the air pressure in intergalactic space (zero).

Here's the complete pressure unit family as stored in the Conversions.txt file:

```
PSI > kPa = ou * 6.8947573
PSIa > kPa = ou * 6.8947573
PSIg > kPa = (ou * 6.8947573) + ATMP
kg/cm^2 > kPa = ou * 98.0665
bar > kPa = ou * 100
inHga > kPa = ou * 3.3863887
inHgVac > kPa = ATMP - (ou * 3.3863887 )
millibar > kPa = ou * 0.1
mb > kPa = ou * 0.1

kPa > PSI = ou / 6.8947573
kPa > PSIa = ou / 6.8947573
kPa > PSIg = (ou - ATMP) / 6.8947573
kPa > kg/cm^2 = ou / 98.0665
kPa > bar = ou / 100
kPa > inHga = ou / 3.3863887
kPa > inHgVac = ( ATMP - ou ) / 3.3863887
kPa > millibar = ou * 10
kPa > mb = ou * 10
```

As you can see, the first half of the conversions all convert a source unit to kPa. The second half of the conversions convert kPa to another target unit.

The following master units are used in the Conversions.txt file:

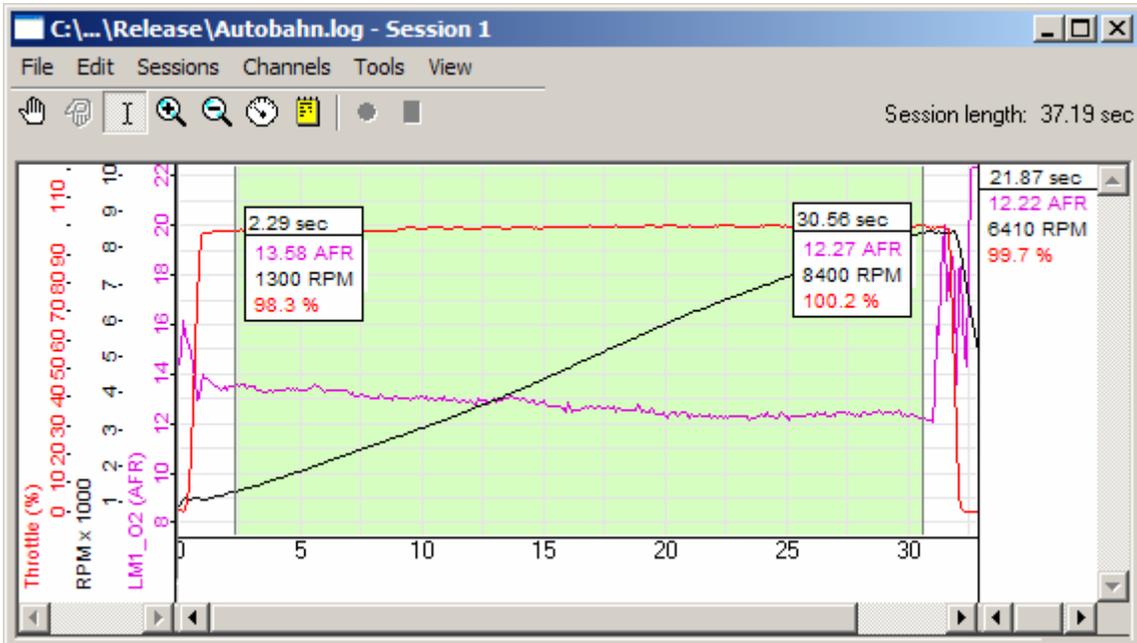
- Temperatures in degree Kelvin (degK)**
- Pressures in kiloPascal (kPa)**
- Acceleration in g**
- Speed in meters per second (m/sec)**
- Weight (mass) in kilograms (kg)**
- Length in meters (m)**
- Volumes in liters (l)**
- Power in kiloWatt (kW)**
- Torque in Newton-meters (Nm)**
- Frequency in Hertz (Hz)**
- Density in kilograms per cubic meter (kg/m³)**

9 Tips & Tricks for using LogWorks

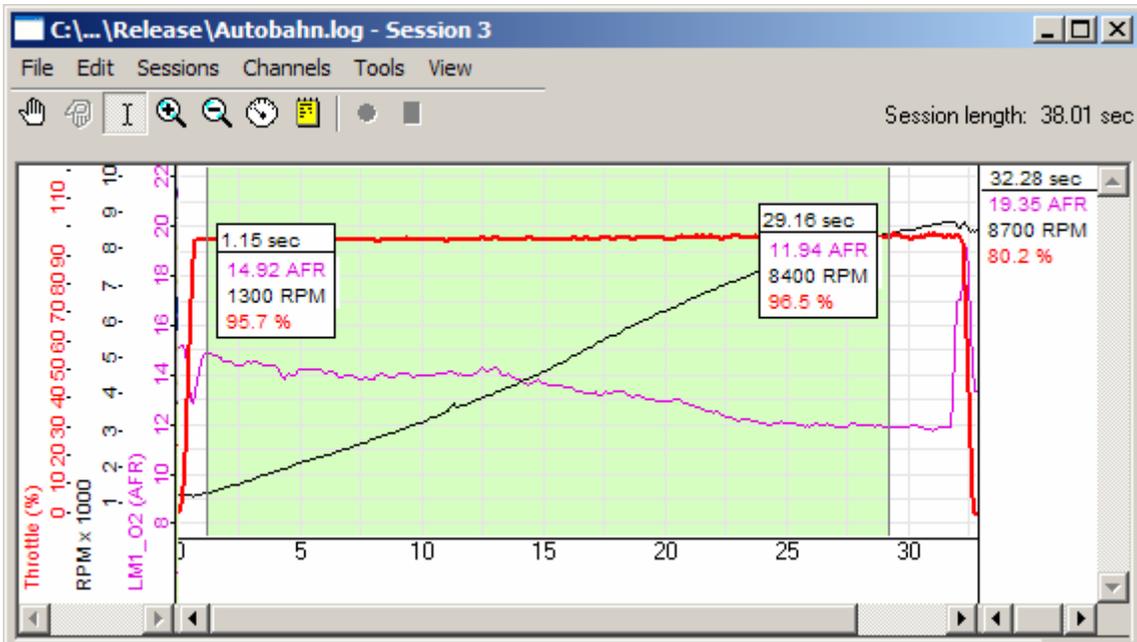
The included log file example Autobahn.log shows a good example of using the features of LogWorks to determine if a fueling change made a difference in power of the engine.

Let's look at Session 1 and Session 3 in the example. Both are 3rd or 4th gear pulls from low RPM to redline. We look at the run from 1300 RPM to 8400 RPM.

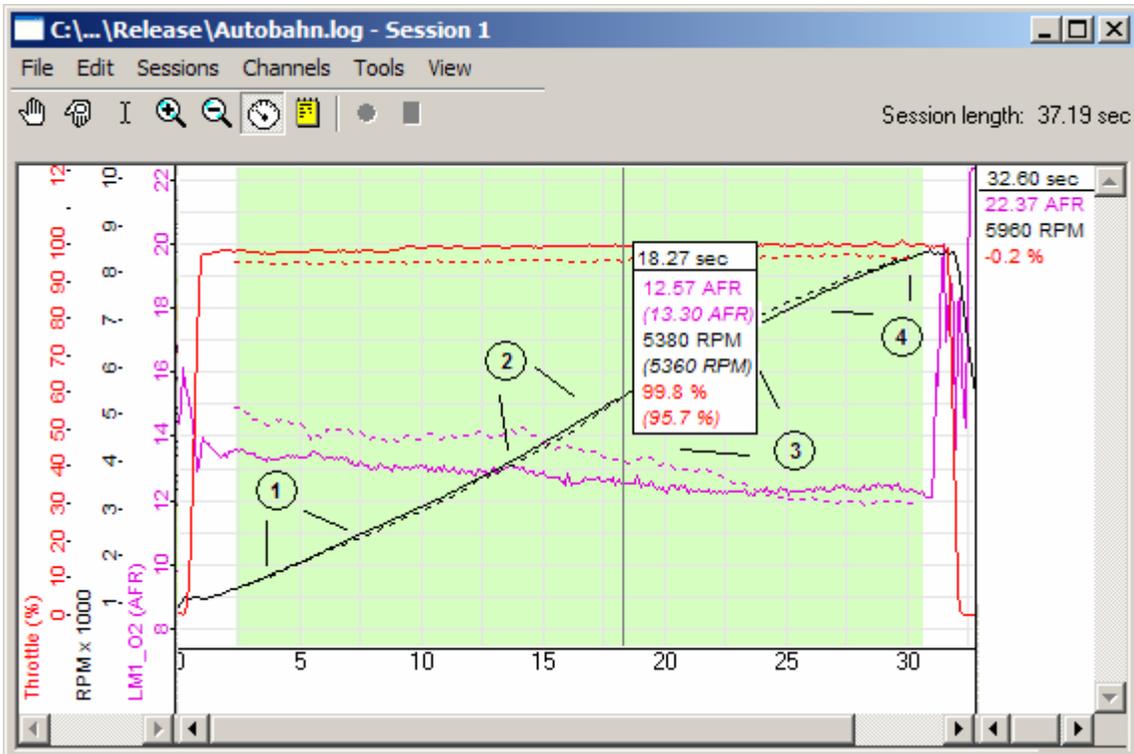
Session 1. Time between 1300 RPM and 8400 RPM is 28.18 sec



Session 3. Time between 1300 RPM and 8400 RPM is 27.93 sec



Now we are using the overlay tool to overlay session 3 over session 1:



What is immediately noticeable is that the AFRs of session 3 are higher than those of session 1 in the area below 7000 RPM, but lower above. Let's see how that affects power and acceleration. Acceleration can be determined by the slope of the RPM curve. The steeper the slope, the higher the acceleration and therefore power (assuming other conditions like weight and wind are the same).

In area 1, acceleration is slightly lower in session 3, while AFRs are higher than in session 1.

In area 2, both RPM slopes match. Therefore the AFR change had little effect.

In area 3, the RPM slope of session 3 is noticeably steeper. The engine made more power with the leaner AFR.

In area 4, the RPM slope of session 3 is flatter. The engine made less power, but AFRs are richer than in that area.

You can also see that when you compare the WOT rows in the charts of the session

Session 1

Throttle (%)	RPM	AFR													
100	13.4	13.4	13.1	13.0	12.9	13.0	12.7	12.6	12.6	12.4	12.3	12.3	12.4	12.4	12.3

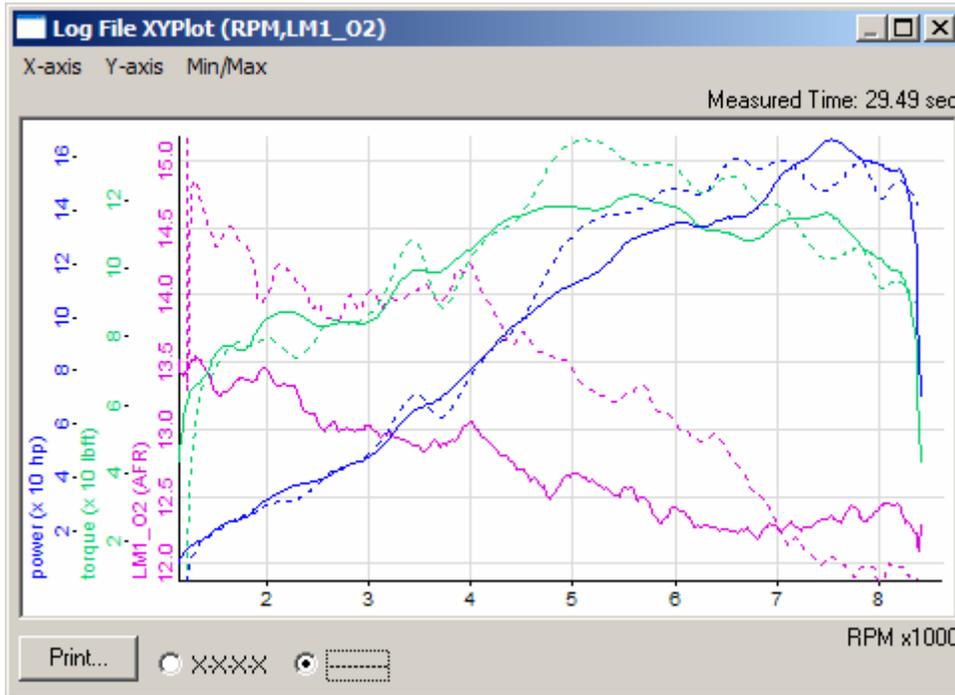
Session 3

Throttle (%)	RPM	AFR													
100	14.7	14.3	14.0	14.0	14.0	14.1	13.7	13.5	13.3	13.1	12.9	12.4	12.1	12.0	12.0

You can see that the power curve can be improved by richening up the fields below ~4500 RPM and leaned out in the fields at 7000 RPM and above.

This can be even better analyzed when using the Math Trace Calculator Library and the X-Y Plot function.

For this example all the WOT runs in Session 1..4 in the example file are selected. The RPM trace is smoothed in those sessions to 1.06 seconds. Then, using the Math library, torque and horsepower are calculated from gear ratios, tire diameter, cars frontal area, weight and aerodynamic coefficient, and the RPM slope. The run in Session 3 is overlaid on session one, and torque, power and AFR together are shown on the X-Y plot:



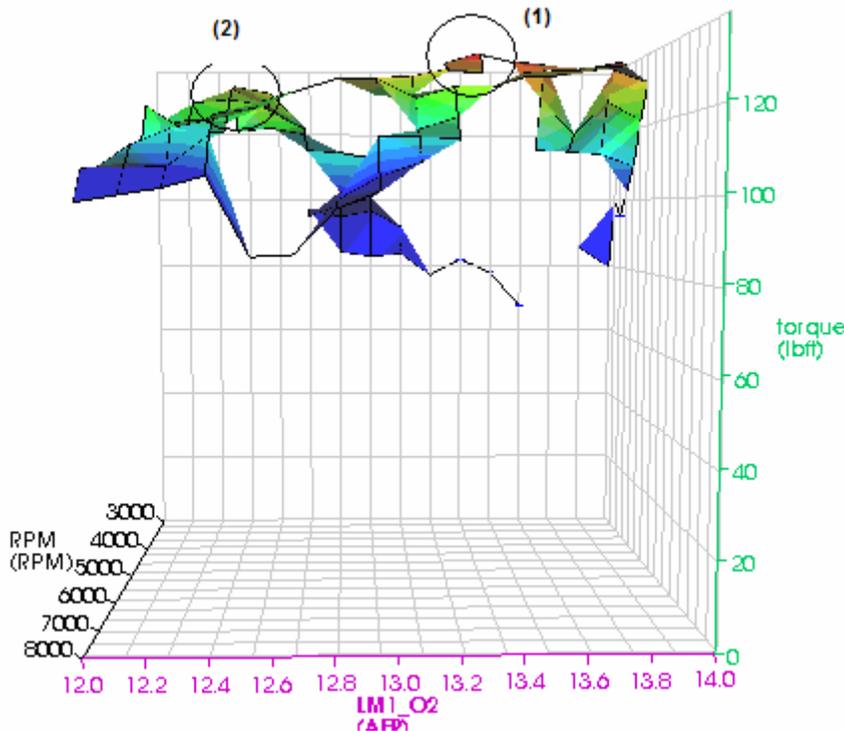
Again, one can see that at the leaner AFR of the overlaid session the torques are higher, except at the low RPMs below about 4500. From about 7000 RPM on the overlay torque curve is lower because the AFR's are richer than in the original session.

Creating a 3D chart of the torque vs. AFR and RPM dependency for the selected WOT areas shows what optimum AFR should be used for max power. This chart is created from only 4 runs (Session 1..4) but illustrates how LogWorks can be used for optimization. More runs will refine the results.

LM1_O2 (AFR)	RPM	torque (lbft)											
		3000	3333	3667	4000	4333	4667	5000	5333	5667	6000	6333	6667
12.00													
12.13											117.4	122.0	113.2
12.27										124.1	119.2	116.0	105.8
12.40							118.5	129.8	128.4	124.9	118.7	115.7	
12.53							119.7	128.1	123.3	123.6			122.3
12.67		97.1	95.4		114.1	117.8	119.2	118.4					125.2
12.80	84.4	95.2	98.8	102.3	113.2								109.8
12.93	79.8	97.0	100.6	105.4	111.7					84.8	115.9	127.9	
13.07	83.8	92.0		107.1						115.7	125.2	88.0	
13.20	75.4							135.2	132.4	132.0			91.5
13.33	80.6						138.7	138.0	132.1		129.7	81.7	
13.47	67.6						136.7			131.1	132.7	43.6	
13.60	53.9				114.1	127.3	135.8	133.5		131.5	137.0		
13.73	34.9				113.6	118.1		133.8	133.3	88.0	116.1	51.5	
13.87	82.0				112.9	126.9	134.6	135.6	133.7		84.5		
14.00	89.2	79.9	70.0	74.1	80.9	71.5	53.0	9.9	9.9	6.3	11.8	0.0	

This shows maximum torque is reached at 5000 RPM and 13.33 AFR.

Here's the same chart as a 3D surface:



One can clearly see the trend to a torque peak (1) at about 13.3 – 13.4 AFR for this particular engine at that engine's current timing settings. A secondary peak exists at a different RPM at (2). The key to good tuning of course is to arrive at the maximum torque achievable without engine knock by varying both, timing and fueling.

10 Interfacing with various sensors

10.1 Electronic parts basics

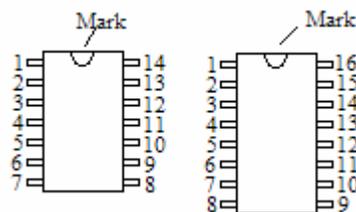
10.1.1 Diodes

Diodes let current pass in one direction (Anode (A) to Cathode (K)) and block current in the other direction. The exception are Zener diodes. They work like regular diodes, but in the reverse direction they will pass current only when the voltage is bigger or equal to the 'Zener' voltage. This has the effect of limiting the voltage over the Zener diode to the zener voltage. On a typical diode the Cathode is marked with a ring as in this picture:



10.1.2 IC's

Typical IC's are either surface mount or through-hole. Through-hole ICs are easiest to use. A typical picture of a 16 pin and 14 pin through-hole IC (DIP) are shown below:



Pin-Number counting starts to the left of the mark and proceeds counter-clock-wise around the chip.

10.1.3 Resistors

Resistors come in many different values and also different tolerance grades and maximum wattage. Typical tolerance grades are 10%, 5% and 1% with 5% being the most common. Wattage ratings are 1W or bigger, 1/2W, 1/4W, 1/8W, and so on. The minimum required wattage rating can be calculated with:

$$V^2 / R$$

Where V is the max voltage the resistor will see, and R is the resistance in Ohms.

The resistance value and tolerance grade on a typical resistor is marked as colored rings (typically 4). The first ring being close to one of the connection leads. The first two rings determine the first two digits of the resistance value. The third ring determines the number of 0's to add to the first two digits to get the total value in Ohms.

Color	Ring1,2 value	Ring 3 zero's	Color	Ring1,2 value	Ring 3 zeros
Black	0	none	green	5	00 000
Brown	1	0	blue	6	000 000
Red	2	00	purple	7	0 000 000
Orange	3	000	gray	8	00 000 000
Yellow	4	0 000	white	9	000 000 000

So the ring-colors Brown-Black-Red would signify 1-0-00 or 1000 Ohms (1 kOhm).

10.1.4 Capacitors (Caps)

Capacitors come in either polarized or unpolarized varieties. Typically polarized values are used when the capacitor value is bigger than 1 uF (micro-Farad). All capacitors have also a maximum rated voltage, which can be fairly low for polarized capacitors. This means that the voltage the capacitor is connected to in the circuit should be smaller than the rated voltage.

On a polarized capacitor the + side or minus side are marked with a + or a – sign. The + side must go to the higher voltage.

Capacitor Symbols

(unpolarized) (polarized)



10.2 Intake air temperature (IAT) or coolant sensors (CT)

Most IAT or CT sensors are actually NTC thermistors. So are many oil-temperature sensors. NTC stands for negative temperature coefficient. These sensors are resistance type sensors and their resistance changes such that it lowers with higher temperature. The resistance curve over temperature is not linear.

Although there are many published resistance curves for commonly available IAT or CT sensors, these tables typically show only the nominal values. Actual production sensors can vary by as much as 10% from the nominal values. For many applications, like turbo or intercooler efficiency calculations, multiple sensors are needed to measure pre- and post intercooler or compressor temperatures. At the tolerance of production sensors, it is therefore necessary to calibrate them to get reliable results.

The LogWorks 2.0 Helper application "Thermistorcalc.exe", which was installed in your LogWorks folder, can calculate the circuit to use and can also produce a custom input lookup table for LogWorks.

For that it needs the resistance of the sensor at three different temperatures. The temperatures MUST differ from each other by at least 25 degC or 45 degF.

10.2.1 Calibrating thermistor sensors

Of the three measurement points, the easiest to get is the middle point. Just leave the sensor in a warm room (Room Temperature at or above 25 degC or 77 degC for at least an hour. Measure

the resistance of the sensor with a digital multimeter and write it down. Also record the temperature with a good thermometer.

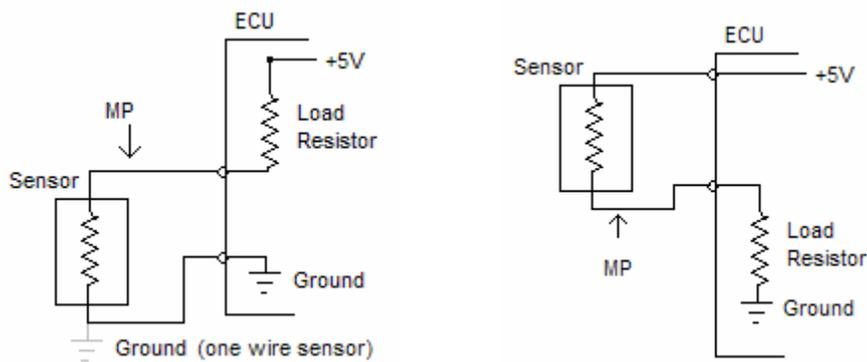
Two other easy temperature standards available to everybody are the freezing point of water (0 degC or -32 degF) and the boiling point of water (100 degC or 212degF). Water does not usually hurt NTC resistor sensors. Just make sure they are thoroughly dried out after the measurement. To get the 0 degC resistance, fill a small plastic container with a mixture of ice-cubes and water. Stick the sensor in the middle and hook it up to the multimeter to measure the resistance. Wait until the resistance has stabilized, indicating the sensor is at the same temperature (0 degC) as the water.

Next put the sensor in a pot of boiling water and repeat the measurement, again waiting for the temperature and resistance to stabilize.

10.2.2 Thermistor circuit

Most ECU's and also the Innovate MTS products do not measure resistance directly, but measure a voltage. To convert the resistance of the sensor into a voltage requires a 5V power supply and a load resistor.

The typical circuit for this looks like any of the following schematics:



A. Sensor Grounded

B. Sensor at 5V

In case A, the sensor is grounded on one side. This is the most common case where the sensor body is in physical contact to the engine, and is grounded through its body. Very often these sensors have only one pin.

To find out, which circuit your ECU uses, measure the voltage between each of the two sensor pins (if it has two) and ground. If one voltage is zero and the other is some voltage between 2 and 5V when the sensor is cold, you have circuit A. If one voltage is 5V while the other is lower, you have circuit B.

To get the voltage curve, you also need to know the value of the load resistor. You can't measure it directly with the multimeter though, because it would interfere with the ECU and can possibly damage it. The method to use goes as follows:

Schematic case A.

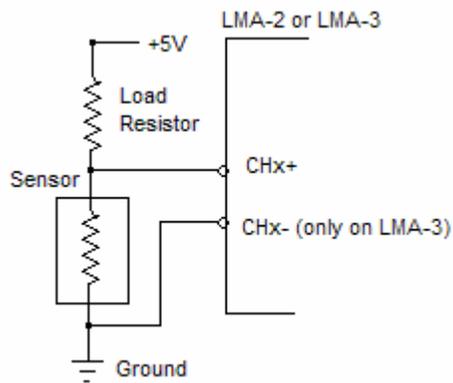
1. Disconnect the sensor from the ECU and measure the voltage between ground and the sensor pin at the ECU (measurement point MP).
2. Switch the multimeter to current measurement and measure the current in mA between MP and ground.

Schematic case B.

1. Disconnect the sensor from the ECU and measure the voltage between the two sensor connection pins of the ECU.
2. Switch the multimeter to current measurement and measure the current in mA between the two sensor connection pins of the ECU.

The load resistance (in kOhm) is the measured voltage divided by the measured current in mA.

If you use a LMA-2 or LMA-3 you have to provide your own load resistor. In case of the LMA-2 you also have to provide a 5V supply. Connect the load resistor and sensor as follows:



If you are using the LMA-2 or LMA-3 to tap into an existing IAT sensor hooked up to an ECU, omit the load resistor in the schematic above, but instead rely on the load resistor built into the ECU, measured as described earlier.

10.2.3 Using the Thermistorcalc program

The Thermistorcalc program creates a thermistor curve by solving the extended thermistor formula:

$$\ln(R) = B1 + B2/T + B3/T^3$$

Where R is in Ohms and T in Kelvin.

Start the Thermistorcalc application. It will show the following dialog box:

Thermistorcalc

Temperatures in: Fahrenheit Celsius

Resistance in: Ohm kOhm

Desired Temperature Range: From to Fahrenheit

Sensor is connected on one side to: Ground +5 Volt

Resistance/Temperature table:

Resistance kOhm	at	Temperature Fahrenheit
<input type="text" value="34.79"/>	at	<input type="text" value="-40.0"/>
<input type="text" value="1"/>	at	<input type="text" value="77.0"/>
<input type="text" value="0.06712"/>	at	<input type="text" value="212.0"/>

Note: Temperatures entered must differ by at least 45 Fahrenheit

Load Resistor Size: Load resistor used is kOhm

Determine best Load Resistor Create Table

Specify if you want enter the temperatures in Fahrenheit or Celsius. Also, specify if the resistances used are in kOhm or Ohm and if circuit A (sensor grounded) or B (sensor at 5V) is used.

NOTE:

Thermistorcalc works only if the circuit (A or B) is run from 5V.

Enter the desired measurement temperature range. The range must be at least 50 degC or 90 degF.

Also enter the three measurement points from the calibration procedure as described above.

If you are making your own circuit, you can have Thermistorcalc calculate the optimum load resistor. The temperature where this circuit has its maximum sensitivity is when the resistance of the sensor and the load resistor are equal. Thermistorcalc calculates the sensor resistance at the mid-point of the specified range and outputs the closest standard resistor value to that.

NOTE:

Do not make the load resistor smaller than about 1/5th of the thermistor resistance at room temperature.

Once all fields are filled out, click on the 'Create Table' button. Thermistorcalc will generate a lookup table that can be loaded into LogWorks for a custom input setup. See chapter 3.3 for details.

The file that Thermistorcalc generates is named:

Thermistor.txt

And is located in the same folder as the Thermistorcalc application.
For a typical install of the Innovate Motorsports software, this folder is:

C://Program Files/Innovate!

10.3 Using external MAP sensors

Many people use GM or other brand MAP sensors. These sensors output a linear 0.5V voltage when supplied by 5V.

Typically these sensors have 3 pins. One is 5V supply, one is output and one is ground. The sensors come in different ranges. Very typical are 1 bar (for normally aspirated engines) and 3 bar (for boosted applications).

10.3.1 Calibrating a 3 bar (or more) MAP sensor

Use a good tire pressure gauge to measure the air pressure in your spare tire. Remember, tire pressure gauges use gauge pressure. Lower the pressure in the tire to about 29 PSI (3.013 bar or 3.072 kg/cm²).

Connect the tire valve to the sensor's input port and note the output voltage. Also note the current atmospheric pressure in inHg or millibar.

Next measure the sensor output at normal atmospheric pressure.

For LogWorks the two points needed to set up a MAP channel (absolute pressure), calculate the absolute pressures as follows:

For PSIa:

$$\text{PSIa} = \text{atmospheric pressure (in inHg)} * 0.491 + \text{measured pressure (in PSI)}$$

For kPa:

$$\text{kPa} = \text{atmospheric pressure (in millibar)} * 0.1 + \text{measured pressure (in bar)} * 100$$

or

$$\text{kPa} = \text{atmospheric pressure (in millibar)} * 0.1 + \text{measured pressure (in kg/cm}^2) * 98.07$$

10.3.2 Calibrating a 1 bar MAP sensor

Calibrating a 1 bar sensor is a little more difficult than calibrating a 3 bar sensor because a convenient vacuum source is usually not available to the average user. If you have or can borrow a good vacuum gauge, it is easy.

Connect the vacuum gauge with a T connection to the manifold of the engine. Connect the MAP sensor also to this T. Run the engine at idle and note the vacuum and voltage.

Then switch the engine off. The MAP sensor will measure atmospheric pressure. Note the current atmospheric pressure in inHg or millibar.

Vacuum gauges typically measure gauge pressure in inHg or mmHg (or Torr).

For LogWorks the two points needed to set up a MAP channel (absolute pressure), calculate the absolute pressures as follows:

For PSIa:

$$\text{PSIa} = \text{atmospheric pressure (in inHg)} * 0.491 - \text{measured pressure (inHg)} * 0.491$$

For kPa:

kPa = atmospheric pressure (in millibar) * 0.1 - measured pressure (mmHg or Torr) * 7.5

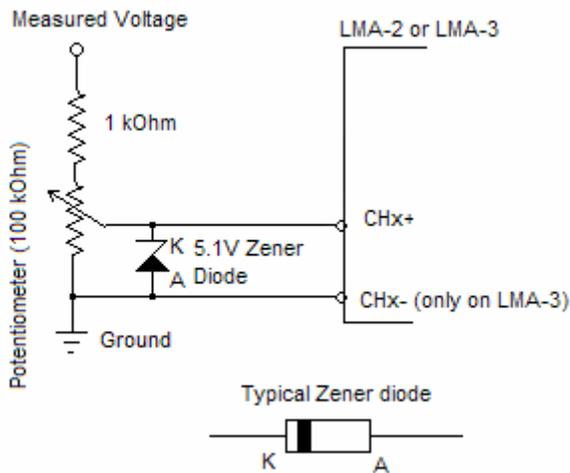
10.4 Measuring voltages higher than 5 Volt

Because the Innovate Motorsports devices are designed for the common 0..5V sensors, their input range is limited to 0..5V.

A simple voltage divider can reduce the measured voltage by a certain ratio, determined by the divider ratio, which is in turn dependent on the values of the resistors used as divider.

Alternatively a potentiometer can be used. Recommended is a 100 kOhm potentiometer. The advantage of a potentiometer is that ANY ratio can be simply dialed in.

The following shows a simple potentiometer circuit:



The 1 kOhm resistor (1/8 Watt or more) and the Zener diode (1/10 Watt or more) are for protection of the LMA-2 or LMA-3 in case the input voltage is too high and the output of the circuit exceeds 5.1V.

Potentiometers have typically 3 pins. The middle one is the slider (indicated with an arrow or pointer in the schematic). The other two can be connected either way as in the schematic.

To calibrate, connect the point "Measured Voltage" to the car battery and measure the voltage between the slider of the potentiometer and ground. Also measure the battery voltage.

The divider ratio is then:

Ratio = Battery voltage / slider voltage

10.5 Using Thermocouples

Thermocouples are nothing but two wires of different materials joined together at one end. The materials used determine the thermocouple type. The most common is Type K.

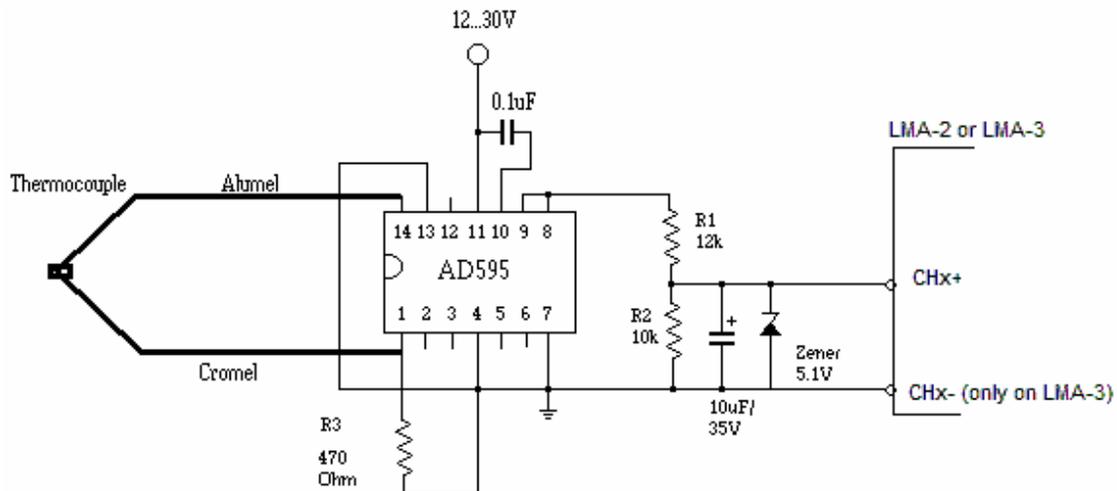
When two different metals are joined, a voltage is created at the junction. This voltage is determined by the temperature gradient along the wires and by the metals used. That's why only wires of the same materials as the two thermocouple sides should be used. The voltage is very small (in the microVolt range). Therefore it has to be amplified. Also the voltage is dependent on the temperature gradient, meaning the temperature difference between the ends of the wire. So the temperature of the device measuring (the cold junction) has to be known. This is called cold-junction compensation. The LMA-3 has a thermocouple input and also provides the cold-junction compensation.

Inserting different metals in between thermocouple and measuring device (for example to extend the wires) should be avoided. The junction between the thermocouple wire and for example a copper wire would also create a voltage and change the readings. That's why thermocouple wires of the right type for each side of the thermocouple must be used.

Sometimes it is necessary that multiple thermocouples have to be logged.

The following schematic uses the AD595 integrated circuit from Analog Devices. This device is a single chip thermocouple amplifier with cold-junction compensation. The device can be ordered from www.digikey.com.

The circuit can measure between 0 degC (-32 degF) at 0V output and 1100 degC (2012 degF) at 5V output.



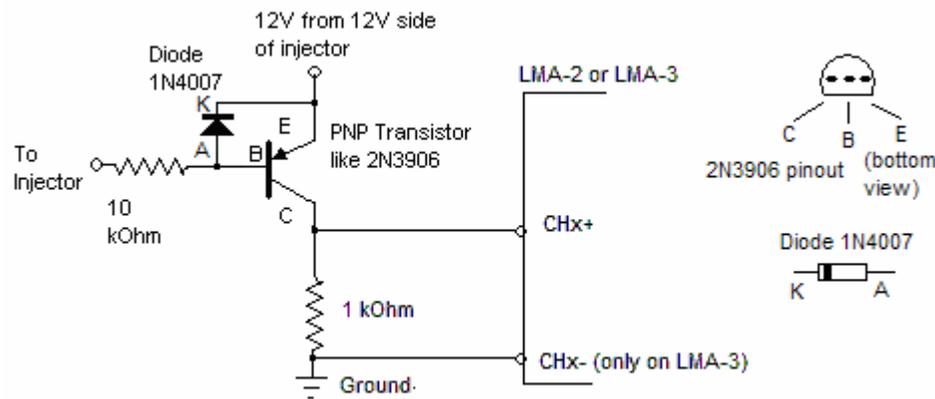
10.6 Measuring duty cycle of peak-hold injectors

Peak-Hold injectors are also called low impedance injectors. The voltage at the active pin of those injectors during an injection pulse first goes to ground (the peak phase) and then rises to 5 to 10 Volt (the hold phase). Because for the LMA-3 everything above 2.5V is high, the LMA-3 can see only the peak phase in many cases, but not the hold phase.

The following circuit allows the LMA-3 to be used with regular injectors as well as with peak-hold injectors.

NOTE:

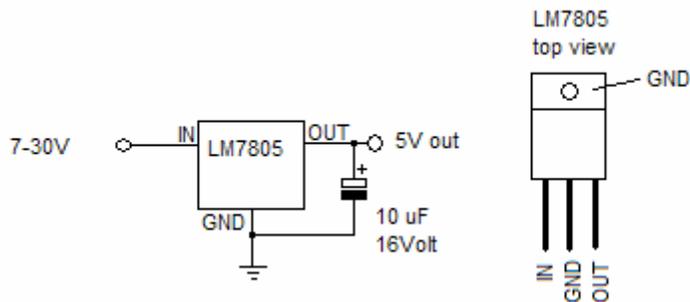
Some ECU's control PH injectors in PWM mode. This means that they at first ground the injector's active pin during the peak phase, and then rapidly switch ground on-and off during the hold phase. This circuit will NOT work for that method of control.



When setting up the duty cycle measurement in LogWorks, positive duty cycle must be used compared to negative duty cycle as when the LMA-3 is directly connected to an injector.

10.7 Making a 5 Volt supply for external sensors

This simple circuit will create a stable 5V supply from a 7-30 Volt source. Max current should be about 300mA without heat sink on the regulator. 800-900mA with heat-sink.



A LM340 can be used instead of an LM7805 as well. The 10uF capacitor is optional (reduces noise).

10.8 And finally, a weird one

Very often one can see small front-wheel-drive cars on the road with huge wings mounted on the trunk lid. But there's no corresponding aerodynamic down-force device in the front. Of course, in the majority of cases the wing is there for the 'cool factor' because many race-cars have wings (birds do too, but birds also have no penis).

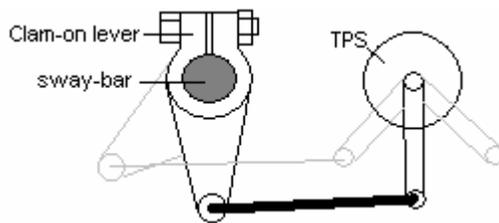
In a race car the wing creates aerodynamic down-force. The down force allows to increase cornering speed because more force is put vertically on the tires without increasing the mass of the car (which would create more side force proportionally). The aerodynamic forces created by wings and under-car aerodynamics can be very large. For example in a Formula 1 car at speed the down-force is twice the car's weight (car could drive upside down on the underside of a road and would still stick with a force equal to its own weight).

In the above case one can only hope that these people never drive their car at speed. The down-force of that wing, extending past the end of the car, will lift the front of the car up and make it unstable and dangerous, especially in cross-wind situations.

But there is a legitimate need to measure down-force in a race car. Here's how it can be done with the MTS:

Any performance car has front- and rear sway-bars (also called anti-roll bar). These are typically pieces of round spring steel (sometimes hollow tubes) that transfer the deflection force from the outer wheel in a corner to the inner wheel. During that deflection the center of the sway-bar stays pretty stationary because the bar is twisted. During normal suspension deflection on both wheels on the axle the bar rotates with the suspension movement.

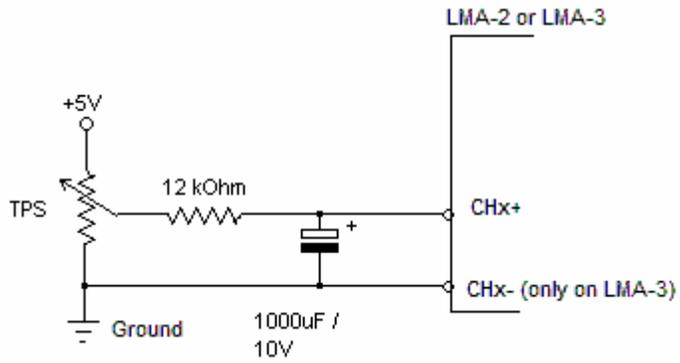
To measure down-force, one can use the car's suspension springs a spring-scale. To do that, fabricate a clamp-on lever that clamps to the center of the sway-bar. Use this lever to actuate a throttle position sensor (TPS) as in the following drawing:



Dimension the relationship between the clamp-on lever and the TPS's lever such that the TPS goes through its movement range of about 90 degrees for the full suspension travel. Then hook up the TPS sensor to 5V and measure its output voltage. Load the car up with 25 lb or 50lb sand-bags (over the axle) and record the sensor voltage for each load to calibrate your 'spring scale' for each axle.

Enter that table as custom lookup table in LogWorks (voltage vs. load).

Hook the TPS sensor to the LMA-2 or LMA-3 with the following circuit:



The low-pass filter created by the 12 kOhm resistor and 1000 uF capacitor will filter out most 'noise' coming from road surface irregularities.

Note for the electronically challenged:

You can use a capacitor with a higher voltage rating than 10V also..

11 Revision History

1.0 -- 07/15/05

Initial Release

1.1 -- 8/15/2005

General Corrections