Using MasterTune and DataMaster to Tune Harley-Davidson Motorcycles

The Turbo Shop Inc.

Copyright and Disclaimer Notice

Table of Contents

1. Introduction:

This document describes the basic operation of the Harley-Davidson Delphi fuel injection system, and includes information on how to tune the vehicle for best operation using the TTS MasterTune, DataMaster and VTune software. Specific hints are given to help solve common issues encountered when tuning modified vehicles.

1.1.   Historical Perspective:

Harley-Davidson motorcycles first introduced EFI systems back in the 1990's on their touring motorcycles. These systems were produced by Magneti-Marelli and use the Alpha-N (throttle position based) technology for controlling fuel and timing.

The H-D Delphi EFI system was first introduced in 2001 as a replacement for the Marelli EFI system. These systems are termed "ESPFI" (Electronic Sequential Port Fuel Injection) by Delphi, and is a "Speed-Density" type controller.

The first Delphi system is referred to as the "EFI-2" ECM. In 2002, this system was included with the new "Revolution" water-cooled VRSC models. Two versions of this ECM were produced: one for the air-cooled motor, and the other with additional hardware to control the fans and purge system found on the liquid-cooled VRSC models.

For model year 2005 bikes, the ECM hardware was updated to a higher performance processor with more memory and capabilities and is called the "VooDoo" ECM. Two basic derivatives of this ECM have been produced to date: One works with the normal "Big Twin" models, and the other works only with the Sportster models. The Sportster ECM has some capability removed as a cost reduction measure, and cannot be used in any of the "Big Twin" bikes.

For model year 2006, closed loop capability was added to several models. These used the standard ECM, but required additional wiring and the correct ECM "firmware" (the embedded software inside the ECM) to support the oxygen sensors.

For model year 2008, a new ECM was released for the "Drive By Wire" (DBW) bikes. This was a major evolution of the VooDoo, and is called the "FreeBird" ECM. As of this writing, the Freebird is only used on the 2008 – 2009 DBW Touring bikes.

Over the years, various Delphi replacement ECMs have been produced which can be retrofitted into the earlier Delphi-equipped vehicles. Check with your dealer for the latest part numbers and model compatibility.

The Delphi ECM used by Harley-Davidson is a remarkably reliable and sophisticated EFI controller. During development, TTS has programmed these units thousands of times without any failures. When considering the development and testing that Delphi and Harley put these controllers through, it is no wonder that an ECM hardware failure rarely occurs.

1.2.   The Big Picture

In the big picture, the EFI system uses information from various sensors on the engine to calculate fuel quantity and spark timing. There is a complex relationship between what the sensors report to the ECM and what the resultant fuel and timing are. This relationship is controlled by hundreds of look-up tables and settings built into the calibration. MasterTune provides the ability to make changes to the major tables governing fuel delivery and spark timing.

The engine sensors include the following:
- MAP sensor – measures manifold pressure
- TPS sensor – measures throttle position
- CKP sensor – measures the crankshaft position and RPM
- IAT sensor – measures intake air temperature
- ECT sensor – measures engine coolant temperature
- VSS sensor – measures vehicle speed
- O2 sensor – measures deviation from stoichiometric air-fuel ratio
- BAS – Bank Angle Sensor – detects if bike is tipped more than 45 degrees
- Cruise Control switch
- Jiffystand (Sidestand) sensor

The ECM uses information from these sensors to control the following items:
- Spark Timing
- Injector Pulse Width
- IAC position
- Throttle Body position (DBW Vehicles)
- Fuel Pump
- Purge Solenoid
- Coolant fans (VROD)

Basically, the ECM uses information from its sensors to calculate the engine's airflow and load, and from that deliver the correct fuel and spark timing. The closed-loop system (starting in 2006) allows the ECM more flexibility to adapt to changing conditions and components on the engine under normal running conditions.

1.3.   Why tune the EFI system?

The ECM can adapt to small changes in equipment without need to modify a calibration. For instance, if a high-flow air cleaner or slip-on mufflers are installed, the ECM will adapt to this change. However, if both are installed, the ECM should be recalibrated for best results.

As more radical modifications are made such as camshaft, heads, larger displacement, it is required to recalibrate the ECM else drivability will suffer and engine damage could occur.

1.4.   Air-Fuel Ratio Adjustment

Air-Fuel Ratio (AFR) is a key parameter to making the Harley engine run properly. This section contains some common ways used to adjust the Air-fuel ratio.

1.4.1.   Closed-loop Bike AFR adjustment

Most H-D bikes built since 2006 are equipped with O2 sensors and are capable of closed-loop operation. The major difference between open-and closed-loop is that closed-loop can better compensate for changes in engine operating conditions and fuel composition, maintaining the desired Air-Fuel Ratio (AFR) in the closed-loop regions of the calibration.

By default, most calibrations enable closed-loop mode over 90 percent of normal operating conditions – i.e. idle, part throttle and cruise operation. This closed-loop region is determined by the AFR table setting. **Setting a cell to the value of 14.6 acts as a switch telling the ECM to enter closed-loop mode in that region**. If the tuner does not desire closed-loop operation, set the value to an AFR other than 14.6. However, it should be noted that when in open-loop mode, the VE tables MUST be calibrated to correctly control the AFR. This is done using the included VTune software.

When the AFR cell is set to 14.6 (remember, this value means "enter closed loop"), the actual AFR is now determined by the "**O2 bias**" table voltage setting. This table allows trimming the closed-loop AFR over a range of 14.0 to 15.0 (the limit of the OEM switching sensor) by adjusting the O2 sensor bias voltage. To determine the setting for a specific AFR, use the O2 calculator built into MasterTune.

1.4.2.   Open-loop bike AFR adjustment

For the 2005 and earlier open-loop bikes, the AFR value is determined by the combination of the AFR table and the VE table values, In order for the AFR table to be accurate, the VE table must be calibrated to match the engine build. Later bikes can use VTune to do this, but earlier bikes require use of a calibrated AFR meter, either portable or in conjunction with a dynamometer.

The basic calibration procedure is simple; Set the entire AFR table to a constant value (say 13.5) and adjust the VE table such that you get a measured AFR value of 13.5 out the tailpipe. Once this calibration is complete, the AFR map can be set as desired and the ECM will calculate the correct amount of fuel to deliver that AFR.

1.5.   The TTS MasterTune Tuning System

The TTS MasterTune suite (MasterTune, DataMaster and VTune) gives any owner the ability to tailor the calibration to their needs. This gives the owner the best of both worlds: OEM reliability coupled with a calibration that matches their exact needs. As the owner makes upgrades or changes, MasterTune allows changing the calibration to match. Also, the bike can be returned to the original OEM calibration at any time.

TTS MasterTune system is a collection of 4 software programs that run on a PC, and an interface that connects the ECM to your PC. The four software programs are
- MasterTune
- DataMaster
- VTune
- TTS Updater

1.5.1.   MasterTune

The MasterTune software is used to program a new calibration into the factory ECM. It also allows modifying the calibration to handle virtually any engine build from stock all the way to the Destroyer drag bikes. With proper tuning, the factory ECM has capability to handle any build from mild to wild, while delivering factory reliability and excellent economy!

1.5.2.   DataMaster

The DataMaster software is used to monitor ECM operation while the bike is running. It can record and playback all tuning related data from the ECM, and also allows reading and clearing trouble codes. In order to correctly tune the bike, it is necessary to record how the ECM is responding while riding or on a dyno. DataMaster provides this capability.

1.5.3. VTune

The VTune software is use to calibrate the ECM's VE tables on closed-loop bikes which use the factory O2 sensors. Once the VE table has been calibrated to match your engine build, it is possible to dial in the desired AFR at any RPM and throttle setting to meet the riders needs. The VTune software is designed to allow the rider to perform this calibration while riding the bike on a closed course without use of a dyno. If a dyno is used in conjunction with VTune, it speeds up the calibration process substantially.

1.5.4. TTS Software Updater

The TTS Software Updater is used to connect to the TTS server and download the latest calibrations and software versions. The software updater automatically checks the installed software versions and calibration files, and at the users request will download and install updates.

2. Step-by-Step Getting Started Guide

This section summarizes the process for getting started tuning your bike with MasterTune.   This section covers installing the software and setting up the computer.

2.1. Setup the Laptop for Collecting Data

The following recommendations will aid in collecting data while riding the vehicle:

1. Configure the laptop for VTune data collection by disabling power save modes as detailed below. Note that some laptops also have Hard Drive "shock detection" (also called "active protection system" which may need to be adjusted to prevent vibration from disabling the hard disk drive while riding.
2. Prepare a saddlebag to securely hold the laptop while riding. This should include foam padding to cushion the laptop from road shock as best possible. Note that some laptops produce a lot of heat, so do not block any heat vents.
3. If a USB cable is being used, make sure that it has a very secure connection to the PC. Any interruption of this connection will terminate data collection. It may be necessary to shim the USB connector with thin cardboard (such as a business card) to prevent it from vibrating.
4. Make sure the laptop battery is fully charged since it will be running at full power during data collection.

2.1.1.   Disabling Laptop Power Save Modes:

Most laptops are configured to hibernate or suspend after several minutes of inactivity. Recording data on the road requires that the laptop stay 'alive' during the entire ride, often 30 to 60 minutes. Follow these instructions to configure the laptop for long term data collection.

	Access the computer's power options by opening **Control Panel** and clicking on the Power Options icon. The exact names may change somewhat with different versions of windows, but the following guidelines remain valid.
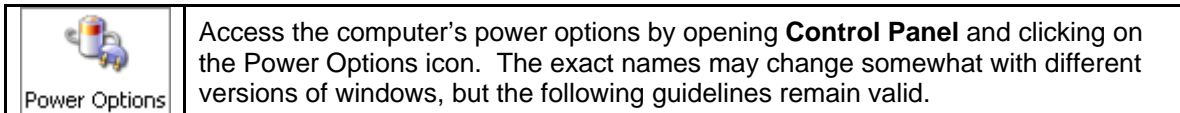
Figure 2-1: Computer Power Options

Under the ***Power Options - Power Schemes*** tab, select the ***Always On*** scheme and make the following settings:

- Turn Off Monitor – any setting OK as monitor will power off when lid is closed.
- Turn Off Hard Disks - Set to **Never**
- System Standby - Set to **Never**

Under the ***Power Options - Hibernate*** tab:
- Enable hibernation is **NOT** checked

Under the ***Power Options - Advanced*** tab, Power buttons section:
- *When I close the lid of my portable computer* setting is **"Do Nothing"**

You may also disable wireless cards to prolong battery life. Refer to the card's manufacturer for instructions on how to do this.

For Vista computer systems, power options are accessed on the "advanced power settings" dialog:
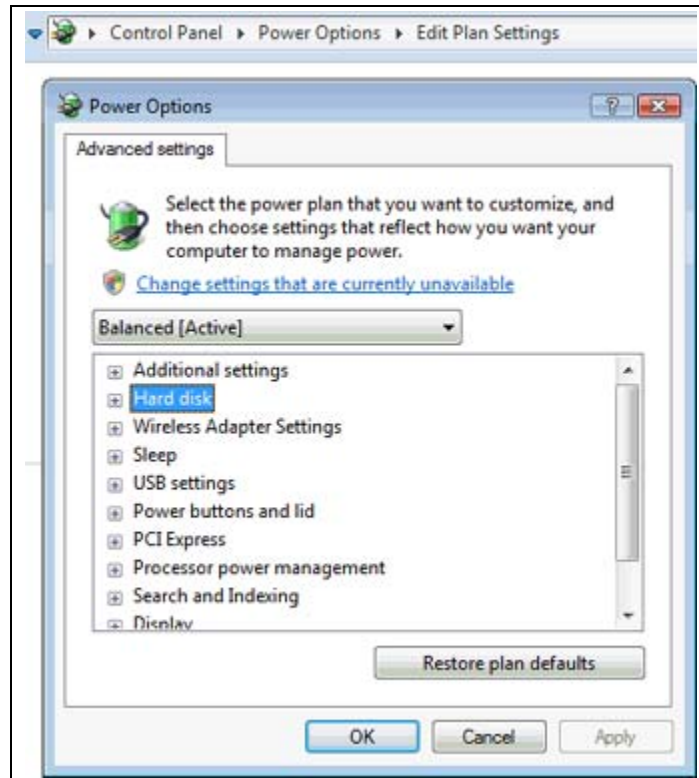
Figure 2-2: Vista and Win7 Power Management Dialog

NOTE: For Vista and Windows 7, under *Advanced settings – USB settings*, the USB selective suspend setting should be set to **Disabled**. This prevents the USB interface from being powered off during data collection. If desired, you can set up a custom power plan just for VTuning and switch to this plan when tuning the bike.

2.1.2. Vista Computer Systems: Configure Network Autotuning

If your computer uses the Vista OS there is a feature that controls network performance. This can cause very slow downloads from the internet. The following procedure prevents this problem from occurring:

1. Log onto an administrator account
2. Select *Start – All Programs – Accessories*
3. Right-click on *Command Prompt* and select *Run as administrator*
4. Vista will need your permission to continue – Press *OK* and the command prompt will open
5. In the command prompt box type the following line exactly:

   `netsh interface tcp set global autotuninglevel=disabled`
6. Press the *Enter* key

If successful, the response will be *Ok.*, Figure 2-3. If there is an error, make sure the line is entered exactly as above and make sure the command prompt was started using the right-click *Run as administrator* option.
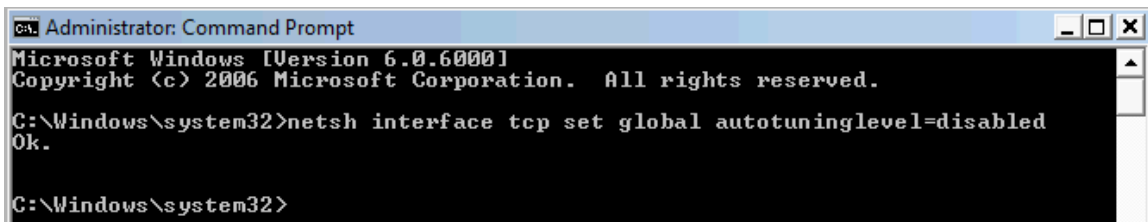
Figure 2-3: Configure Network Autotuning

2.2. Install the TTS Software

The TTS software is installed from the CD supplied with the MasterTune kit. The CD will auto run when first inserted and bring up the installation menu:
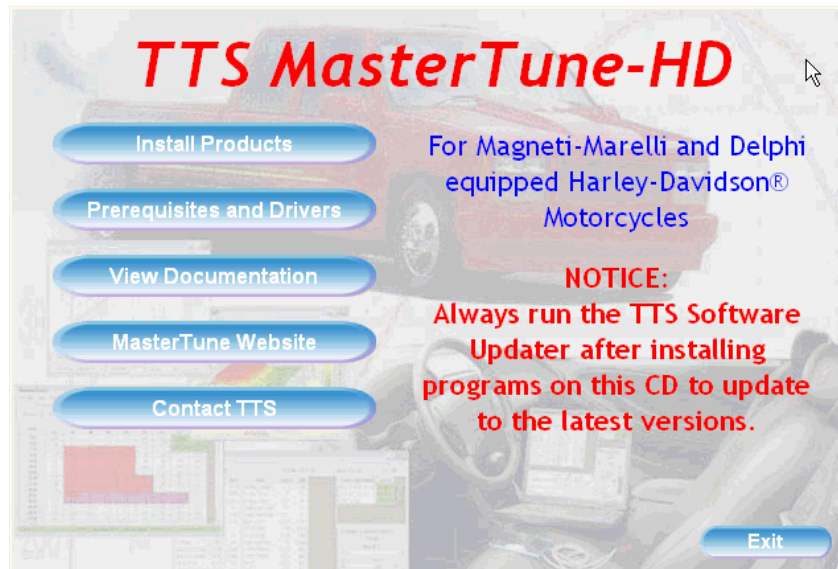
Figure 2-4: Install CD Main Window

- *Products* contains installs for MasterTune, DataMaster, VTune and the Updater
- *Prerequisites and Drivers* contains the .Net 2 framework and USB drivers
- *Documentation* allows viewing the Help files on the CD

Click on the **Install Products** button to open the Products window:

Figure 2-5: Install Products Window

Click the **Delphi Equipped Motorcycles** button to bring up the program installs for the 2001 and later Delphi equipped motorcycles:

Figure 2-6: Install Delphi-based Motorcycle Products

There are 4 Delphi-based programs and a manual set that are installed from the CD:
- MasterTune-HD
- DataMaster-HD
- VTune-HD
- Manual Set (PDF's):
    - TTS Tuning Guide
    - TTS Calibration Listing
    - TTS Tech Bulletin listing
- TTS Software Updater

Click on each button to install the associated software. Note that all software installs require administrative privileges on your computer, and Vista or Win7 will request your password before the installs can be completed.

Note: MasterTune, VTune and the TTS Software Updater will install the Microsoft .Net 2 framework on the computer if it is not present. This can take considerable time on older systems.

2.3. Run the TTS Software Updater

After all programs are installed you **MUST** run the software updater to get the latest versions of all programs, the calibration files, and the manuals.

Note: The calibration files and manuals can only be obtained by running the updater; they are not included on the CD.

TTS Software Updater v100	Click on the TTS Software Updater icon to launch the software updater utility. This will show the TTS Software Updater window, Figure 2-7.
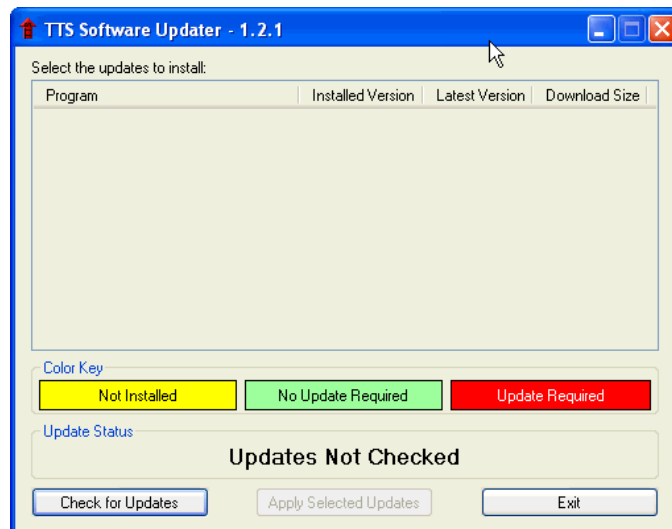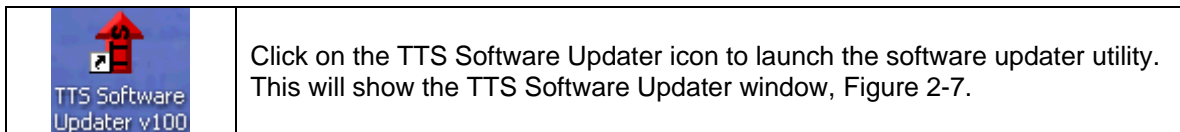
Figure 2-7: Initial Software Updater Window

2.3.1. Check for Updates

Click the *Check For Updates* button to check the TTS software versions. The first time the updater is run, it may need to update itself – In this case it will present the Update Required dialog (Figure 2-8) indicating a new version is available. Click *Yes* to install the new updater version. Follow the on-screen instructions to complete the install.
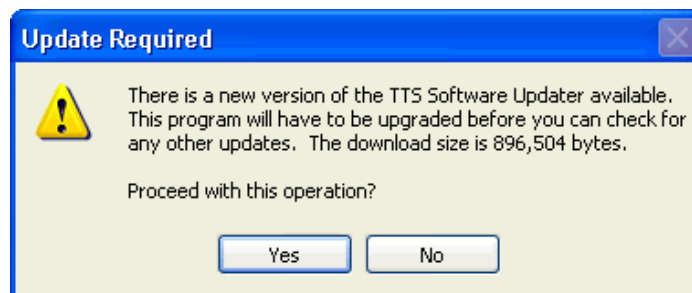
Figure 2-8: Updater Update Dialog

After the latest version of the updater is installed, you will need to start the updater again by clicking on the Updater icon. Then, click the **Check For Updates** button again and this time the versions of all the installed software will be shown, Figure 2-9:
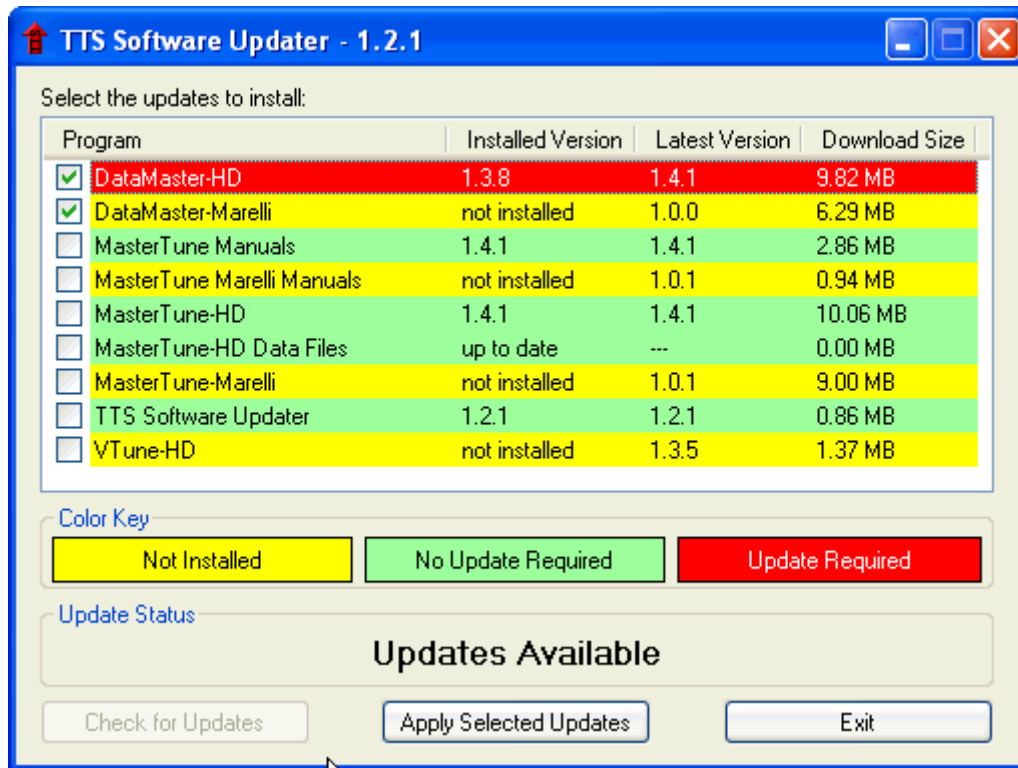
Figure 2-9: Software Updater Version Status

The program update status is color coded:
- Green = No update is required, the latest version is already installed
- Red = Update is required to get latest version
- Yellow = The program is not installed on this system

In the example above, DataMaster and MasterTune are not installed, The manuals need to be updated, and VTune and the updater utility are already up to date.

2.3.2.   Select Updates to Install
You must check the box on each line that you want to install the updates for. In the following Figure 2-10, only the DataMaster and the MasterTune manuals will be updated.
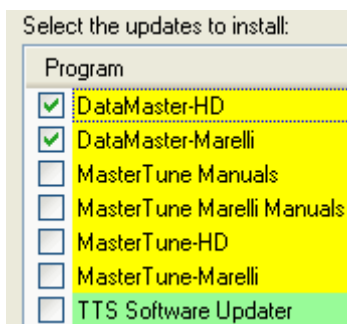
Figure 2-10: Updater Selections

After the update selections are made, click the *Apply Updates* button to begin the update process. All selected updates will be downloaded, then the installer will run for each update.

Tip: If you are on a slow internet connection, only check a single update each time to download. After the single update is installed, select the next update needed. This way, if an error occurs during downloading, you will not waste time retrying the download.

2.3.3.   Updating Calibration Files

After MasterTune has been installed, there is a new update for MasterTune Data Files shown on the updater list, Figure 2-11. These are the calibration files you need for programming the ECM.

Figure 2-11: Update Calibration Files

If the **MasterTune-HD Data Files** item is red, this indicates that new calibration files are available. Check the box and click Apply Upgrades to download the latest calibrations.

Note: When calibration files are upgraded, existing files with the same name will not be overwritten. Only calibration files that do not exist in your folder are copied over. Calibration files are individually copied to each users "My Documents" folder. For this reason, if there are multiple accounts on the PC used for programming, you will need to run the updater for each account separately.

Tip: If you want only the latest calibration files in your "My Documents" folder, you can delete the existing files and then run the updater to install the latest files.

2.4. Run MasterTune and Save your Original Calibration

The first time you use MasterTune, **always save the original calibration** so you can restore your bike to stock or recover from programming errors.

NOTE: Third party equipment attached to the diagnostic bus (such as a Power Commander) can interfere with the save and programming process. TTS recommends disconnecting these devices during programming.

2.4.1.   Connect the Vehicle Interface

Notice: Refer to your vehicle's manuals for the location and access method for the diagnostic data test connector. This connector usually found under the side cover or seat.

Some bikes have an accessory connector identical to the diagnostic connector. Make certain the proper connector is used!

To connect the interface, follow these steps:

- Connect the ECM programming cable (with the 4-pin long rectangular connector) to the TTS interface Male connector, Figure 2-12.
- Connect the laptop serial or USB cable to the TTS interface Female connector.
- Connect the serial cable or USB adapter to the laptop.
- Plug the ECM programming cable into the bike's diagnostic connector usually found under the side cover or seat.

Figure 2-12: TTS Interface and Vehicle Cable

Note: We have found that some PC serial ports will cause the interface to "lock up" if connected to the PC **after** the interface is powered up from the vehicle. If this occurs, unplug the cable to the vehicle to reset the interface. To prevent this problem from occurring, connect the interface to the PC serial port prior to connecting to the vehicle following the above sequence.

2.4.2. Start MasterTune and Open the Save and Restore Window

Start the MasterTune application by clicking on the desktop icon or from the Start menu. The first time MasterTune is started, it will present a file dialog for you to select a calibration file. For the save and restore operation, no file needs to be selected, so just click *Cancel* on this window.

Select *File – Save or Restore Factory Calibration* from the main menu to bring up the Save and Restore form, Figure 2-13:
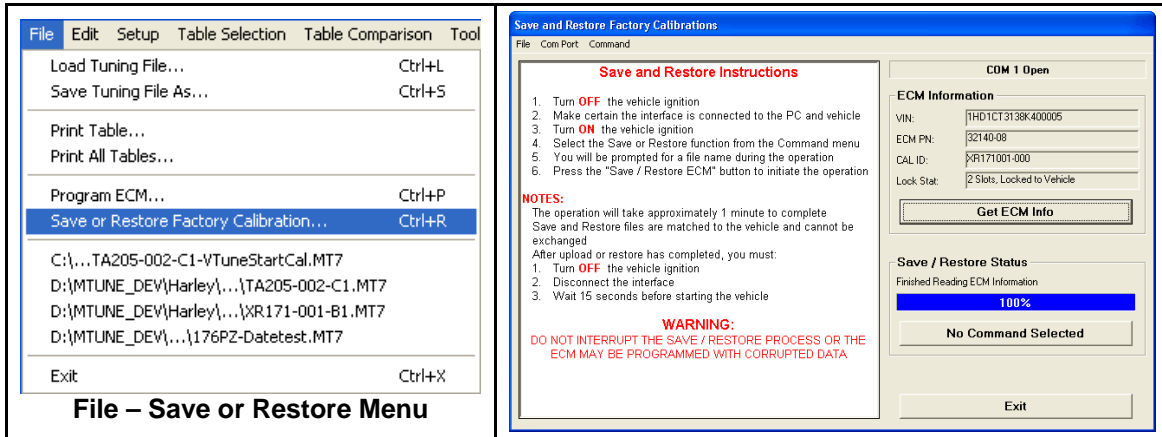
Figure 2-13: Save and Restore

2.4.3. Select the Com Port

Select the Com port that is connected to your interface. Then, turn on the bikes ignition and handlebar switch. This will power up the ECM and interface, allowing it to communicate to the laptop. Click the *Get ECM Info* button on the right side of the screen to make sure the laptop is communicating with the ECM. This will display the VIN, ECM PN, Cal ID and interface locking status. If there is an error, probably the incorrect COM port is selected. Refer to section 7 for information on troubleshooting communication problems.
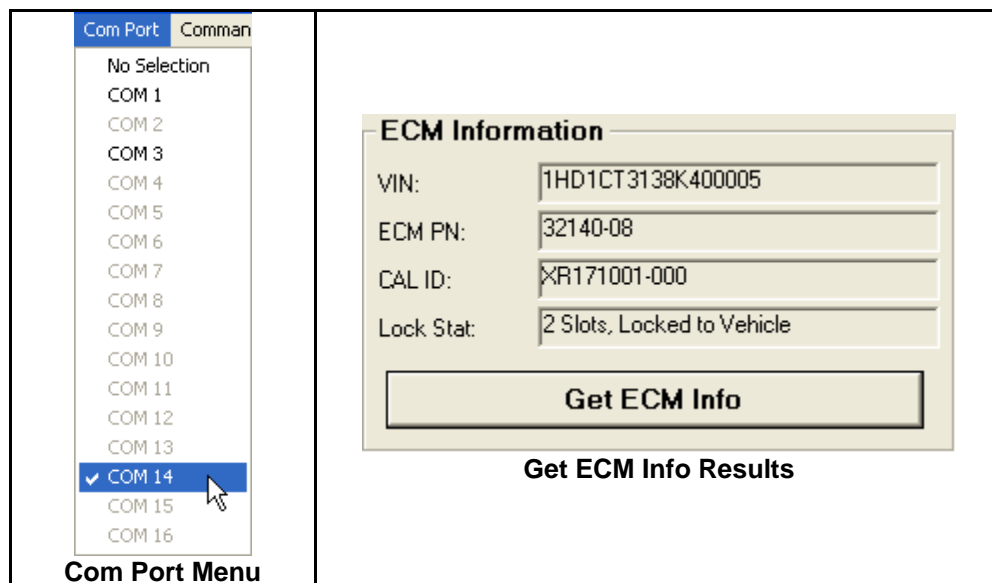
Figure 2-14: Checking ECM Communication using Get ECM Info

2.4.4. Upload and Save the Existing Calibration

Next, from the menu bar select **Command – Save ECM Calibration**. The Save / Restore status panel will now have a button that reads **Save ECM Calibration**. Click this button to begin the save process. You will be prompted for a file name and then a form will be presented for you to enter information about your vehicle. Click OK to begin the upload. This will take about one minute to complete.

Command Menu

The Upload Status Panel
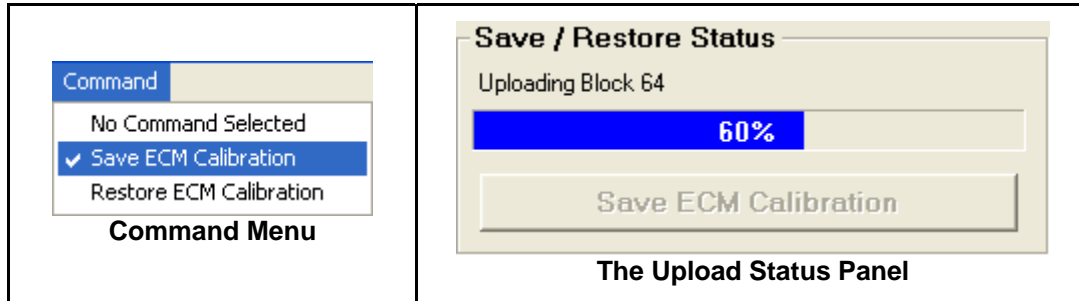
Figure 2-15: Uploading Calibration

When the upload has completed, a message will be presented advising you to turn off the ignition and wait 15 seconds before starting the vehicle. Turn off the ignition and wait 15 seconds before continuing on. Click the **Exit** button to go back to the main MasterTune window.

Caution: If there are any errors when saving the factory calibration, do not program the bike. This process must be error free to guarantee a good upload that can be used to restore the factory calibration should it be necessary. If there are problems here, it is most commonly due to using a non-TTS USB interface.

2.5. Select and Set-up the Calibration

After you have uploaded and saved the original calibration, you can proceed to select and program a new TTS calibration.

Use the latest MasterTune calibration file listing (obtained by running the TTS Updater and installing the manual) to select a starting calibration that most closely matches your current bike's configuration.

As a general rule, use the following selection priority if your exact combination is not found. This works for most builds.
1. Match the vehicle year and model to get the correct calibration level (i.e.176, 205)
2. Match the camshaft selection (if not stock) as close a possible
3. Match the head configuration (if not stock)
4. Match the exhaust configuration

If the engine displacement or injector flow are different, you will adjust this in the ECM Constants in section 2.5.3

2.5.1.   Open the Calibration

When MasterTune is first started, a file dialog will be presented to select the calibration you want. Note that by default, only MT8 files will be shown. To select another file type, use the "File Type" dropdown box at the bottom right of the file dialog and select a different file type: MT6, MT7 or MT8. Click the "*Open*" button to load the calibration for editing.
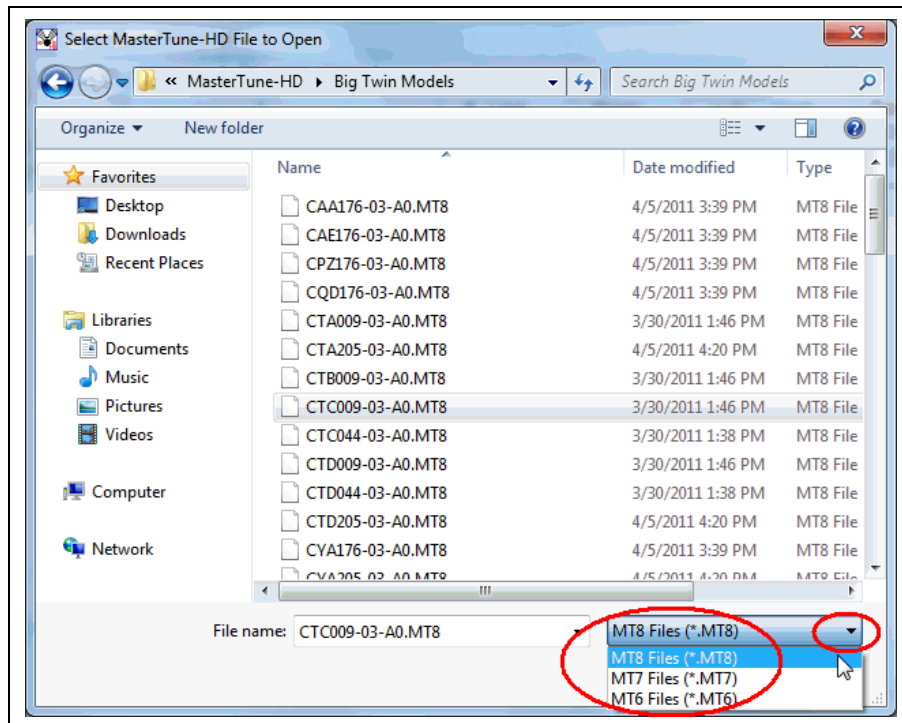
Figure 2-16: Selecting a Calibration Type – Win7

Note the Windows XP file dialog is slightly different and the file type selection is directly below the file name box, Figure 2-17.
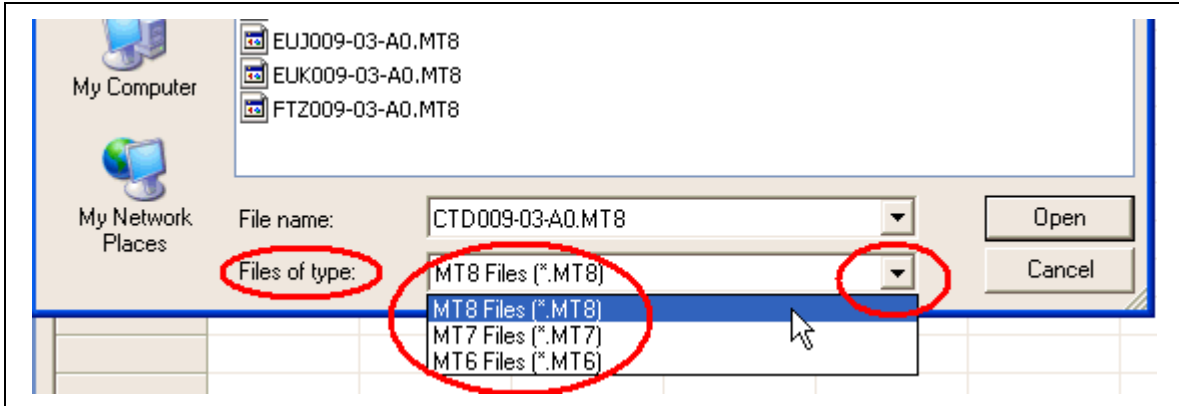
Figure 2-17: Selecting a Calibration Type – Win XP

2.5.2. Edit the file comments
Edit the file comments to keep track of the file you are modifying.
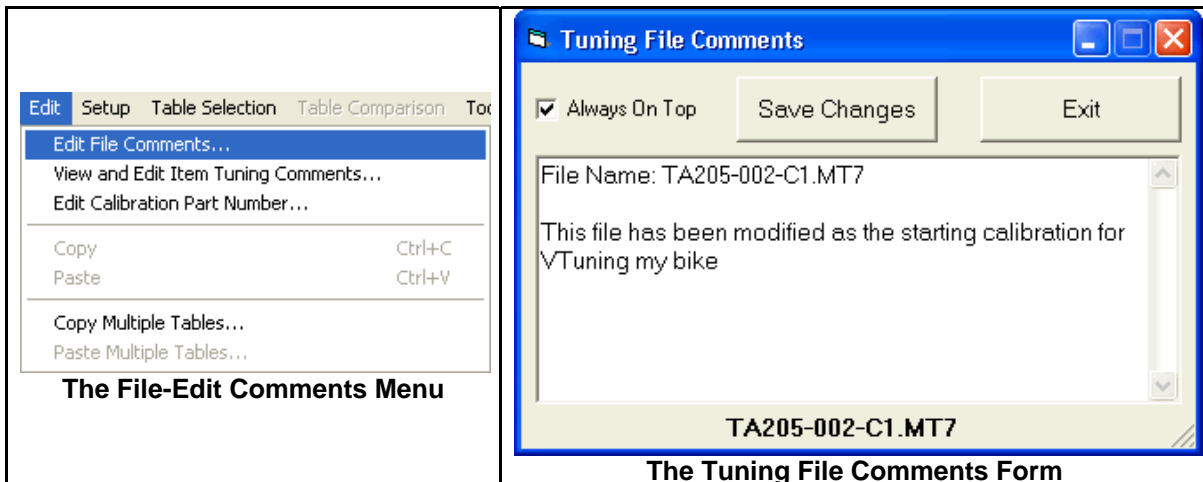
Figure 2-18: File Comments

Tip: The calibration ID can also be edited in the main MasterTune window by selecting the *Edit – Edit Calibration Part Number* menu option. Many tuners will code the last 3 digits of the part number to track the version of the file they are using.

2.5.3. Set the Engine Displacement and Injector Size

If the calibration file you selected is for a bike with a different displacement or injector size, you will need to adjust these settings in the Constants window.

To view the Constants, go to the *Table Selection* menu and select the bottom-most entry called *ECM Tuning Constants*, Figure 2-19: ECM Tuning Constants. If your engine build already matches these settings, make no changes here, otherwise change the settings to match your engine build.

Note: Injector size should be set to 85% of the static flow rate of the injector as rated at the Harley fuel pressure (4.0 bars). If you are using H-D injectors, use the H-D supplied rating. If you are using aftermarket injectors, contact the vendor for this information.

The Constants Settings
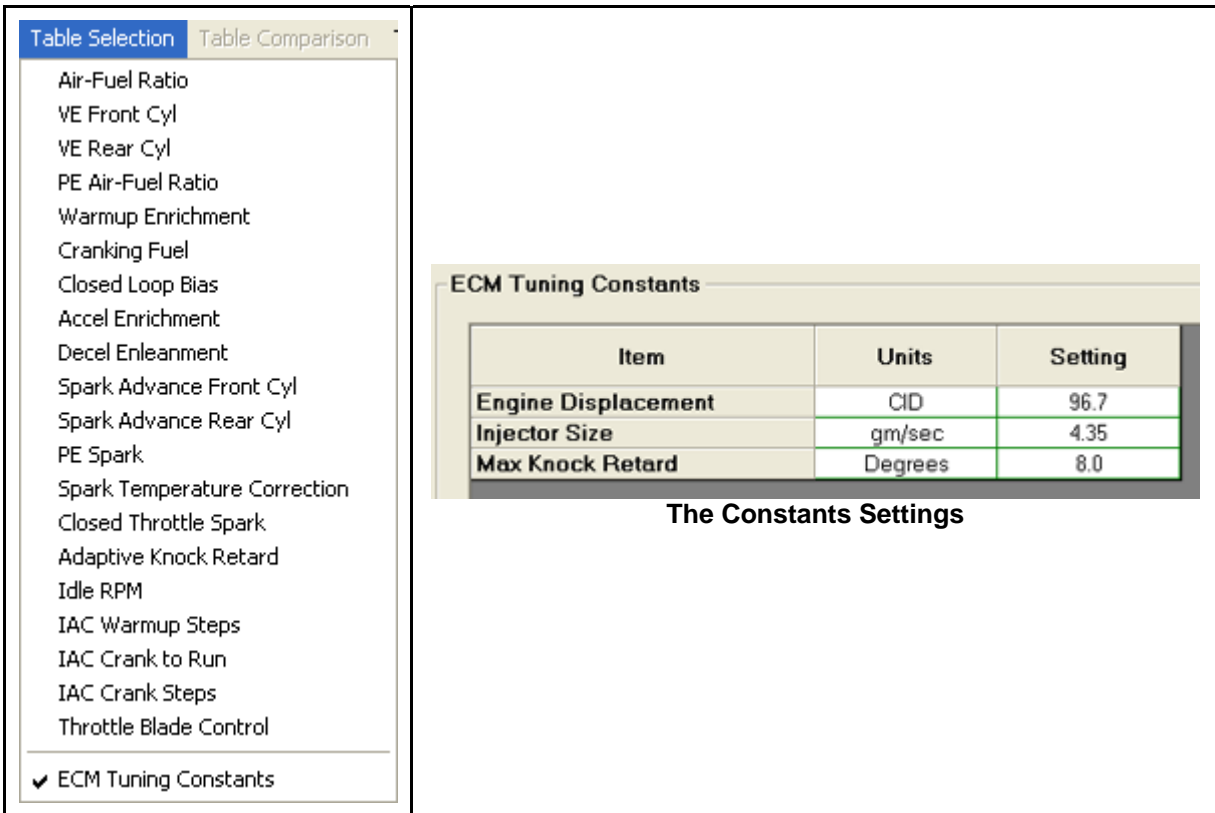
Figure 2-19: ECM Tuning Constants

2.5.4.   Save Your New Calibration File

Save your new calibration file giving it a name you will remember. You will need this file again later.

File – Save As Menu

File Save Dialog
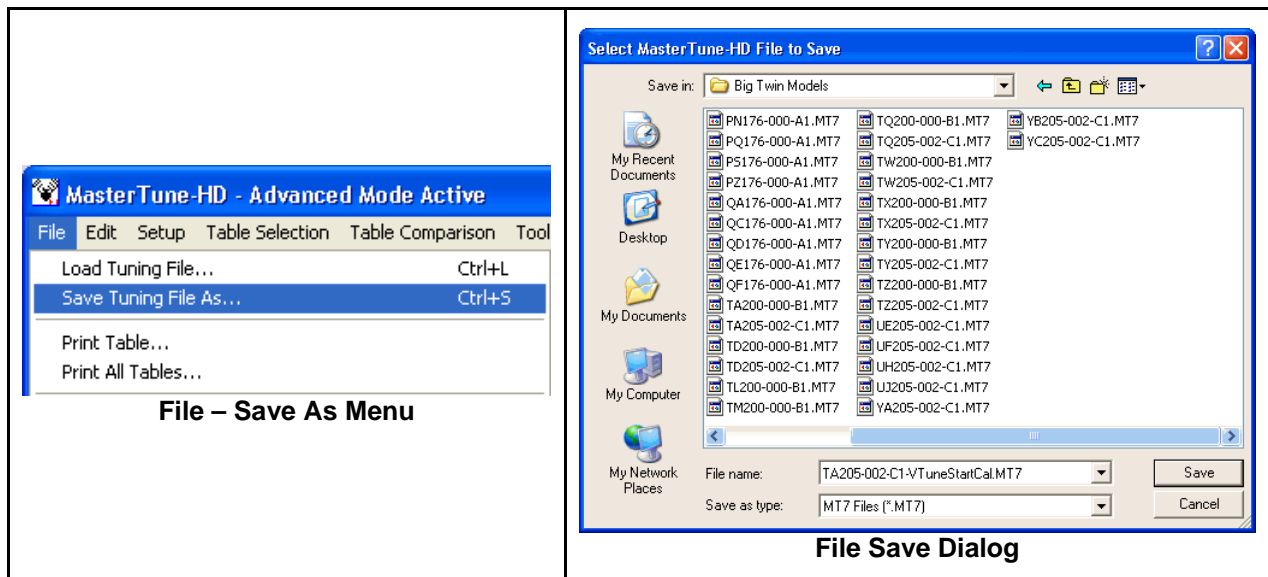
Figure 2-20: Saving the Calibration File

2.6. Program the Calibration into the ECM

After you have saved a copy of your new calibration, you can program it into the ECM.

2.6.1. Open the Programming Window

From the main MasterTune screen, select **File – Program ECM** to bring up the programming window. A warning window will be presented – read the information and click **I Accept** to acknowledge the notice.

Program ECM Menu

The Programming Window
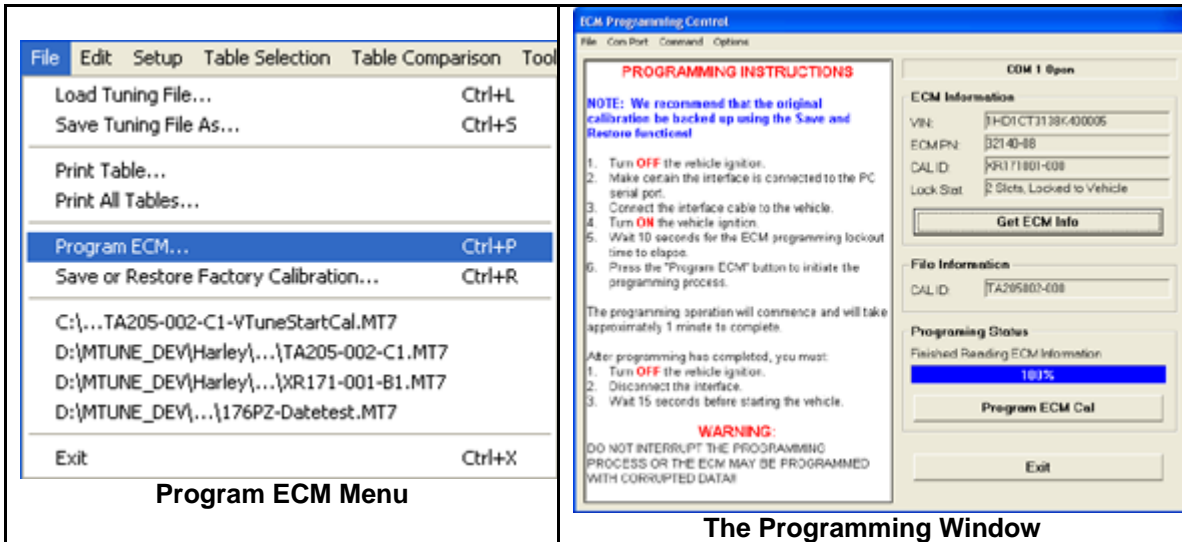
Figure 2-21: ECM Programming Window

2.6.2. Check ECM Communication

Make certain the correct COM port is selected (If you just did this when saving the original cal it should already be set-up correctly). Turn on the Ignition and handlebar switch and click **Get ECM Info** to test the communication to the bike. This will read the VIN, ECM PN, Cal ID and interface locking status and display them on the screen. Again, if there is an error here check that the correct COM port is selected and refer to section 7 for information on troubleshooting communication problems.

Com Port Menu

Get ECM Info Results
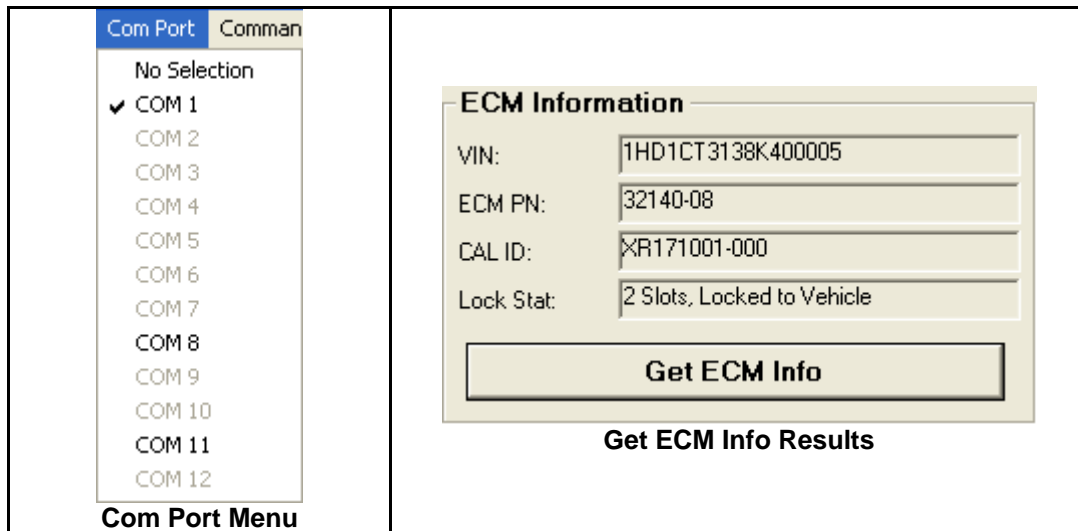
Figure 2-22: Checking ECM Communication

2.6.3.   Program the Calibration

Wait a few seconds for the ECM ignition lockout timer to expire (10 seconds from key-on). Then, click the **Program ECM Cal** button to begin the programming process.

2.6.3.1.   ECM Setup Options

For 2005 and later bikes, you will be presented with a dialog to change the ECM Setup Options:
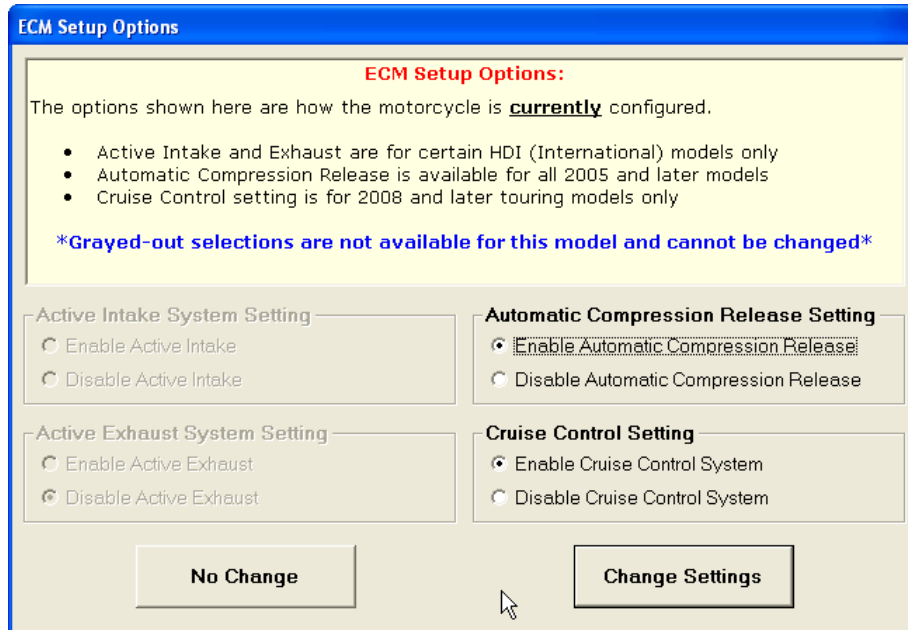
Figure 2-23: ECM Setup Options

When this form is first displayed, the motorcycle's current settings are shown. Note that not all models support all the options:

- "Active Intake" (Intake Flapper - HDI models only)
- "Active Exhaust" (Exhaust Flapper - HDI models only)
- Automatic Compression Release (If ACR solenoids are installed)
- Cruise Control Enable (2008 and later touring models)

Not all models support all the options; if a selection is grayed-out the option is not available for the model being programmed. Make any changes and click **Change Settings** to apply the changes or click **No Change** to discard any changes and skip this operation.

Tip: The ECM Setup Options form can be enabled or disabled from showing by a selection in the programming Options menu:

 The Programming Options Menu	Disabling this item speeds up programming if no changes are needed for the ECM Setup Options.
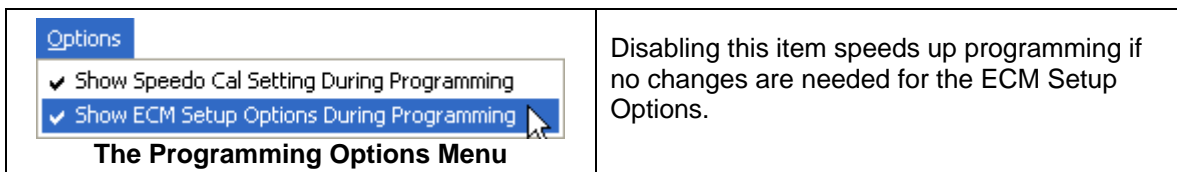
NOTE: Making this menu selection only determines if the ECM Setup Options form will be shown <u>after</u> programming is started. The form is not shown until then.

2.6.3.2.   Speedometer Calibration

Next, the Speedometer Calibration form will show:

Speedometer Calibration

Speedometer Calibration Guidelines
VROD 28-tooth Sprocket: 1328 to 1341
VROD 30-tooth Sprocket: 1200 to 1240
BigTwin: 1950 to 2280
Sportster: 2140 to 2355

A Lower Setting gives a Higher Reading

Notice for 2001 to 2003 BigTwin Bikes
This setting only effects the values displayed by the odometer and scan tool. A minimum change of 10 units is required to make a difference.

Speedometer Calibration Setting

Current Setting: 2365

New Setting: 2365

Calculator

No Change   Change Settings

Figure 2-24: Speedometer Calibration Form

If your speedometer reading is off, you can make adjustments here. Note that for 2003 and earlier bikes, this only affects the odometer and scan tool readings as the speedometer signal does not route from the ECM.

- If the speedometer reading is too high, **increase** the setting value
- If the speedometer reading is too low, **decrease** the setting value

Make any changes desired and click **Change Settings** to apply the changes or click **No Change** to skip this operation.

2.6.3.3.   *Programming Complete*

The programming operation will take about 1 minute to complete.

Programming Status Panel	**Programming Complete Message**
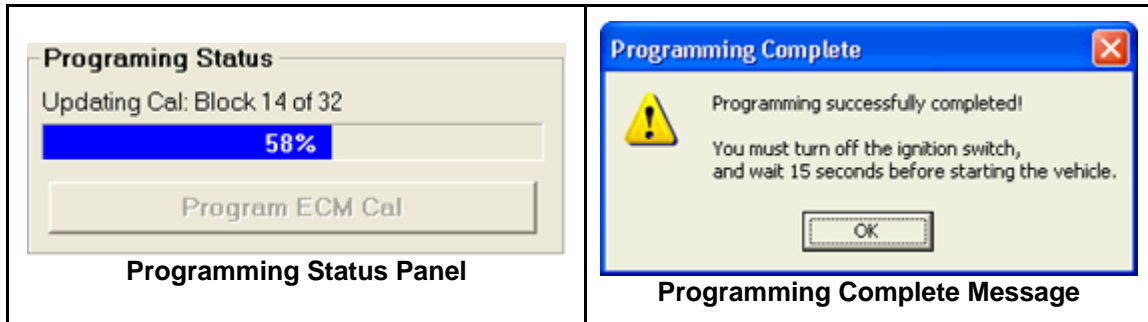
Figure 2-25: Programming Status

When completed, the Programming Complete window is shown. Click OK and turn the ignition power off, wait 15 seconds, then power back on.   Click the **Get ECM Info** button to verify the new calibration has been programmed. The calibration ID for your new calibration will now appear in the CAL ID box.

Congratulations! Your bike is now programmed with your new calibration! Turn the ignition off, exit the programming window and close the MasterTune application. Disconnect the interface from the bike, and you are ready to ride!

3. Tuning

This chapter will help you get familiar with making basic calibration changes. Examples used in this section come from calibration TA205-002-C2.MT7, a 2008 closed-loop Drive-By-Wire (DBW) bike. Other calibrations are similar to this and the same principals apply.

3.1.   Understanding Tables

The majority of your tuning will involve making changes to tables (also called "look-up" tables) that the ECM uses to control various functions. Basically, what a table does is take inputs measured by the bike's sensors (such as RPM, Speed, MAP, Temperature and Throttle) and looks up what to do based on the readings. These sensor values are split into the X (horizontal) and Y (vertical) "breakpoint" axis.

In some cases, the sensor readings will be above or below the table axis values. Any value below the axis minimum value will take on the value from the minimum breakpoint.

Correspondingly, if the sensor reading is above the maximum axis value will take on the value from the maximum breakpoint.

When sensor readings are between two breakpoint values, the ECM will interpolate between the surrounding cell values and calculate the value.

Example - Using Figure 3-1 Closed Loop Bias table, determine the bias voltage under the following conditions:
- At 5000 RPM, 80 kPa the bias voltage will be 625 mV
- At 1500 RPM, 20 kPa, the bias voltage will be 566 mV
- At 2000 RPM, 90 kPa, the bias voltage will be 605 mV (=(586 + 625) / 2)

RPM	MAP (kPa)				
	30	45	60	80	100
1000	566	566	566	586	625
1500	566	566	566	586	625
2000	566	566	566	586	625
2500	586	586	586	586	625
3000	625	625	625	625	625

Figure 3-1: Closed Loop Bias Table

3.1.1.   The Four Major Sensor Variables

There are four major variables used in the tuner adjustable tables:
- RPM – The engine RPM
- MAP – The Manifold Absolute Pressure, in kPa
- TPS – The throttle position in percent
- Temperature – The engine temperature in degrees Centigrade

Most of these are self explanatory. However, the MAP reading deserves a bit of explanation. Manifold Pressure is measured by a sensor in the intake manifold. This sensor responds to "absolute" pressure – in other words it can read vacuum as well as pressure somewhat above atmospheric. Absolute pressure is measured relative to a perfect vacuum, and the units of measurement are Kilo Pascals (kPa). Zero kPa is a perfect vacuum, while 100 kPa is atmospheric pressure at sea level, approximately 14.7 Psia.

The Harley MAP reading at idle is typically 30 to 40 kPa, while under full load the MAP will read close to 100 kPa.

3.1.2. Lambda-based Calibrations

Beginning in 2010, calibrations for the Drive-By-Wire bikes changed from AFR-based fuel control to Lambda-based fuel control. Refer to section 3.5 for a detailed explanation of Lambda and how it relates to AFR.

Table 3-1 indicates which tables have been changed and their equivalent Lambda name:

Table 3-1: Lambda Calibration Table Changes

AFR Table Name	Lambda Table Name	Comment
Air-Fuel Ratio	Main Lambda	Units are now Lambda
VE Front Cyl	VE Front Cyl	X-Axis units are changed to MAP
VE Rear Cyl	VE Rear Cyl	X-Axis units are changed to MAP
PE Air-Fuel Ratio	PE Lambda	Units are now Lambda
Warmup Enrichment	Warmup Enrichment	Units are now Lambda
Closed Loop Bias	N/A	Removed for Lambda Cals

3.1.2.1. Lambda Tuning Implications

Tuning with a Lambda calibration is a bit different than with an AFR based calibration. First off, the use of lambda gives better control over the AFR when in closed loop operation. In closed loop operation, the fuel mixture is controlled directly in the **Main Lambda** table. The Closed Loop Bias table which allowed trimming the AFR has been removed, as it is no longer needed.

VTune and DataMaster have been updated to work with Lambda calibrations which utilize **MAP** instead of **TPS** for their Volumetric Efficiency (VE) calculations. Both programs will detect if a Lambda calibration is in use and automatically reconfigure as necessary.

When setting up a Lambda calibration for VTune, the Main Lambda table entries below 100 kPa should be set to a Lambda value of 0.981. This calls for closed-loop operation and is rich enough to allow VTune runs under load. After all VTune runs have been made, set the Main Lambda table to the factory or to the values desired for the desired performance. Use the MasterTune O2 calculator (under the **Tools** menu) to convert AFR to Lambda units when making Lambda settings.

3.1.2.2. Lambda Calculator

For your convenience, MasterTune has added a Lambda-to-AFR calculator on the main tool bar.

To use the calculator, first enter the stoichiometric AFR of the fuel being used. Next, enter the AFR to show the equivalent Lambda value, or vice-versa - entering the Lambda to show the equivalent AFR.	14.68 Stoich 14.45 AFR 0.984 Lambda

Deg C	Steps
-16	45
0	35
20	25
32	15
42	15
64	15
80	15
96	15
112	15
160	15
176	15
192	15

Figure 3-3: Crank to Run Steps vs. Temperature

To calibrate the Crank to Run Steps, you want to adjust for a smooth RPM ramp-up to idle speed when the engine first starts.   If the value is set too high, the engine will have a flare in RPM when starting. Conversely, if the value is too low the engine will stumble when starting and climbing up to idle speed.

3.3.   Engine Idle and Warmup

As the engine warms up, the idle speed is controlled by the **Idle RPM** table, Figure 3-4.

Caution: When adjusting the idle RPM table, do not set the idle speed below 900 RPM as this could cause the oil pressure to fall too low resulting in engine failure.

Deg C	RPM
-16	1360
0	1304
20	1200
32	1104
42	1000
64	1000
80	1000
96	1000
112	1000
160	1000
176	1000
192	1000
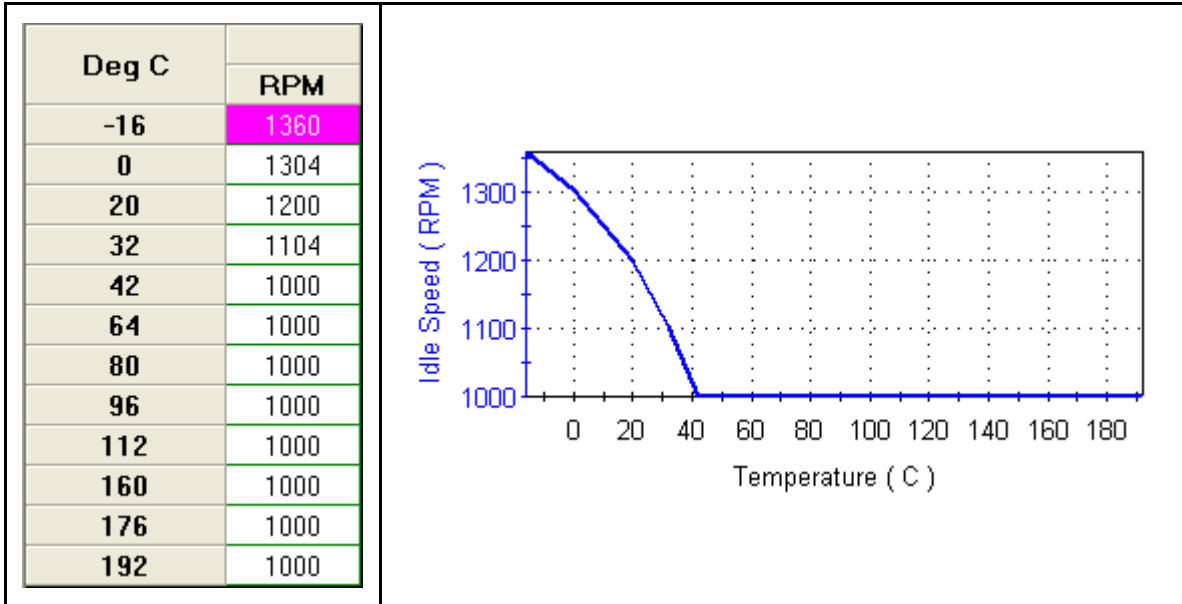
Figure 3-4: Engine Idle Speed vs. Temperature

In order to maintain stable idle speed tracking during warmup, the **IAC Warmup Steps** table is used, Figure 3-5. This table (along with some internal settings) establishes the predicted position that the IAC needs in order to maintain RPM at a given temperature. The actual IAC position will vary as somewhat depending on internal friction/drag in the engine (i.e. oil viscosity).

Deg C	Steps
-16	49
0	49
20	49
32	42
42	36
64	25
80	20
96	15
112	10
160	10
176	10
192	10
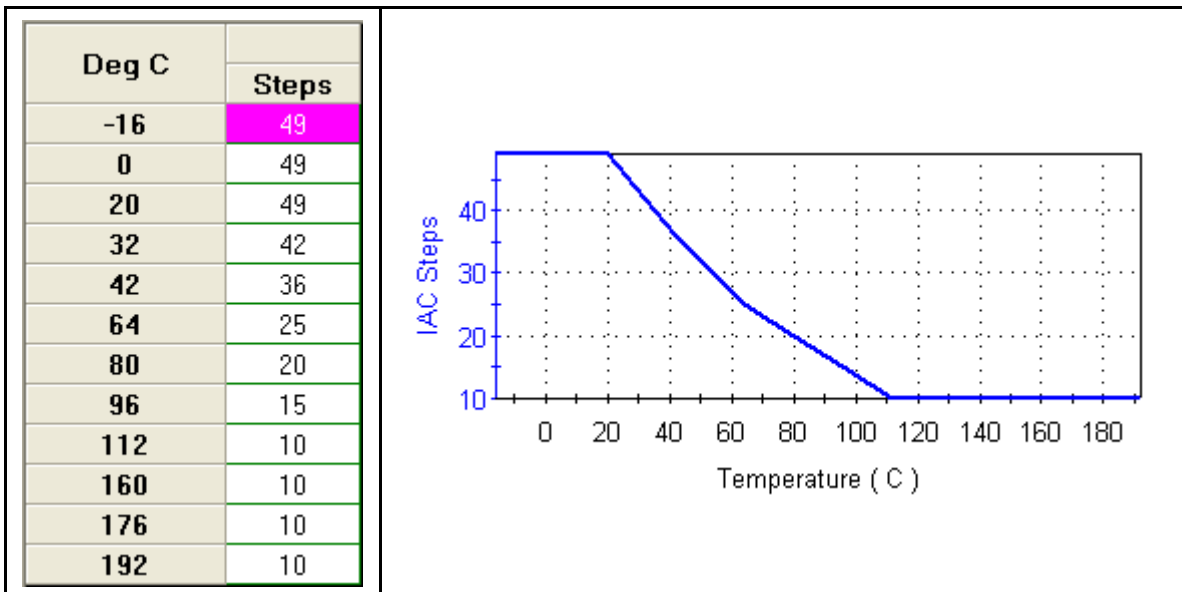
Figure 3-5: IAC Warmup Steps vs. Temperature

It is not possible to directly correlate the IAC position with the IAC Warmup Steps table, as IAC position is the **sum** of several internal settings, variables, and learned offsets which are not accessible. ***The IAC Warmup Steps only contribute part of the actual IAC position reported by DataMaster***.

If the bikes warm-up idle speed is unstable, adjusting this table may help solve the issue. Some experimentation will be required! Make the adjustments at the temperatures where the instability is noted. Too many steps will cause a flare in RPM, while too few will cause a stumble.

3.3.1.   Warmup Enrichment

After the engine starts and begins warm up, the **Warmup Enrichment** table (Figure 3-6) adds additional fuel, much like a choke on a carburetor.   The fuel from this table is exponentially decayed out over time, and it is only active for 20 to 30 seconds. The table is activated only once per key-on; if the engine stalls and is restarted without cycling the ignition, enrichment continues from its value when the stall occurred.

Note:
Warmup enrichment is mostly needed at light load when combustion is unstable, so at manifold pressures greater than 40 kPa it is gradually phased out.
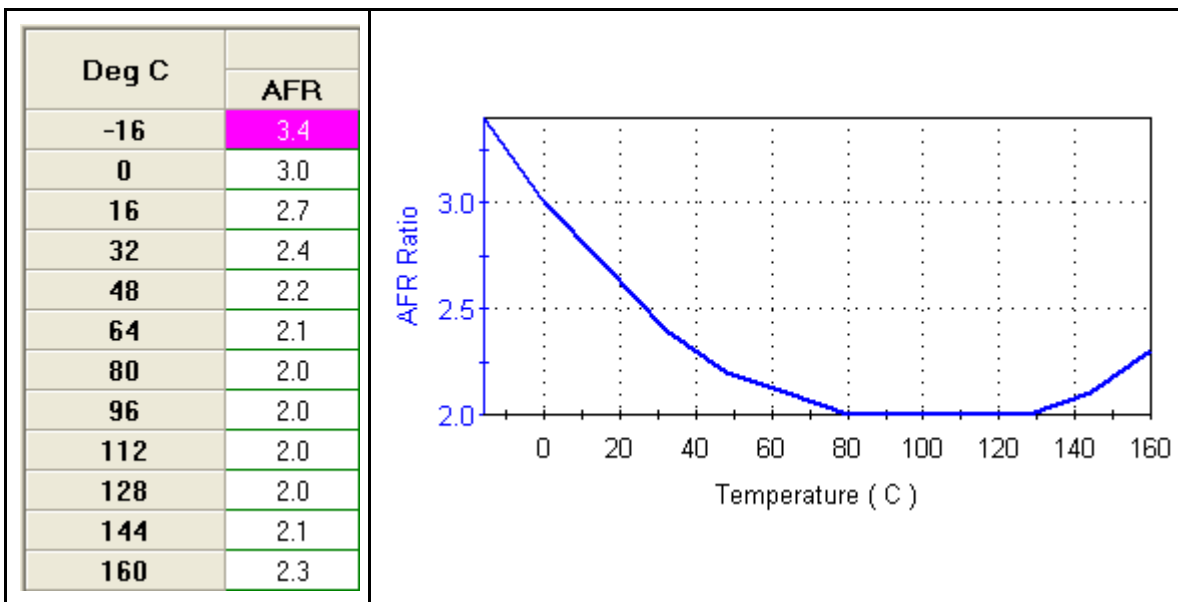
Figure 3-6: Warmup Enrichment vs. Temperature

To calibrate the Warmup Enrichment table, observe how the engine runs on startup.   If the engine blows black smoke for a few seconds after starting, remove some fuel from the table at the temperatures this occurs at.   Note that if you smell gas while cranking and get an initial puff of black smoke, the Cranking Fuel table is set too rich, and should be backed off.

Note that the warmup AFR is typically increased at high temperatures. This is to deal with a heat-soaked engine restart. It turns out that some fuel is lost due to vaporization on the very hot manifold, thus the AFR is increased to compensate for this.

3.3.1.1.   Lambda Warmup Enrichment Table

For Lambda calibrations, the Warmup Enrichment table uses Lambda units instead of AFR units. Other than that, it works identically.

Deg C	Air-Fuel Lambda
-16	0.205
0	0.185
16	0.158
32	0.137
48	0.130
64	0.130
80	0.130
96	0.116
112	0.116
128	0.116
144	0.116
160	0.116
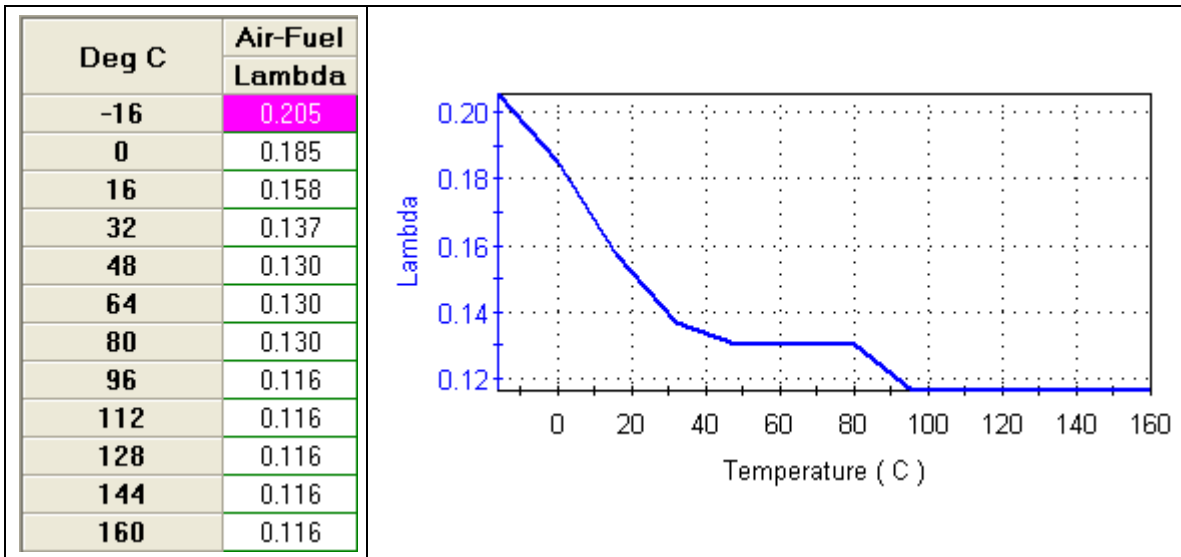
Figure 3-7: Lambda Warmup Enrichment vs. Temperature

3.3.2.   Idle Spark

During the closed-throttle idle and warmup phase the timing is controlled by the **Closed Throttle Spark** table, Figure 3-8. This table is typically set to a value of 20 to 25 degrees and is used if the TPS is less than 1 percent.

RPM	Deg C				
	-16	0	22	40	64
700	25.00	25.00	25.00	25.00	25.00
900	25.00	25.00	25.00	25.00	25.00
1500	25.00	25.00	25.00	25.00	25.00
2000	25.00	25.00	25.00	25.00	25.00
4000	25.00	25.00	25.00	25.00	25.00

Figure 3-8: Closed Throttle Spark

3.3.3.   Idle Speed Stabilization (Level 44 only)

Level 44 calibrations introduced a mechanism for stabilizing the idle speed using adjustments to the spark timing. This results in a smoother idle with less RPM "hunting". There are two constants described below that control this feature

3.3.3.1.   Idle Spark Control Gain

The Idle Spark Control Gain constant sets how much change in spark is made for a given RPM error. This controls overshoot and undershoot of the RPM target. This value should be adjusted to give the most stable idle. The units are degrees timing per 100 RPM error.

3.3.3.2. Idle Spark Control Max

Idle Spark Control Max is the Maximum amount of spark that will be added or removed to correct the idle speed. This prevents the system from going too crazy with the idle spark timing!

3.4.   Engine Run

During steady-state running fuel is calculated based on the AFR table and VE tables, and spark is determined by the main Spark Advance tables. There are a number of alternate modes which may be activated from run mode, including Power Enrichment (PE) mode, open loop and closed loop modes. Note that early vehicles do not support closed loop mode.

3.4.1.   The Volumetric Efficiency (VE) table

The VE table (Figure 3-9) is the key table that models the engine airflow such that AFR can be accurately calculated. This table is principally influenced by camshaft selection, exhaust system, head design and the intake manifold. The VE values developed for a similar engine build are a good starting place for the tuner.

RPM	Throttle Position (Percent)												
	0	2	5	7	10	15	20	25	30	40	60	80	100
750	59.0	61.0	77.5	78.5	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0
1000	59.0	61.0	77.5	78.5	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0
1125	59.0	62.5	77.5	80.5	85.0	88.5	86.5	86.5	86.5	86.5	86.5	86.5	86.5
1250	59.0	64.0	77.5	82.0	86.0	93.5	89.0	89.0	89.0	89.0	89.0	89.0	89.0
1500	59.0	64.0	80.0	89.0	90.0	93.5	93.5	90.5	90.5	90.5	90.5	90.5	90.5
1750	59.0	64.0	80.0	89.0	93.5	93.5	93.5	90.5	90.5	90.5	90.5	90.5	90.5
2000	59.0	64.0	80.0	89.0	92.0	93.5	93.5	90.5	89.0	89.0	89.0	89.0	89.0
2250	53.5	64.0	80.0	89.0	91.5	93.5	93.5	90.5	89.0	86.0	86.0	84.0	84.0
2500	53.5	62.0	73.5	84.0	91.5	93.5	94.5	94.5	94.5	89.0	89.0	89.0	89.0
2750	53.5	62.0	73.5	82.0	90.0	96.5	99.5	100.5	101.0	93.5	93.5	93.5	93.5
3000	53.5	62.0	70.5	82.0	93.5	100.5	100.5	100.5	101.0	99.5	99.5	99.5	99.5
3500	60.0	62.0	67.0	82.0	93.5	100.5	103.0	103.0	103.0	103.0	103.0	103.0	103.0
4000	60.0	60.0	67.0	84.0	92.5	100.5	103.0	103.0	103.0	103.0	102.0	102.0	102.0
4500	60.0	60.0	67.0	84.0	92.5	105.0	109.0	109.0	109.0	102.0	102.0	102.0	102.0
5000	60.0	60.0	67.0	84.0	92.5	107.0	107.0	107.0	107.0	98.5	98.5	98.5	98.5
5500	60.0	60.0	67.0	84.0	92.5	107.0	107.0	107.0	99.5	92.5	92.5	92.5	92.5
6000	60.0	60.0	67.0	84.0	92.5	107.0	107.0	107.0	99.5	92.5	92.5	92.5	92.5
6500	61.0	71.0	75.0	84.0	92.5	107.0	107.0	107.0	99.5	96.5	94.5	92.5	92.5
7000	61.0	71.0	75.0	84.0	92.5	107.0	107.0	107.0	99.5	96.5	94.5	92.5	92.5

Figure 3-9: Typical Volumetric Efficiency Table

There are several techniques that can be used to calibrate the VE table. These basically involve setting the entire AFR table to a constant AFR value, then adjusting the VE values such that the AFR of the exhaust matches that value. This can be done manually, or more quickly using the TTS VTune program. Refer to Chapter 4 for details on the VTune program.

After the VE values are calibrated, the AFR can then be set for the desired power, economy, and emissions performance. Note that more radical Harley engine builds will typically show two distinct VE ridges, Figure 3-10.

| VE Table – Mild Build | VE Table – Hot Build |
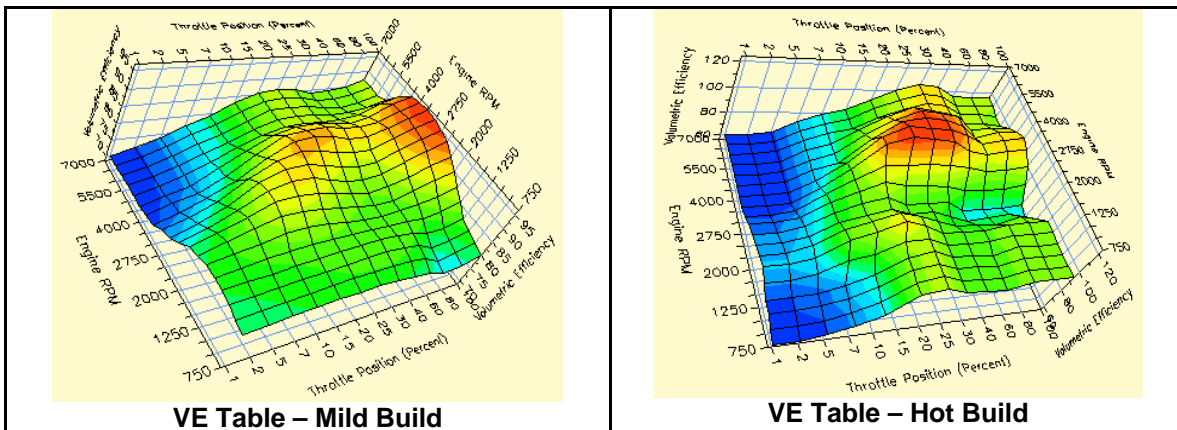
Figure 3-10: VE Table Comparison

3.4.1.1.   Lambda VE tables

Lambda calibrations use **MAP** for the horizontal X-Axis in place of **TPS**. This makes correlation to the Main Lambda table much easier, and gives better coverage of the engine load range.

RPM	MAP (kPa)											
	15	20	30	35	40	50	60	70	80	90	95	100
750	69.0	69.0	69.0	70.0	70.0	73.0	78.0	83.0	75.0	70.0	70.0	83.0
1000	69.0	69.0	69.0	71.0	70.5	73.0	78.0	83.0	75.0	70.0	70.0	83.0
1125	69.0	69.0	69.0	71.0	71.0	76.5	79.0	85.0	75.0	70.0	70.0	85.0
1250	69.0	69.0	69.0	69.5	72.0	79.0	79.0	85.0	75.0	70.0	70.0	85.0
1500	68.0	68.0	68.0	71.5	74.5	77.0	81.5	87.0	77.5	75.0	70.5	83.0
1750	71.0	71.0	71.0	73.5	77.5	81.5	86.5	88.5	85.0	82.0	82.0	82.0
2000	68.0	68.0	71.5	74.5	77.5	82.5	90.5	91.0	87.5	82.0	82.0	82.0
2250	68.0	68.0	76.0	80.0	83.5	88.5	93.0	91.0	85.0	85.0	85.0	88.5
2500	75.0	75.0	83.0	83.5	92.0	97.5	94.5	91.0	85.0	85.0	85.0	89.0
2750	70.0	71.0	81.0	84.0	93.0	93.0	88.0	85.0	85.0	85.0	85.0	89.0
3000	70.0	71.0	78.5	84.0	88.0	91.5	83.0	83.0	83.0	83.0	83.0	90.5
3500	74.0	74.0	78.5	85.5	88.5	92.0	96.0	96.5	82.0	82.0	85.5	96.5
4000	74.0	74.0	87.5	93.5	100.0	100.5	98.5	93.0	84.5	84.5	87.0	95.0
4500	74.0	74.0	86.0	93.0	100.0	100.0	91.0	85.0	89.5	85.0	85.0	85.0
5000	74.0	74.0	86.0	93.0	100.0	100.0	91.0	81.0	84.0	78.0	77.5	79.0
5500	74.0	74.0	86.0	93.0	100.0	100.0	91.0	81.0	85.0	74.0	74.0	81.5
6000	74.0	74.0	86.0	93.0	100.0	100.0	92.0	85.0	85.0	74.0	74.0	74.0
6500	74.0	74.0	86.0	93.0	100.0	100.0	92.0	85.0	85.0	74.0	74.0	74.0

Figure 3-11: Typical Lambda VE table

VTune and DataMaster VTune data collection have been changed to work with this new table axis.

3.4.2. The AFR Table

There are two basic AFR table types: Open Loop and Closed Loop. Early bikes without O2 sensors can only run in open loop mode (Figure 3-12) while later bikes with O2 sensors may operate in either open or closed loop depending on the table setting (Figure 3-13).

RPM	MAP (kPa)								
	20	30	40	50	60	70	80	90	100
750	13.9	13.8	13.8	13.8	13.8	13.3	12.1	12.1	12.1
1000	13.9	13.8	13.8	13.8	13.8	13.3	12.1	12.1	12.1
1250	13.9	13.9	14.1	14.2	14.2	13.8	12.1	12.1	12.1
1500	13.9	13.9	14.1	14.2	14.2	13.8	12.4	12.4	12.4
1750	13.9	13.9	14.1	14.2	14.2	13.8	12.5	12.5	12.5
2000	13.9	14.1	14.1	14.2	14.2	13.8	12.6	12.6	12.6
2250	13.9	14.1	14.1	14.2	14.2	13.8	12.6	12.6	12.6
2500	13.9	14.1	14.1	14.2	14.2	13.8	12.6	12.6	12.6
2750	13.9	14.1	14.1	14.2	14.2	13.8	12.6	12.6	12.6
3000	13.9	14.1	14.1	14.2	14.2	13.8	12.5	12.5	12.5
3500	13.9	14.1	14.1	14.1	14.1	13.8	12.5	12.5	12.5
4000	13.9	12.9	12.9	12.9	12.9	12.8	12.5	12.5	12.5
4500	13.9	12.6	12.5	12.5	12.5	12.5	12.5	12.5	12.5
5000	13.9	12.5	12.5	12.5	12.4	12.4	12.4	12.4	12.4
5500	13.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
6000	13.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
7000	13.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4

Figure 3-12: Typical Open Loop AFR Table

RPM	MAP (kPa)											
	20	30	40	50	55	60	65	70	75	80	90	100
750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
1750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
3000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	13.0
3500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	13.0
4000	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.7	13.7	13.0
4500	13.2	13.2	13.2	13.2	13.2	13.2	13.1	13.1	13.0	13.0	13.0	13.0
5000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
5500	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6500	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
7000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0

Figure 3-13: Typical Closed Loop AFR Table

On closed-loop capable bikes, setting the AFR value to exactly **14.6** will allow the ECM to operate in closed loop mode for that particular RPM and MAP cell. Figure 3-13 illustrates a stock closed loop table designed to keep the engine in closed loop mode over the idle and part throttle regions, and richen up at full throttle and high RPMs.

Note: **14.6** is a "switch" value that allows the ECM to operate in Closed Loop Mode and use the Closed Loop Bias Table (CLB, Figure 3-16) to control the AFR.

3.4.2.1.   Main Lambda Table

For Lambda calibrations, the ***Air-Fuel*** table has been replaced by the ***Main Lambda*** table. This table accomplishes the same result as the AFR table, but uses Lambda units to adjust the fuel mixture.   Lambda calibrations do not utilize a closed-loop bias table; the closed-loop fuel mixture is set directly in the Main Lambda table. Refer to section 3.5 for additional information on Lambda and AFR.

RPM	MAP (kPa)													
	15	20	30	40	45	50	55	60	65	70	75	80	90	95	100
750	0.976	0.976	0.977	0.977	0.984	0.984	0.984	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
1000	0.976	0.976	0.977	0.977	0.984	0.984	0.984	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
1125	0.976	0.976	0.986	0.986	0.986	0.986	0.984	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
1250	0.976	0.976	0.986	0.986	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
1500	0.976	0.976	0.988	0.988	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
1750	0.976	0.976	0.989	0.988	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
2000	0.976	0.976	0.989	0.988	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
2250	0.976	0.976	0.989	0.988	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
2500	0.976	0.976	0.989	0.988	0.986	0.986	0.986	0.984	0.984	0.982	0.981	0.977	0.869	0.863	0.856
2750	0.976	0.976	0.986	0.986	0.984	0.984	0.984	0.982	0.982	0.982	0.981	0.977	0.869	0.863	0.856
3000	0.976	0.976	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.981	0.977	0.869	0.863	0.856
3500	0.976	0.976	0.977	0.977	0.977	0.977	0.977	0.977	0.977	0.977	0.969	0.958	0.869	0.863	0.856
4000	0.952	0.952	0.952	0.952	0.952	0.952	0.952	0.952	0.945	0.938	0.928	0.917	0.869	0.863	0.856
4500	0.904	0.904	0.904	0.904	0.904	0.904	0.904	0.904	0.900	0.897	0.887	0.876	0.863	0.859	0.856
5000	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.869	0.863	0.856	0.856	0.856
5500	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.873	0.869	0.863	0.856	0.856	0.856	0.856
6000	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.876	0.873	0.869	0.863	0.856	0.856	0.856	0.856

Figure 3-14: Typical Main Lambda Table

The Main Lambda table directly controls closed-loop AFR over a range of values, typically 0.977 to 1.020 which corresponds to an AFR change of +0.29 (leaner) to –0.34 (richer) than the stoichiometric AFR value. When the Lambda value in a given cell is in the closed-loop mode, the cell contents will be marked by bold text and a vertical bar on the left side of the cell.

Figure 3-14 illustrates a typical Lambda table. In this example the upper left quadrant is all in closed loop mode, while the rest of the table is considerably richer ranging from 0.958 to 0.856 lambda.

If a cell is adjusted to a Lambda value outside of the closed loop region, the text will change to normal font and the marker bar will disappear. For example, the cell at 1000 and 1125 RPM and 40 kPa has been richened enough to place it into open-loop mode.

RPM	30	40	45
750	0.977	0.977	0.984
1000	0.977	0.972	0.984
1125	0.986	0.964	0.986
1250	0.986	0.986	0.986

Figure 3-15: Lambda Cell Changed to Open Loop

The following table illustrates the conversion between AFR and Lambda for two different fuel blends. These values can be generated using the O2 Calculator built into MasterTune.

Table 3-2: Lambda - AFR for Two Fuel Blends

Lambda	AFR – Blend "A"	AFR – Blend "B"
1.020	14.97	14.56
1.015	14.90	14.48
1.010	14.83	14.41
1.005	14.75	14.34
1.000	14.68	14.27
0.995	14.61	14.20
0.990	14.53	14.13
0.985	14.46	14.06
0.980	14.39	13.98
0.975	14.31	13.91
0.970	14.24	13.84
0.965	14.17	13.77
0.960	14.09	13.70
0.955	14.02	13.63
0.950	13.95	13.56
0.925	13.58	13.20
0.900	13.21	12.84
0.875	12.85	12.49
0.850	12.48	12.13

Blend "A" stoichiometric AFR is 14.68 (in the old days...)
Blend "B" stoichiometric AFR is 14.27 (typical value today)

Keep in mind that when tuning using Lambda, you are basically controlling how complete the combustion is regardless of the AFR value. This is determined by the O2 sensor by measuring the free oxygen in the exhaust gas. If the Lambda value = 1.000, this is considered perfect combustion with all fuel and oxygen burned. Values greater than 1.000 have extra oxygen (=lean), and values less than 1.000 have extra fuel (richer).   Lambda gives better closed-loop control of the combustion process (and therefore emissions) which is why the manufactures are now using this method.

3.4.3. The Closed Loop Bias Table

The actual AFR that is maintained in closed-loop mode is set by the Closed Loop Bias table, Figure 3-16. The closed loop bias table is used to adjust the closed loop AFR, typically to run the mixture a bit richer than the table value of 14.6 would indicate. Setting the value in this table to 450 mV will result in a closed loop AFR of 14.68; increasing the value will give a richer mixture and decreasing the value will give a leaner mixture. In the following example, the offset of 645 mV will target a AFR of approximately 14.64.

Note: Lambda calibrations do not have a Closed Loop Bias table.

Refer to Table 3-3 in section 3.5 for information on converting O2 voltage to AFR values.

RPM	MAP (kPa)				
	30	45	60	80	100
1000	605	605	605	645	645
1500	605	605	605	645	645
2000	605	605	605	645	645
2500	605	605	605	645	645
3000	645	645	645	645	645

Figure 3-16: Closed Loop Bias Table

Note: When a value other than 450 mV is entered into the CLB table it will create an offset in any table controlling AFR. The AFR offset is determined using the O2 calculator. For example, at 780 mV the AFR offset is (14.68 – 14.43) = 0.25 (richer) . For all tables that show AFR, the actual value is 0.25 less than what is displayed on the table. This assumes that the VE table has been correctly calibrated.

3.4.4. Adaptive fuel control

When in closed-loop mode, the Delphi ECM will adapt to engine and environmental changes to maintain a consistent AFR. This works by the ECM first using the VE table to calculate how much fuel to deliver to hit the targeted AFR value. It then uses the O2 sensor to determine what the AFR actually is. If there is a difference, the ECM makes an adjustment and stores the difference in a "Adaptive Fuel Value" (AFV) cell for that particular RPM-MAP load region (there are up to 24 AFV cells per cylinder depending on the calibration). Over time, the AFV cells will develop a correction profile that is applied to the fuel calculation for each load region. These values are saved in the non-volatile EEPROM memory and will be reloaded each time the bike is started.

Key point: The adaptive values will be applied to the fuel calculation whether the ECM is operating in open- **or** closed-loop mode!

Because of the time required for the AFV cells to learn, we want the AFR calculation to be as accurate as possible to prevent a "hiccup" while the system learns - for that reason (and others), the VE tables must be calibrated to match the engine. Note that when MasterTune flashes a calibration to the ECM, the AFV cells are always cleared, so any previously learned values are removed from the calibration process. Unfortunately, there is no way to view the learned contents of the AFV cells at this time.

3.5.   Stoichiometric Air-Fuel Ratio, Lambda, and Oxygen Sensors

Air-Fuel ratio(AFR) is defined as the ratio of air to fuel weight (technically called "mass"):

$$AFR = \frac{mass(air)}{mass(fuel)}$$

Stoichiometric AFR is the air – fuel mixture at which the most complete combustion takes place. Chemically speaking, at stoichiometric AFR the fuel components will be completely oxidized resulting in no free oxygen or unburned hydrocarbons in the exhaust.

The ratio of a fuel's actual AFR to its stoichiometric AFR is called Lambda, where

$$Lambda = \frac{AFR(actual)}{AFR(stoich)}$$

When the Lambda value = 1.000, the fuel is completely burned. For emissions reasons, it is desirable to maintain a lambda value near 1.000 so the catalytic converter can operate efficiently. There is much more to this, but that discussion is beyond the scope of this manual.

The oxygen sensors used in the H-D EFI system were originally developed by Bosch and work by measuring the free oxygen in the exhaust gas to determine the Lambda value. They are calibrated such that Lambda = 1.000 at the sensor output voltage of 450 mV. These sensors have their response curve tuned to operate in a very narrow range of lambda centered at 1.000, Figure 3-17. Note that this curve is only approximate, and may vary somewhat with different fuel blends.
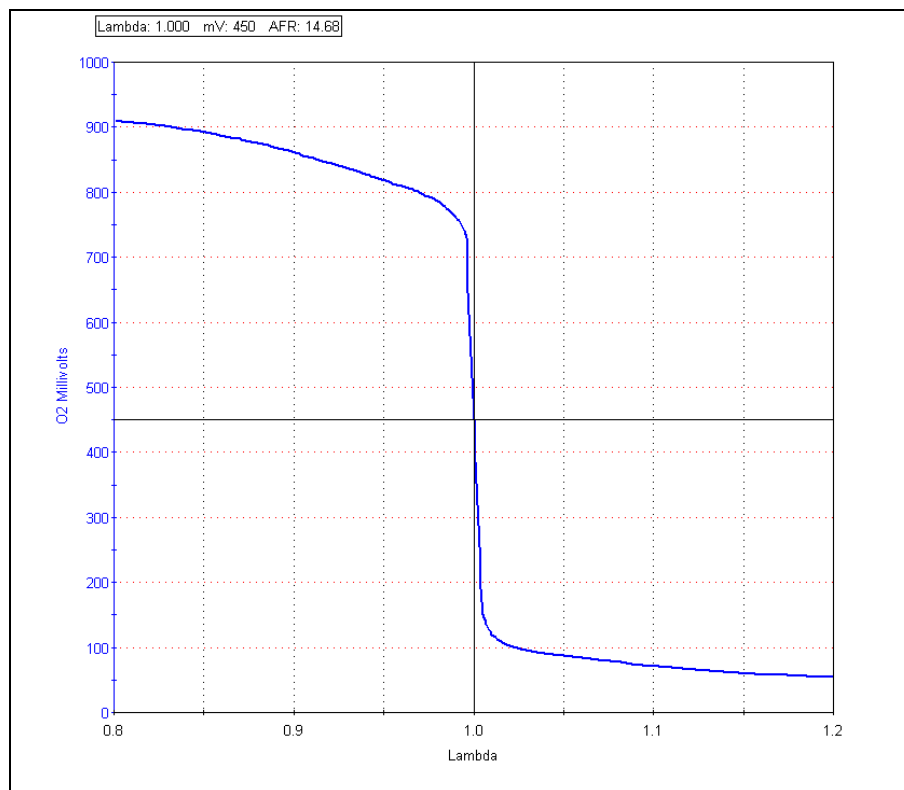
Figure 3-17: Switching Oxygen Sensor Response

Note that when Lambda is less than 1.000, the AFR is "rich" and conversely when Lambda is greater than 1.000 the AFR is "lean".

Key Point: Closed-loop operation attempts to keep the O2 voltage at an average value determined by the CLB table, Figure 3-16. This equates to keeping the free oxygen in the exhaust at some particular value. What the actual AFR is at this point depends on the fuel blend being burned!

Keep in mind that since the O2 sensor is only measuring Oxygen in the exhaust gas, a leaky gasket will throw off the reading resulting in the ECM increasing the fuel delivered and dropping the fuel economy.

Table 3-3 illustrates the relationship between Lambda, AFR and the O2 sensor voltage. Note that AFR is determined by the fuel blend; in this example the fuel has a stoichiometric AFR set to 14.68. This table was generated using the O2 calculator built into MasterTune.

Stoichiometric AFR: 14.68

Lambda	AFR	O2 mV	Lambda	AFR	O2 mV	Lambda	AFR	O2 mV
0.800	11.74	909	0.991	14.55	758	1.020	14.97	102
0.810	11.89	907	0.992	14.56	756	1.030	15.12	95
0.820	12.04	904	0.993	14.58	750	1.040	15.27	90
0.830	12.18	901	0.994	14.59	746	1.050	15.41	87
0.840	12.33	896	0.995	14.61	741	1.060	15.56	84
0.850	12.48	893	0.996	14.62	730	1.070	15.71	80
0.860	12.62	887	0.997	14.64	645	1.080	15.85	78
0.870	12.77	882	0.998	14.65	580	1.090	16.00	73
0.880	12.92	875	0.999	14.67	515	1.100	16.15	71
0.890	13.07	868	1.000	14.68	450	1.110	16.29	69
0.900	13.21	862	1.001	14.69	385	1.120	16.44	66
0.910	13.36	853	1.002	14.71	320	1.130	16.59	64
0.920	13.51	844	1.003	14.72	255	1.140	16.74	62
0.930	13.65	836	1.004	14.74	190	1.150	16.88	60
0.940	13.80	828	1.005	14.75	150	1.160	17.03	58
0.950	13.95	819	1.006	14.77	142	1.170	17.18	58
0.960	14.09	809	1.007	14.78	135	1.180	17.32	56
0.970	14.24	799	1.008	14.80	129	1.190	17.47	55
0.980	14.39	786	1.009	14.81	124	1.200	17.62	55
0.990	14.53	761	1.010	14.83	120			

Table 3-3: Lambda Sensor Calibration @ 14.68 AFR Stoichiometric

When adjusting the CLB table, the minimum resolution is 20 mV. For this reason, along with the shape of the lambda curve, it is not possible to accurately control the AFR outside of a narrow region, from about 250 to 800 mV sensor voltage.

The normal range for the CLB setting is between 250 and 675 mV. TTS does not recommend setting the CLB voltage above 800 mV, as over time O2 sensors degrade and loose the ability to respond at their voltage extremes.

Note: Today's fuel blends have a stoichiometric AFR varying from 14.28 to 14.68! Closed loop operation helps compensate for this variation.

3.6. Power Enrichment (PE) Mode

Power Enrichment mode is active at higher RPMs and when the throttle position is greater than 95 percent. This is also called "Wide Open Throttle" (WOT) mode.

The purpose of PE mode is to operate the engine at maximum torque AFR and spark values for a short time, then adjust to more conservative values to reduce engine temperature.

The RPM at which PE mode is activated is set by the PE Enable RPM Setting on the constants page.

Figure 3-18: PE RPM Setting

There are two tables that come into play during PE mode, the **PE AFR** and **PE Spark** tables.

3.6.1. The PE AFR Table

Figure 3-19 illustrates a typical PE AFR table. In this example, an AFR of 12.5 develops best power and is maintained for about 8 seconds. At that time, the AFR is gradually richened to 10.2 to prevent engine overheating.

Seconds	AFR
0.0	13.0
2.0	13.0
4.1	12.8
6.2	12.8
8.3	12.6
10.4	12.6
12.4	12.6
14.5	12.5
16.6	12.4
18.7	12.2
20.7	12.0
22.8	11.8
24.9	11.2
26.9	10.5
29.0	10.3
31.1	10.2
33.1	10.2
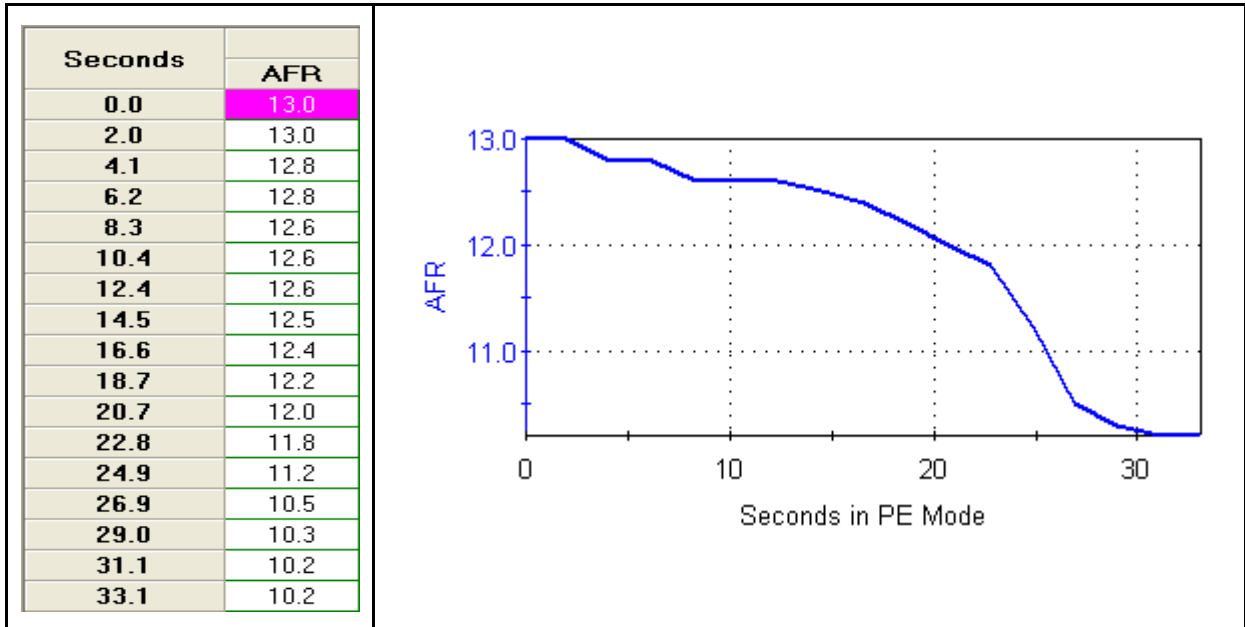
Figure 3-19: Typical PE AFR Table

Some calibrations were released with a "sawtooth" shaped PE AFR table, Figure 3-21. The reasoning behind this was that after the engine had cooled from the rich mixture, the mixture could be leaned out again to produce more power for a short time. It is unknown if this is an effective strategy!

Seconds	AFR
0.0	12.0
2.0	12.0
4.1	11.1
6.2	10.5
8.3	10.5
10.4	10.5
12.4	12.0
14.5	12.0
16.6	12.0
18.7	11.4
20.7	10.6
22.8	10.4
24.9	10.4
26.9	10.3
29.0	10.3
31.1	10.2
33.1	10.2
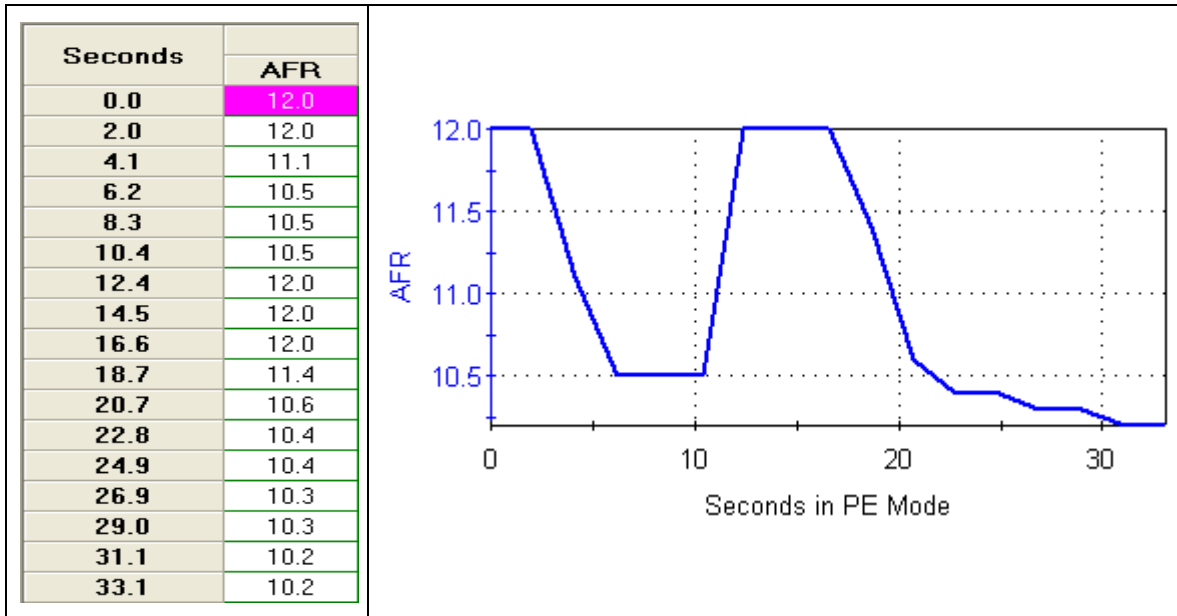
Figure 3-20: Sawtooth PE AFR Table

3.6.1.1.   Lambda PE Air-Fuel Table

For Lambda calibrations, the PE AFR table is calibrated in Lambda units. Other than that, it works identically to the AFR based calibrations.

Seconds	Air-Fuel Lambda
0.0	0.856
2.0	0.856
4.1	0.856
6.2	0.856
8.3	0.856
10.4	0.856
12.4	0.849
14.5	0.849
16.6	0.849
18.7	0.849
20.7	0.849
22.8	0.821
24.9	0.767
26.9	0.719
29.0	0.705
31.1	0.698
33.1	0.698
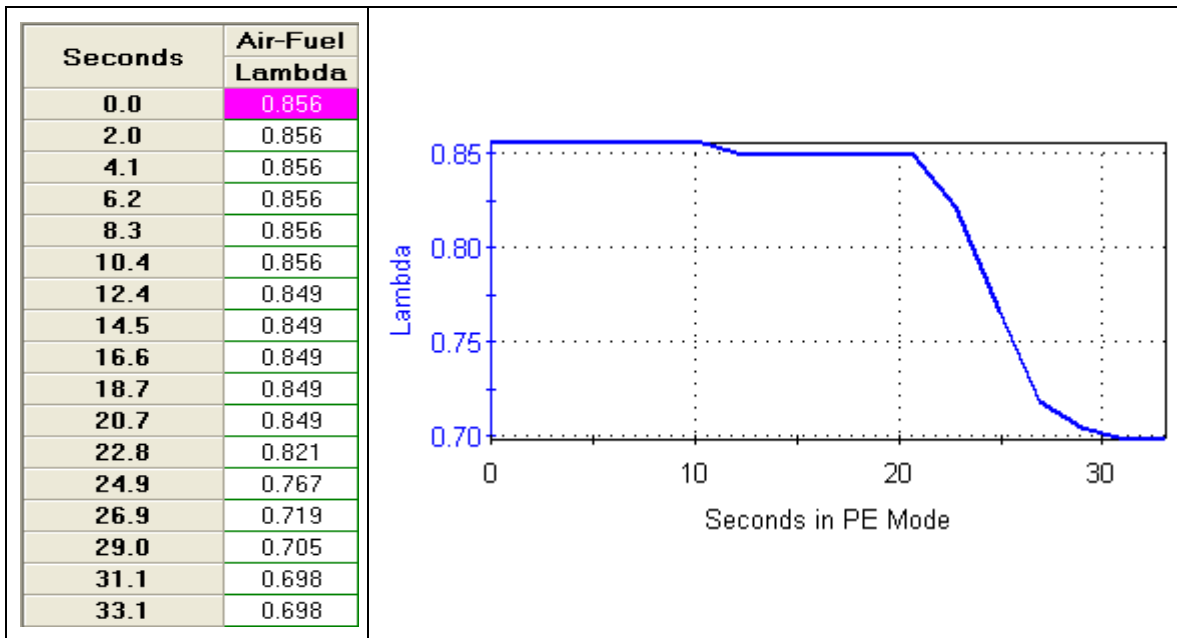
Figure 3-21: Lambda PE Air-Fuel Table

3.6.2. The PE Spark Table

Figure 3-22 shows a typical PE Spark advance table. Note that in this example that additional spark (4 degrees) is added for about 8 seconds to bring the engine to best power, then tapered out as heat builds under full load.

Most calibrations have this table set to zero. Additional spark should only be added with careful evaluation for knock.

Seconds	Spark Degrees
0.0	4.00
2.0	4.00
4.1	4.00
6.2	4.00
8.3	4.00
10.4	3.00
12.4	2.00
14.5	1.00
16.6	0.25
18.7	0.25
20.7	0.25
22.8	0.25
24.9	0.25
26.9	0.25
29.0	0.25
31.1	0.25
33.1	0.25
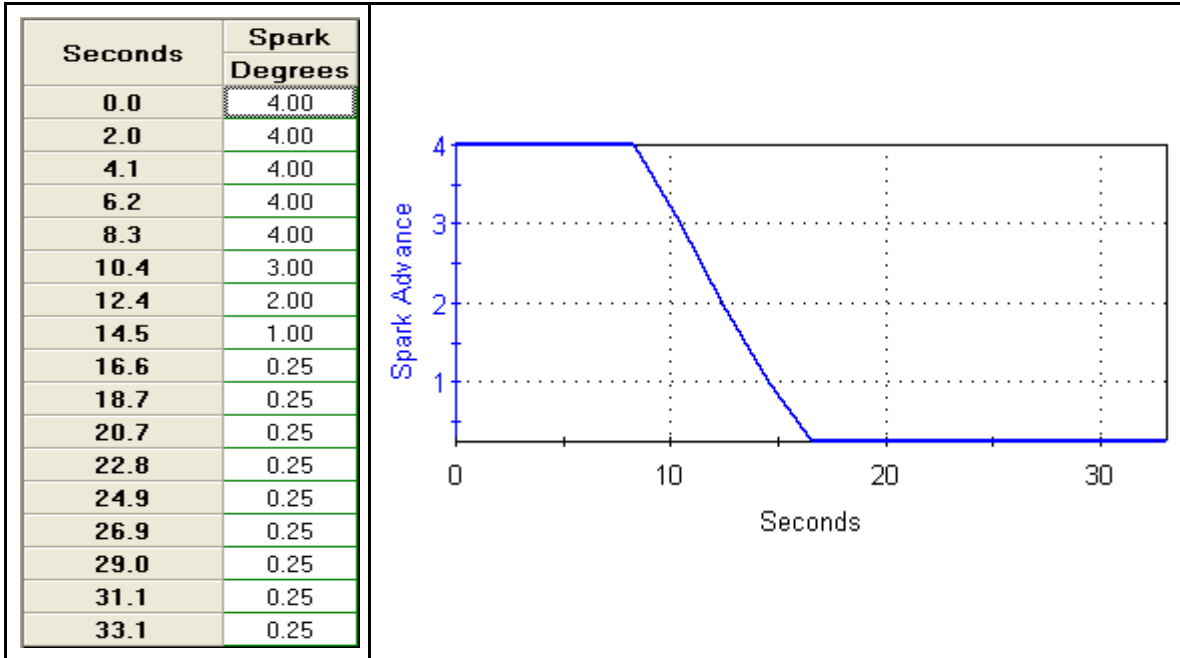
Figure 3-22: PE Spark Table

3.7.   Transient Fuel

Transient Fuel is fuel that is added or removed from the base fuel calculation for short periods of time; typically decaying to zero over about 10 – 20 engine revolutions. There are two principal components that contribute to this: Acceleration Enrichment (AE) fuel and Deceleration Enleanment (DE) fuel.

AE fuel is added during sudden load changes such as snapping the throttle open, while DE fuel is subtracted when the load is suddenly reduced such as snapping the throttle closed.

Figure 3-23 illustrates the affect of transient fuel on the Base Pulse Width (BPW) at the injector. Note that the affect of the AE correction is to add fuel to the BPW, while DE correction removes fuel. The final fuel delivered is the sum of the Raw PW + AE fuel + DE fuel.
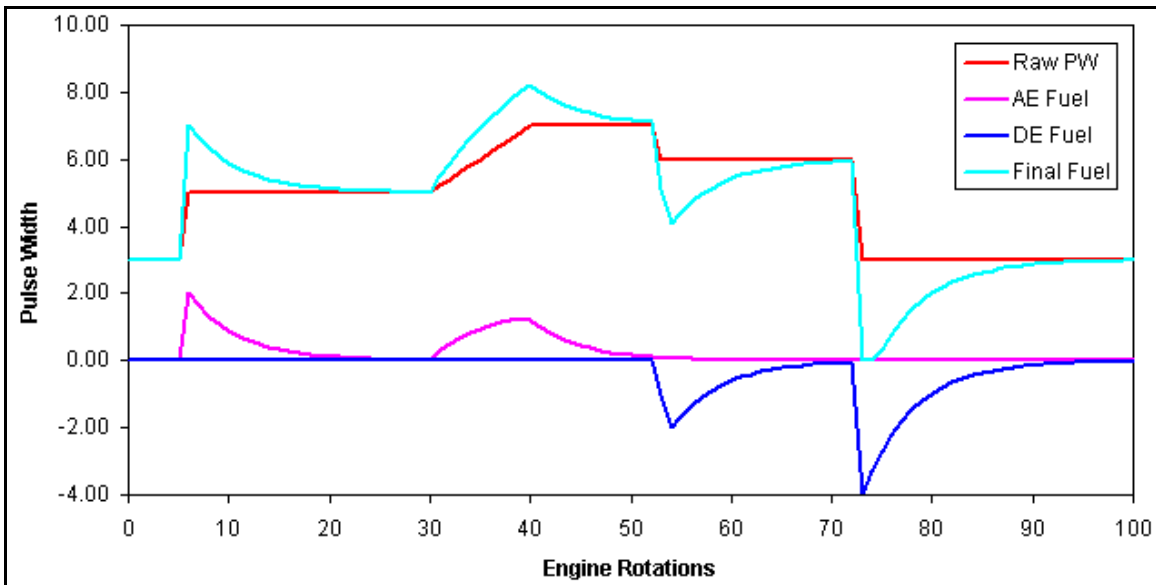
Figure 3-23: AE and DE Fuel Correction

3.7.1.   Acceleration Enrichment Table

AE fuel is controlled by the Accel Enrichment Multiplier table, Figure 3-24. This function acts much like an accelerator pump on a carbureted vehicle and prevents vehicle hesitation when the throttle is quickly opened. AE mode can be triggered by either an increase in throttle position or by a sudden increase in the MAP value. AE mode will be terminated if the throttle is quickly decreased. To increase the AE fuel delivered, increase the multiplier value.

Deg C	Mult
0	2.00
16	1.70
32	1.41
48	1.13
64	0.91
80	0.73
96	0.61
112	0.48
128	0.38
144	0.33
160	0.33
176	0.33

Figure 3-24: Accel Enrichment Multiplier

3.7.2.   Deceleration Enleanment Table

DE fuel is controlled by the Decel Enleanment Multiplier table, Figure 3-25. The intent of this table is to temporarily remove fuel when the throttle is closed. DE mode is terminated if the throttle is opened more than about 3 percent. Note that **larger** multiplier values **remove more fuel**, just the opposite of the AE table!

This table affects exhaust "popping" when backing off the throttle. Typically, popping occurs because the mixture is too lean. Setting the multiplier value lower will richen the mixture and may help this condition.

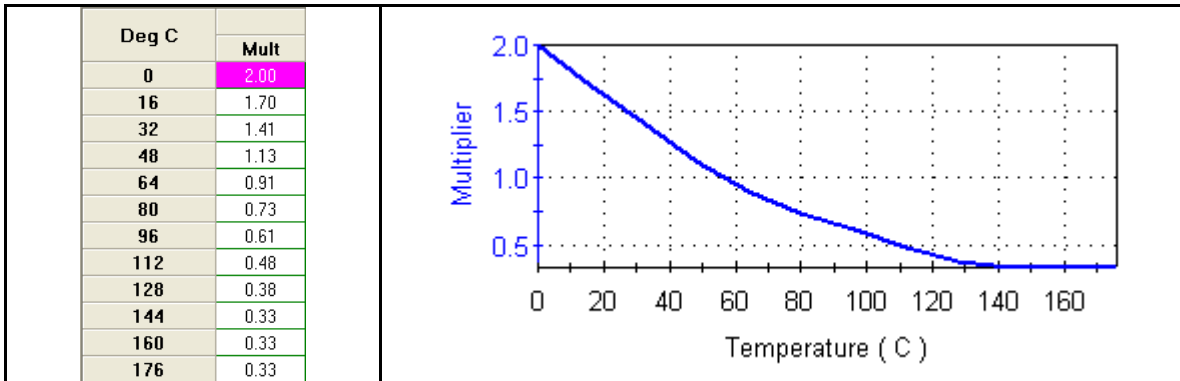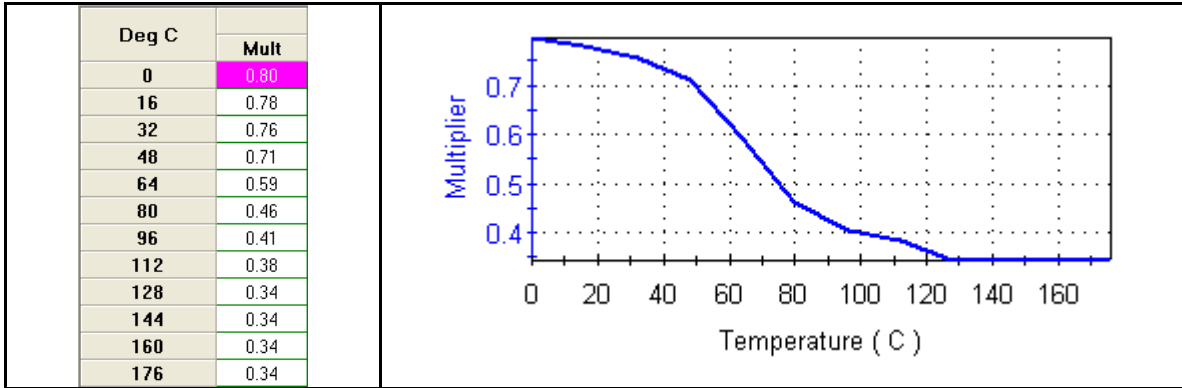| Deg C	Mult
0	0.80
16	0.78
32	0.76
48	0.71
64	0.59
80	0.46
96	0.41
112	0.38
128	0.34
144	0.34
160	0.34
176	0.34

Figure 3-25: Decel Enleanment Multiplier

3.8.   The Main Spark Tables

There are two main spark tables, one for each cylinder.   This is because the rear cylinder runs hotter than the front and therefore has different timing requirements. The original factory tables are developed using sensors to measure BMEP (Break Mean Effective Pressure) and adjusting for peak cylinder pressure without knock using a test fuel, then backing off a bit for safety. This is called the MBT (Mean Best Torque) spark advance.

RPM	MAP (kPa)										
	15	20	30	40	50	60	70	80	90	95	100
750	24.00	24.00	24.00	24.00	19.50	14.00	7.00	4.00	1.00	1.00	1.00
1000	24.00	24.00	24.00	24.00	19.50	14.00	8.00	5.00	2.00	1.50	1.50
1125	24.50	24.50	24.50	24.50	20.50	15.00	9.00	6.00	3.00	2.50	2.50
1250	25.00	25.00	25.00	25.00	21.25	16.50	11.00	8.00	4.75	4.25	4.25
1500	26.00	26.00	26.00	26.00	23.00	19.00	15.00	11.00	7.50	6.50	6.50
1750	27.00	27.00	27.00	27.00	25.00	22.00	18.50	13.50	9.50	8.00	8.00
2000	29.00	29.50	29.00	29.00	27.50	25.00	22.00	18.50	14.00	11.50	11.50
2250	32.00	32.50	32.00	32.00	31.00	29.00	25.50	22.25	17.50	14.00	14.00
2500	34.00	36.00	36.00	35.50	34.00	32.00	29.00	25.50	19.50	15.50	15.50
2750	35.00	38.00	39.00	38.50	38.00	35.50	32.50	28.00	21.00	16.50	16.50
3000	35.00	40.00	42.00	41.50	41.00	39.00	35.00	30.00	22.00	17.00	17.00
3500	35.00	40.00	43.50	44.00	44.00	43.00	37.50	31.00	22.00	17.00	17.00
4000	35.00	40.00	44.00	44.00	44.00	43.00	37.50	32.00	24.50	20.00	20.00
4500	35.00	40.00	43.00	43.00	43.00	42.00	37.00	32.50	27.00	24.00	24.00
5000	35.00	40.00	42.00	42.00	42.00	41.00	36.00	33.00	28.00	26.00	26.00
5500	35.00	40.00	42.00	42.00	42.00	41.00	36.00	33.00	30.00	28.00	28.00
6000	35.00	40.00	42.00	42.00	42.00	41.00	36.00	33.00	31.00	30.00	30.00

Figure 3-26: Main Spark Table
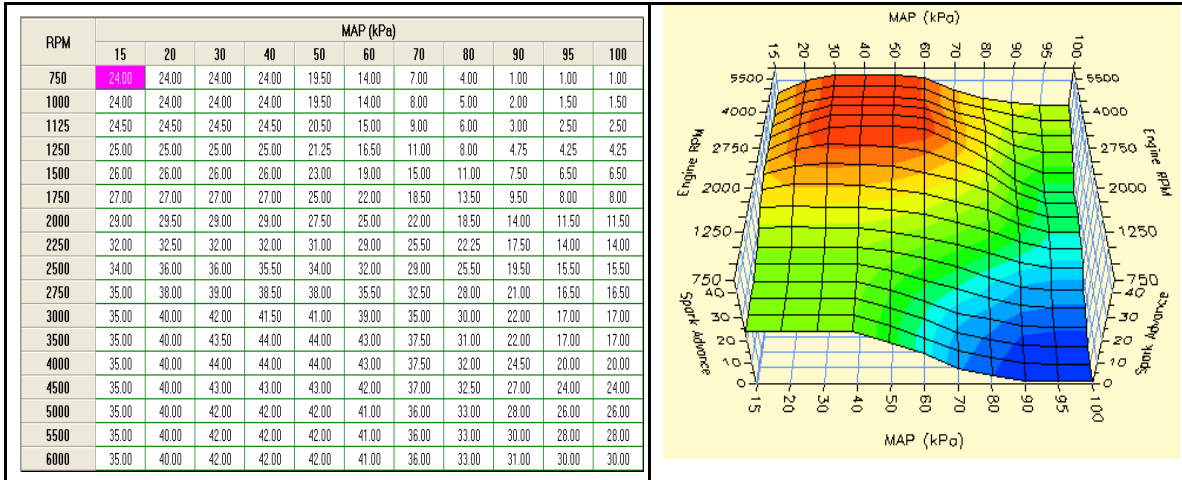
When different engine components are used, the MBT spark setting may differ significantly from the original numbers. This can be determined by running the bike on a dynamometer while

monitoring for any signs of knock, or by using DataMaster to record data while the bike is driven and examining the **Fast Knock Retard** parameter (Figure 3-27).
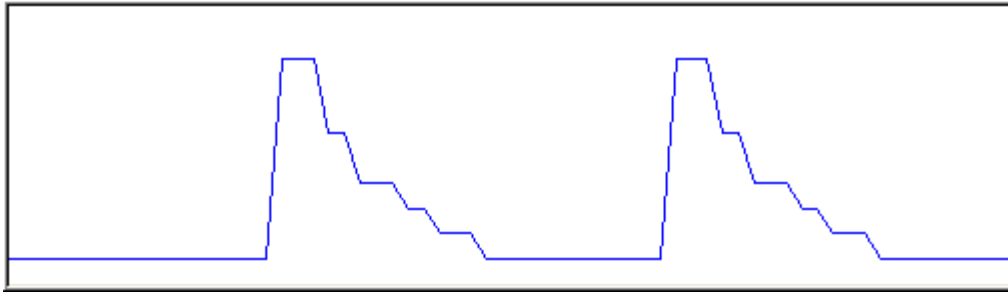

Figure 3-27: Spark Retard

3.9.   The Spark Temperature Correction Table

The Spark Temperature Correction table is used to make corrections to the spark table based on engine temperature extremes. It is used for the following main functions:

1. Remove timing under high-load and temperature to avoid knock
2. Add additional timing when cold to improve drivability
3. Reduce warm-up time by retarding timing in the mid load/temperature regions

In this example, timing is being removed under high temperature and high load conditions.

| Deg C	MAP (kPa)										
	15	20	30	40	50	60	70	80	90	95	100
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	-1.00	0.00	0.00
112	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	-2.50	-2.50	-1.00	-1.00
128	0.00	0.00	0.00	0.00	0.00	-1.00	-2.50	-4.00	-4.00	-2.00	-2.00
144	0.00	0.00	0.00	0.00	-1.00	-2.50	-4.00	-5.50	-5.50	-3.50	-3.50
160	0.00	0.00	0.00	0.00	-1.50	-4.00	-5.50	-7.00	-7.00	-5.00	-5.00
176	0.00	0.00	0.00	0.00	-2.00	-5.00	-6.50	-8.00	-8.00	-6.00	-6.00
192	0.00	0.00	0.00	0.00	-2.50	-6.00	-7.50	-9.00	-9.00	-7.00	-7.00
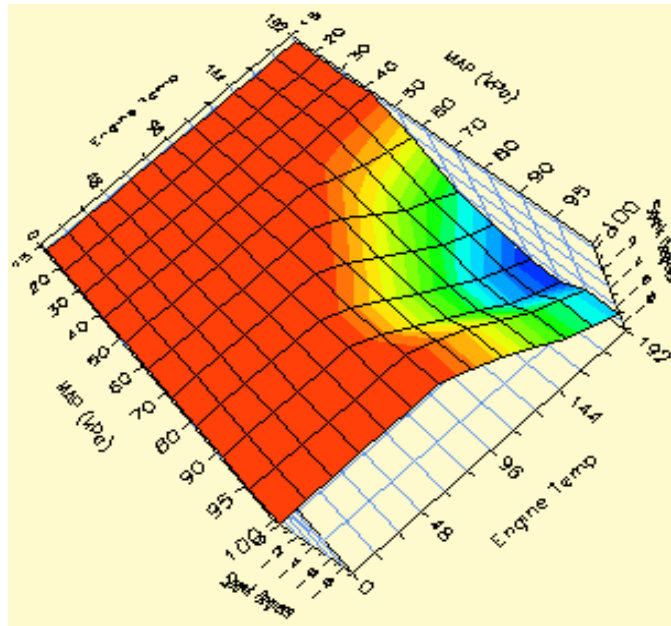
Figure 3-28: Spark Temperature Correction Table

3.10. Adaptive Spark Control

The Delphi ECM utilizes Adaptive Spark Control based on information received from the knock detection system. This system learns a retard value to apply when knock is detected, and this value is retained between key-on cycles. However, at each key-on the remembered values will be reduced towards zero. This gradually clears out the learned knock adapt value and serves to adapt to a change in conditions, such as a tank of low octane fuel being replaced with better fuel.

The Adaptive Knock Retard table determines the maximum amount of **learned spark retard** that can be applied, based on RPM and MAP. When the spark tables are being developed, this table should set this table to zero degrees to prevent influencing the values. After tuning is complete, restore the table to the factory values or set the table to the values appropriate for your engine combination.
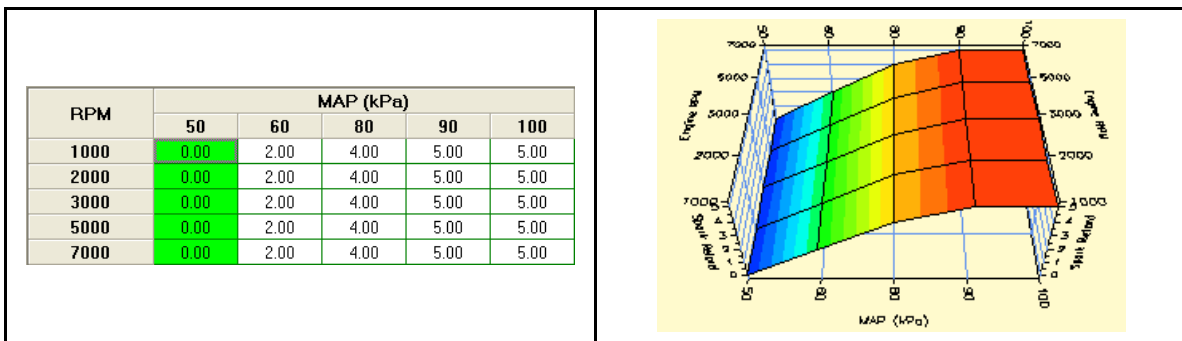
RPM	MAP (kPa)				
	50	60	80	90	100
1000	0.00	2.00	4.00	5.00	5.00
2000	0.00	2.00	4.00	5.00	5.00
3000	0.00	2.00	4.00	5.00	5.00
5000	0.00	2.00	4.00	5.00	5.00
7000	0.00	2.00	4.00	5.00	5.00

Figure 3-29: Adaptive Knock Retard Table

3.10.1.   Fast Knock Retard

Fast Knock Retard is applied immediately when knock is first detected, and decays rapidly over a few seconds unless additional knock is detected, Figure 3-30. This data is what is monitored to determine if the timing is too aggressive.
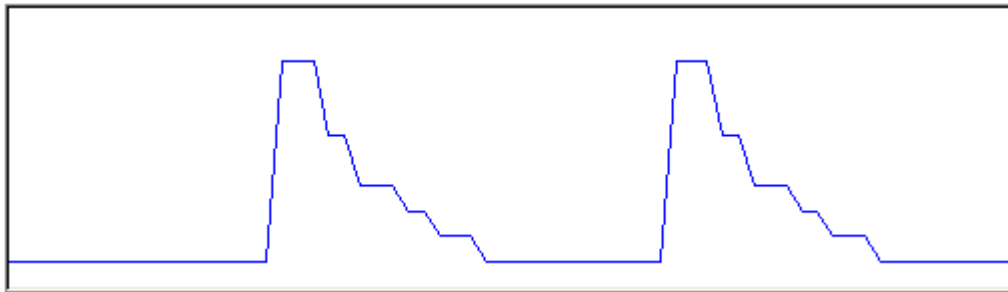

Figure 3-30: Fast Retard Action

Note that the event that caused the Fast Retard action occurred several data frames prior. For this reason, the data must be carefully examined to determine which timing cells should be reduced to fix the problem.

3.11. EITMS - Engine Idle Temperature Management System

The EITMS system was developed to reduce heat buildup during prolonged idling times and controls heat buildup in two stages:
1. Mode 1 – AFR Enrichment
2. Mode 2 – Skip Fire / Rear Cylinder shutoff

Mode 1 will be activated under the following conditions:
1. The engine temperature exceeds 142 °C (Sportsters 230 °C)
2. The Engine RPM is less than 1200 RPM

Mode 2 (Big Twins only) activates if Mode 1 is active AND
1. The engine temperature exceeds 155 °C
2. The vehicle speed is less than 1-2 KPH

Note that Sportster temperatures are much higher due to the location of the temperature sensor and only use EITMS Mode 1 (AFR enrichment).

Note that EITMS takes over AFR control when active and the user AFR tables are ignored.

3.11.1.   Skip Fire Mode IAC Offset Constant

When EITMS mode is activated, the Idle Air Control (IAC) valve is opened a bit further to reduce stumbling when the vehicle begins moving again. Bigger builds may need to increase the number of steps in this constant to prevent stalling the bike when EITMS is active.

3.12. Minimum TPS for Baro Correction Table

The Minimum TPS for Baro Correction table determines under what conditions the BARO calculation will be updated. Big builds may need to adjust this table to make certain the correct Baro value and associated corrections are made.

To calibrate this table, a MT8 calibration must be present in the ECM and a CamTune data file must be recorded on a load-controlled dyno. Start the CamTune data recording with the bike **not** running – This is needed to establish the current ambient Baro pressure reading. Note the static IVO kPa reading: This is the ambient Barometric pressure.

RPM	TPS Percent
0	10.9
800	10.9
1600	15.9
2400	20.9
3200	25.9
4000	30.9
4800	35.9
5600	40.9
6400	45.9

Start the bike and for each RPM setpoint in the table hold the engine speed constant while slowly increasing the throttle until the IVO pressure reading is within 2 kPa of the ambient Baro reading.

Note the TPS setting at which this occurs; this is the TPS you will insert into the table.

Figure 3-31: Minimum TPS for Baro Correction Table

3.13. The EGR Effect Tables

The EGR effect tables compensate the VE calculations for Exhaust Gas Recirculation (EGR) dilution of the intake airflow. These tables are used to shape the VE table at MAP values of 60kPa or less. Typically, these would be adjusted to reduce excessive VE table values, and to flatten out the VE table in the 0 to 60 kPa region.
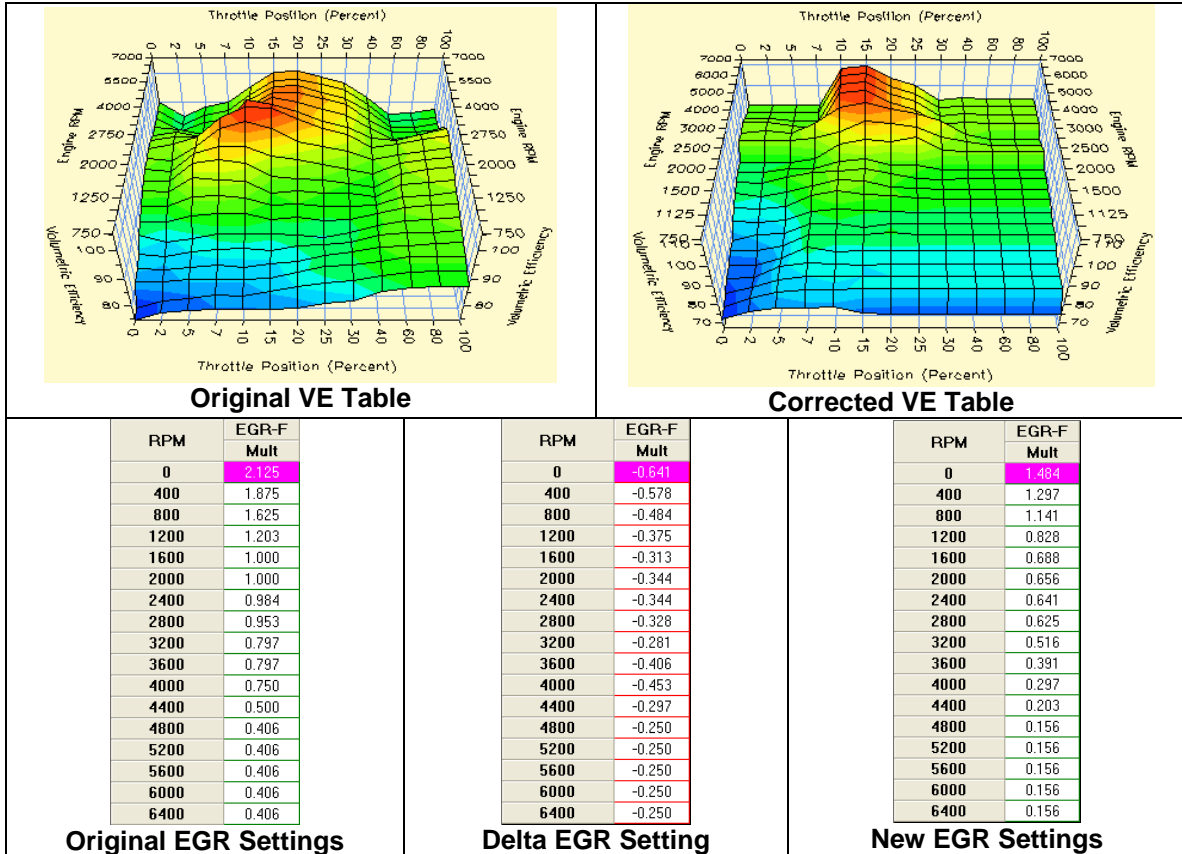

Original VE Table	Corrected VE Table

RPM	EGR-F Mult		RPM	EGR-F Mult		RPM	EGR-F Mult
0	2.125		0	-0.641		0	1.484
400	1.875		400	-0.578		400	1.297
800	1.625		800	-0.484		800	1.141
1200	1.203		1200	-0.375		1200	0.828
1600	1.000		1600	-0.313		1600	0.688
2000	1.000		2000	-0.344		2000	0.656
2400	0.984		2400	-0.344		2400	0.641
2800	0.953		2800	-0.328		2800	0.625
3200	0.797		3200	-0.281		3200	0.516
3600	0.797		3600	-0.406		3600	0.391
4000	0.750		4000	-0.453		4000	0.297
4400	0.500		4400	-0.297		4400	0.203
4800	0.406		4800	-0.250		4800	0.156
5200	0.406		5200	-0.250		5200	0.156
5600	0.406		5600	-0.250		5600	0.156
6000	0.406		6000	-0.250		6000	0.156
6400	0.406		6400	-0.250		6400	0.156
Original EGR Settings			**Delta EGR Setting**			**New EGR Settings**	

Figure 3-32: EGR table setting Affect on VE table

Figure 3-32 illustrates the how changing the EGR Effect table can change the VE table. In this case, the EGR table was adjusted in such a way as to lower the peak VE values and flatten out the table in the part throttle regions.

Note that the affect the EGR table has on the VE table varies with the MAP kPa. Changes are greatest at low kPa regions and taper off to no affect as MAP approaches 60 kPa.

With a Lambda-based VE table, it is very easy to see what cells are affected by the EGR table, as the horizontal axis is already in kPa, so all cells to the left of the 60 kPa column will be affected.

With AFR based calibrations it is more difficult to determine which cells will be affected, so a DataMaster analyzer was developed to show the relationship between what TPS columns will be affected by the EGR table.

To use this analyzer, load your VTune run into DataMaster and select the **View - EGR Effect TPS Analyzer** menu.

This will show the EGR Effect TPS Analyzer form. Select the beginning and end records to analyze, or use the default setting of all records. Click the "Analyze" button to process the data and plot the graph.
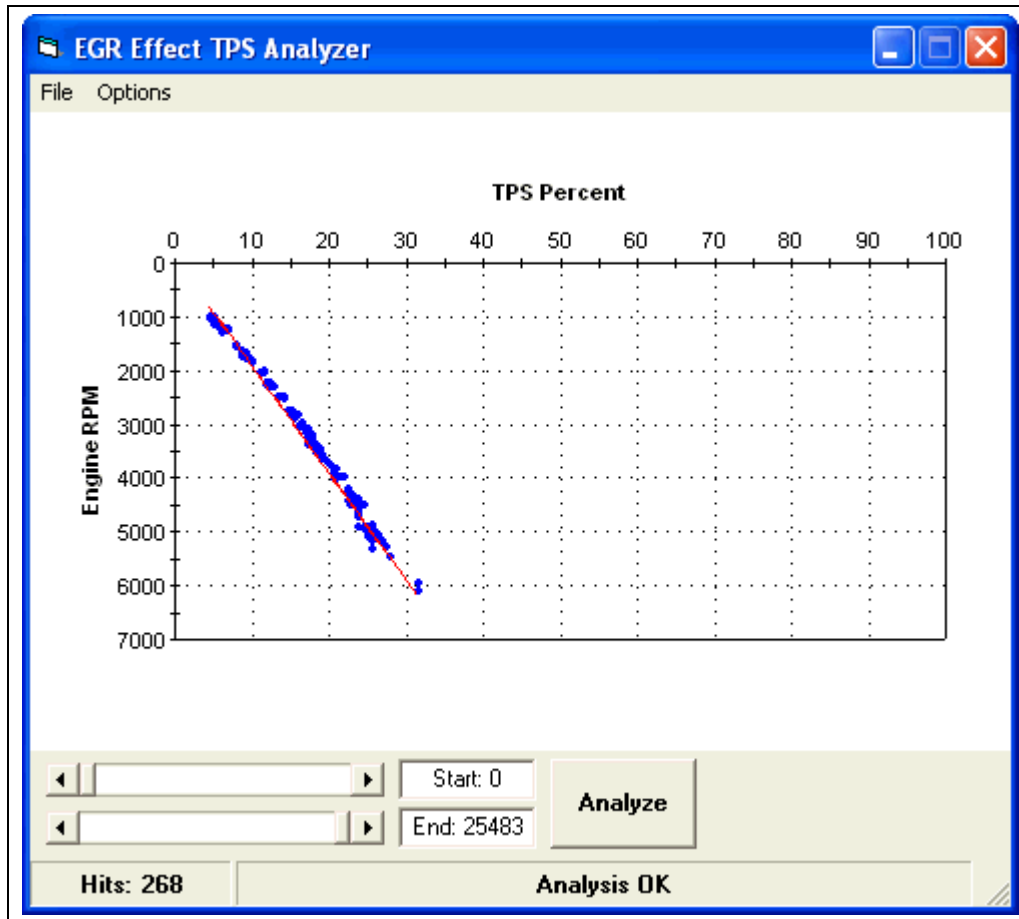

Figure 3-33: The EGR Effect TPS Analyzer

The above graph shows the resulting scatter plot resulting from analyzing a VTune data run. Basically, this shows how far the throttle must be opened at a given RPM to reach 60 kPa MAP. You **must** make sure that you have gathered data in the 58 – 60 kPa range so the plot can be filled in. The thin red line is the "best fit" straight line through the data points. Print this graph using the File - Print menu selection and refer to it when using MasterTune to make VE table adjustments.

The chart below illustrates the TPS needed to reach 60 kPa MAP for each RPM band.   When adjusting the EGR Effect table to flatten the VE table, only VE cells falling within the shaded area defined to the left of the red line will be affected.
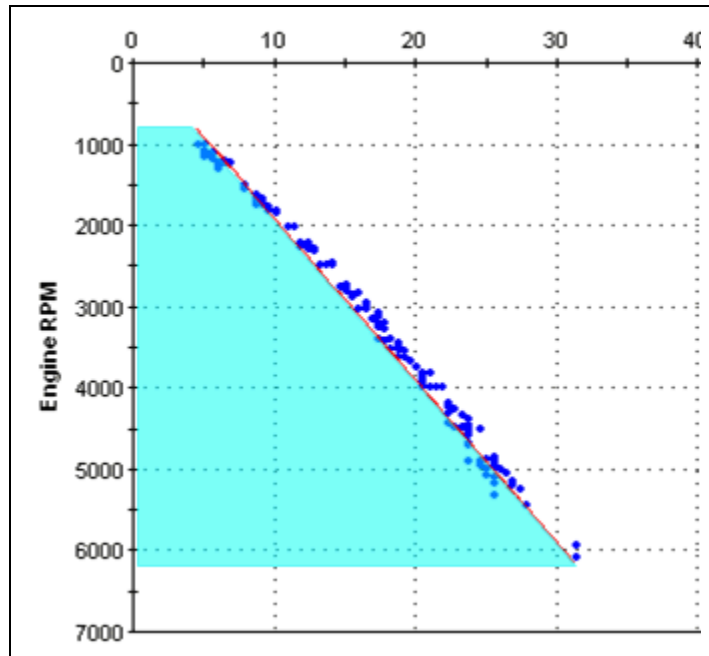

Figure 3-34: TPS needed to reach 60 kPa MAP

NOTE: The shape and position of the above chart will vary depending on the engine build components. The above charts are for a stock 96 inch BigTwin motor.

3.13.1.   Checking for 60 kPa cells using VTUNE

Starting with VTune version 1.7.9, a feature has been added to highlight the text in all cells that collected valid data at a average MAP of 60 kPa or less. This makes it easy to locate the VE cells that the EGR adjustment will affect.

To enable this feature in VTune, generate your VE tables and select *Highlight Low MAP* from the settings menu:

This will bold the text in the cells that have an average MAP of less than 60 kPa.
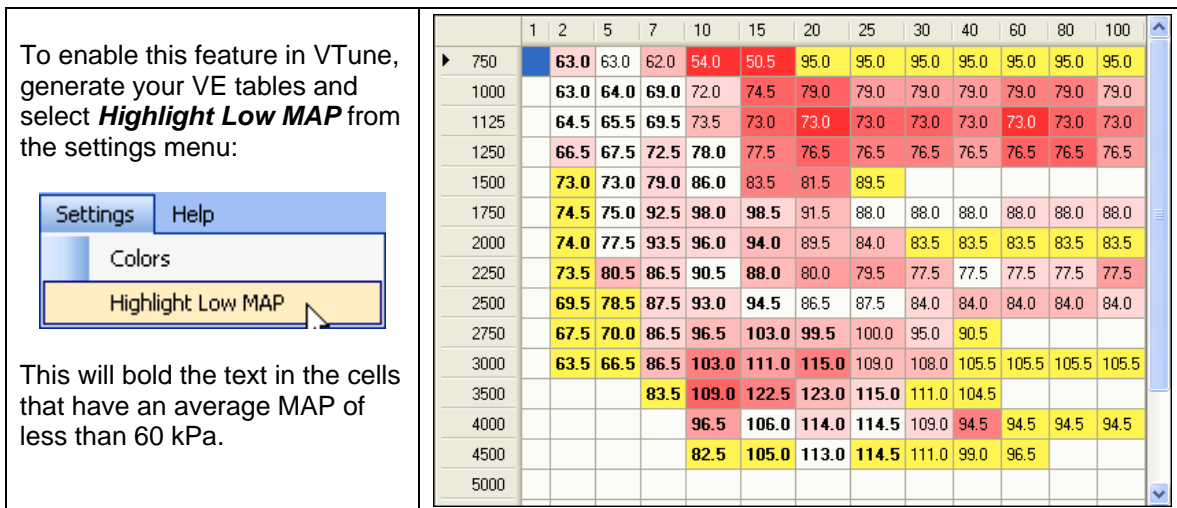
Figure 3-35: VTune Highlighted <60 kPa Cells

Note the results will follow the same trend line as the TPS Analyzer.

4. Detailed Tuning Procedure

The VTune process is used to calibrate the ECM's VE tables such that the desired AFR is obtained under all riding conditions. After the VE tables are calibrated for your engine build, the AFR can be adjusted to the desired mix of performance and economy, and the ECM will maintain these values.

This section presents a step by step procedure that is used when VTuning a bike. This procedure is based around using version 1.3 or later MasterTune software and calibrations.

The basic steps are:
1. Set-up the laptop for data collection on the bike
2. Open MasterTune and back-up your original calibration
3. Select your starting calibration and set it up for VTune
4. Program the VTune calibration into the ECM and exit MasterTune
5. Open the DataMaster program and select Record VTune Data
6. Record VTune data while you ride the bike
7. Open the VTune program and select your calibration and DataMaster files
8. Click on "Generate Tune" to generate the new calibration file
9. Program this **NEW** calibration into the ECM
10. Repeat steps 4 -9 several times until the VTune tables have mostly white cells
11. Restore the AFR and PE Enable RPM to their original value and program this final calibration back into the bike.
12. If desired, make AFR and other adjustments

A flowchart of this procedure is shown in section 4.14

4.1.   Setup the Laptop for Collecting Data

Refer to section 2.1 for details on this operation

4.2.   Save your Original Calibration

The first time you use MasterTune, **always save the original factory (or aftermarket) calibration** so you can restore your bike to stock or recover from a programming error. Refer to section 2.4 for instruction on how to do this.

4.3. Select and Set-up the Calibration

Refer to section 2.5 for directions on selecting the correct starting calibration for your bike and editing the file comments (section 2.5.2).

4.3.1. Set the AFR table to 14.6

Under Table Selection, select the "Air Fuel Ratio" table. Set all cells to 14.6 (or their maximum value) by clicking on the upper left corner to select all cells, then click and hold the increment button until all cells stop changing. Note that some cells are not allowed to be set this lean in order to protect the engine.

RPM	MAP (kPa)											
	20	30	40	50	55	60	65	70	75	80	90	100
750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7
1500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
1750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
2500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.0
3000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	13.0
3500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	13.0
4000	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.7	13.7	13.0
4500	13.2	13.2	13.2	13.2	13.2	13.2	13.1	13.1	13.0	13.0	13.0	13.0
5000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
5500	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6500	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
7000	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0

Figure 4-1: Original AFR Table

RPM	MAP (kPa)											
	20	30	40	50	55	60	65	70	75	80	90	100
750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
1000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
1250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
1500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
1750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
2000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
2250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
2500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
3000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
3500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
4000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
4500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
5000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
5500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
6000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
6500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6
7000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.6

Figure 4-2: AFR Table set to Maximums

If you are using a Lambda calibration, set all the **Main Lambda** table cells below 100 kPa to 0.981. **Make no change to the 100 kPa column**!

RPM	MAP (kPa)									
	20	30	40	50	60	70	75	80	90	100
750	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
1000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
1125	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
1250	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
1500	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
1750	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
2000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
2250	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
2500	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
2750	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
3000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
3500	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
4000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
4500	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
5000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
5500	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856
6000	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.856

Figure 4-3: Main Lambda Table setup for VTune

A lambda setting of 0.981 will call for closed-loop operation, and is rich enough to allow VTune runs under load.

Tip: To quickly set all the cells to the same value follow these steps:
1. Select the region to change
2. Set the increment to 20 units
3. Increment the region until all cells are "maxed out"
4. Decrement the region to the desired value

4.3.2.   Set the Closed Loop Bias table(s)

This step establishes the actual AFR that your bike will have when running in closed-loop mode. TTS calibrates these tables for balance of economy and power, with light load running leaner than high load.

Note: If this is a Lambda Calibration skip this step as there is no Closed Loop Bias table.

Should you desire a different AFR, use the O2 Voltage calculator (in the MasterTune *Tools* menu) to determine a new O2 bias voltage setting. The normal setting range for this table is 250 to 675 mV. TTS does not recommend setting the CLB voltage above 800 mV, as over time O2 sensors degrade and loose the ability to respond at their voltage extremes.

Note that some calibrations have separate closed loop bias tables for the front and rear cylinders. Both of these should be setup following this procedure.

The following illustration shows changing the closed loop bias table to 664 mV across the board. Note the blue color which indicates the cell values were changed.

RPM	MAP (kPa)				
	30	45	60	80	100
1000	566	566	566	586	625
1500	566	566	566	586	625
2000	566	566	566	586	625
2500	586	586	586	586	625
3000	625	625	625	625	625

Closed Loop Bias Table Original

RPM	MAP (kPa)				
	30	45	60	80	100
1000	664	664	664	664	664
1500	664	664	664	664	664
2000	664	664	664	664	664
2500	664	664	664	664	664
3000	664	664	664	664	664

Closed Loop Bias Table set to 664 mV
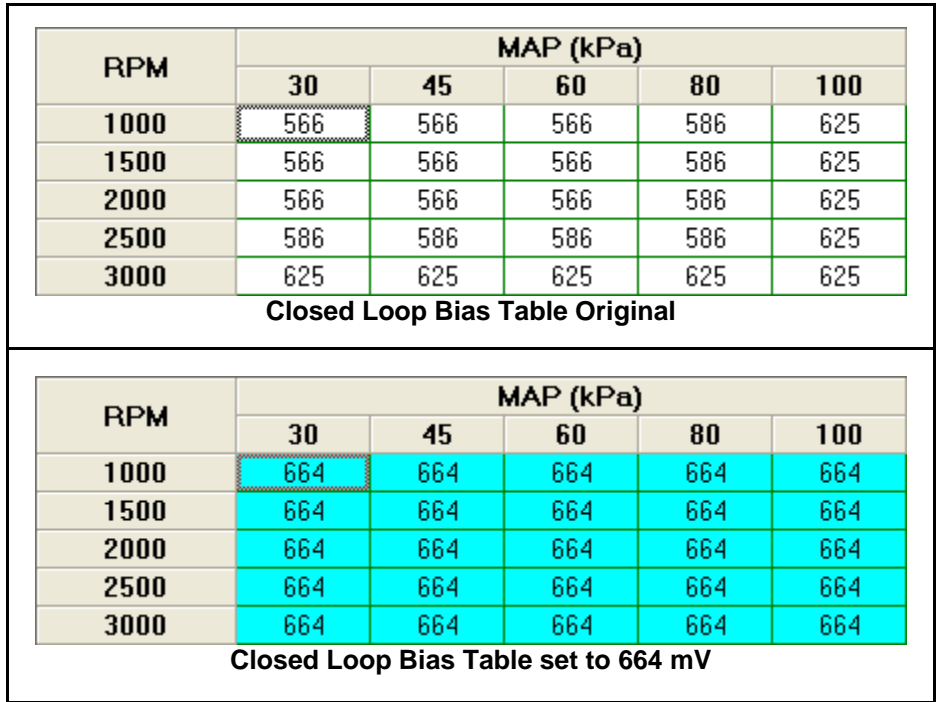
Figure 4-4: Setting the Closed Loop Bias

4.3.3. Disable Power Enrichment (PE) Mode

This step is not necessary for Sportsters, as PE mode is not functional in the current Sportster calibrations.

Under Table Selection, select the "ECM Tuning Constants". On the tabbed dialog in the right pane, select "PE Mode". Set the RPM to 10,000 RPM to disable PE Mode.

Selecting Constants Menu

PE RPM set to 10,000
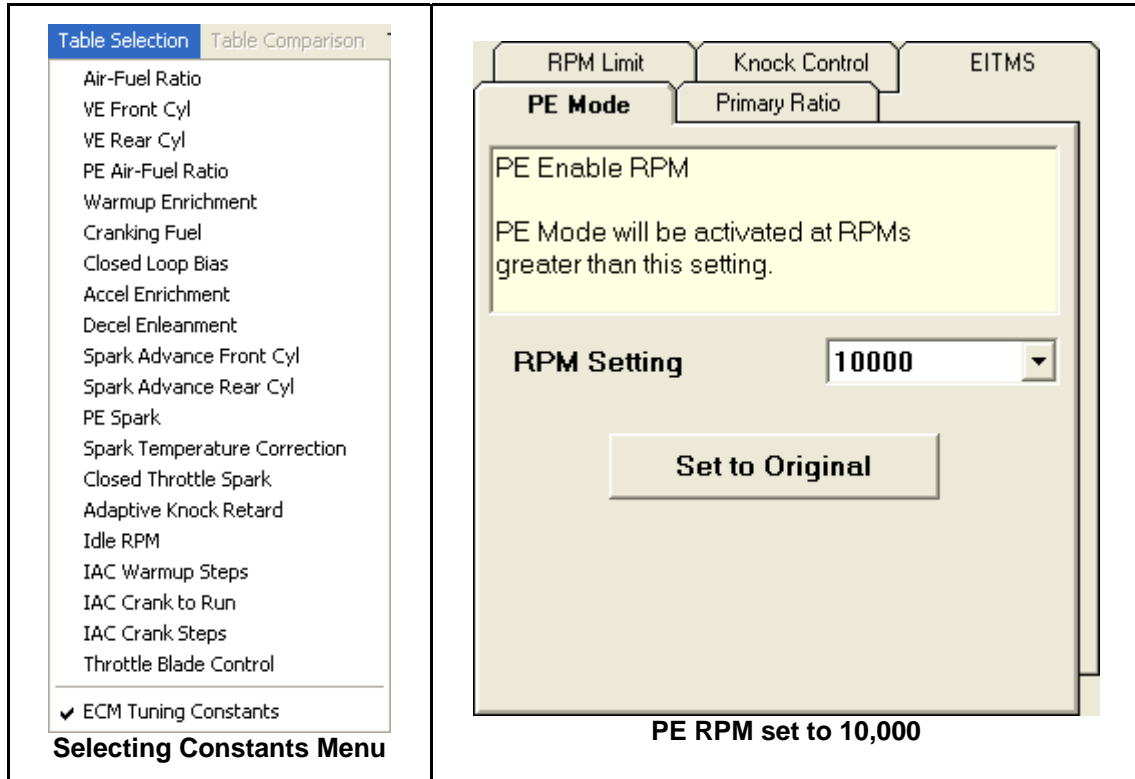
Figure 4-5: Disabling PE Mode

4.3.4. Set the Engine Displacement and Injector Size

If the calibration you selected is for a bike with a different displacement or injector size, change the settings in the **ECM Tuning Constants** on the left pane of the **Constants** page. If your engine build already matches these settings, make no changes to these settings.

Figure 4-6: Setting the ECM Constants

4.3.5. Save Your New VTune Calibration File

Save your new calibration file giving it a name you will remember. You will need this file again later.

File – Save As Menu

File Save Dialog
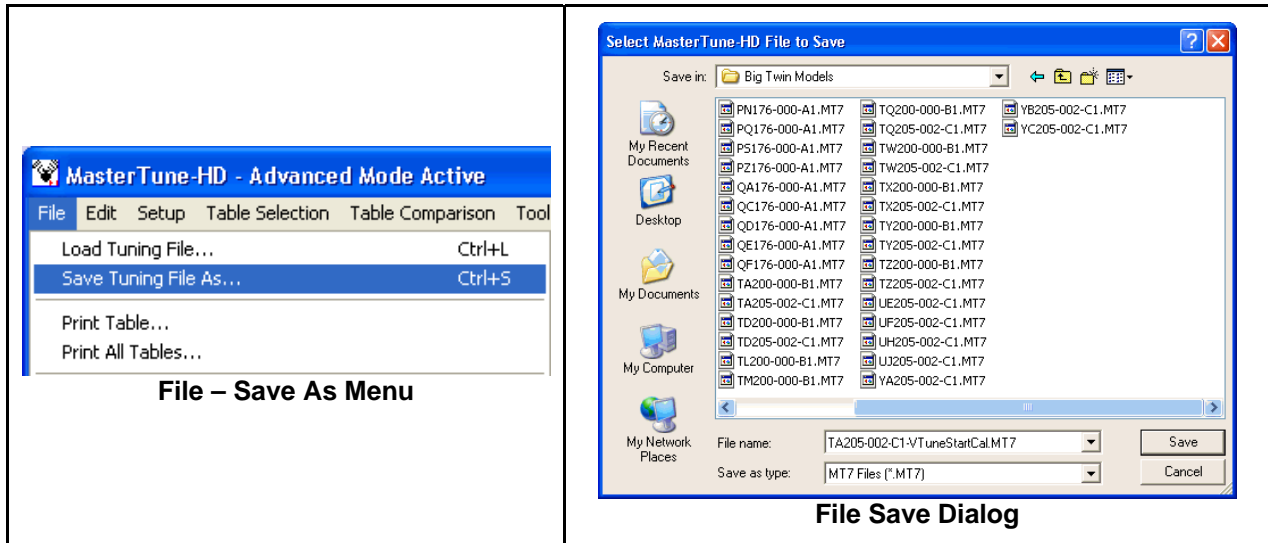
Figure 4-7: Saving the Calibration File

4.4. Program the Starting Calibration into the ECM

After you have created and saved your starting VTune calibration, you must program it into the ECM.   Refer to section 2.6 for instructions on programming the calibration into the ECM.

After programming is complete, exit the programming form and close the MasterTune application, your starting calibration has been programmed into the ECM!

4.5. Setup DataMaster to Record VTune Data

The next step is to use DataMaster to collect VTune data under a wide range of load and RPM conditions.

4.5.1. Open DataMaster for Recording VTune Data

Open the DataMaster program and from the main menu select *File – Record VTune Data*. A file dialog will be presented requesting a file name for this VTune data run. Use the default suggested name, or one of your own unique names you will remember.

Record VTune Data Menu

VTune File Dialog
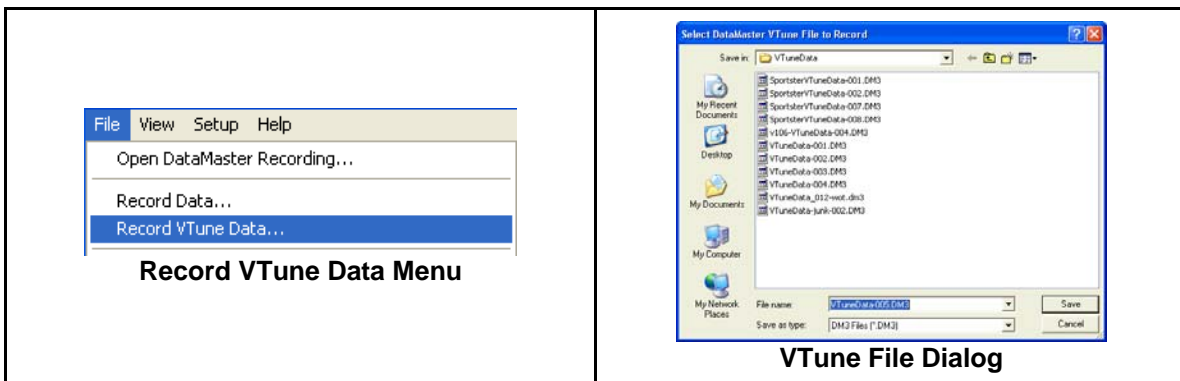
Figure 4-8: Record VTune Data

Click Save, and **two** windows will open: The **Data Recording Control** and the **VTune Recording Histogram**.

4.5.2.   Select the DataMaster Com Port

The first time you run DataMaster to record data, you must select the Com Port that is connected to the ECM interface. This usually is the same Com port that was used when programming the ECM. **Leave all the other settings as-is, as they have been preset for VTune data collection!**

4.5.3.   Check Communications to the ECM

Turn on the Ignition and handlebar switch and click *Get ECM Info* to test the communication to the bike. This will return the ECM PN, Cal ID, and VIN. If this reads OK, you're ready to get started. If there is a problem reading the ECM information, refer to section 7 for troubleshooting tips.
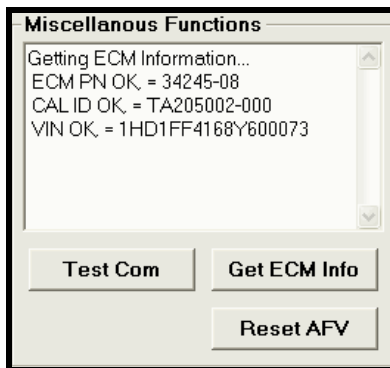
Figure 4-9: Get ECM Info

4.5.4.   Reset the AFV Cells

Next, click the *Reset AFV* button to reset the ECM's AFV (Adaptive Fuel Value) cells. This step is optional if the ECM was just programmed, as MasterTune automatically resets the AFV cells during each programming session.

4.5.5.   Select the VE Setup for your Bike Model

Click on the VTune Recording Histogram window to bring it to the foreground. Use the buttons in the upper left corner to select the setup for your bike: Big Twin, VRSC or Sportster. This sets up the axis breakpoints and the MAP and temperature monitor settings. Under Options, you can select either English or Metric **temperature** readout. **The Data Filter option must ALWAYS be enabled in order to tell if you are collecting usable data!**
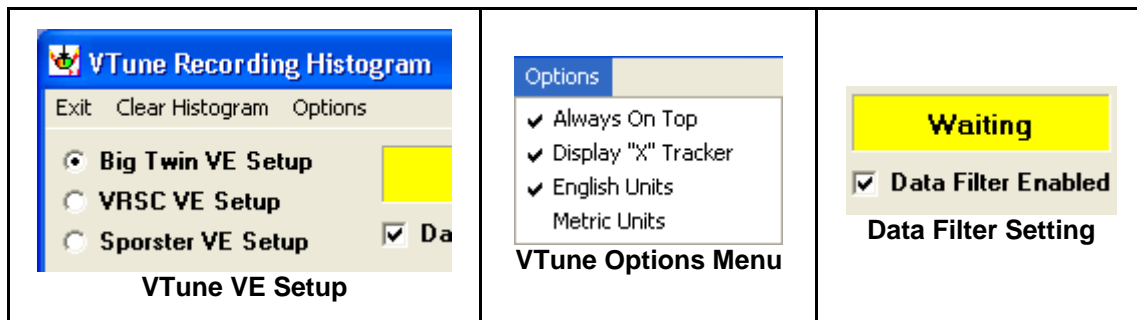
Figure 4-10: VTune VE Setup

4.5.6. Test VTune Data Collection

Start the bike, and click the "*START*" button to test VTune data collection. Note the VTune Start and Stop buttons are 'slaved' to the Data Recording Control window Start and Stop buttons, and either can be used to control logging.   The temperature and MAP fields will remain yellow until they are in normal operational range for the motor. When the temperature field turns green, the bike is ready to ride and collect your VTune data. You can start and stop data collection as much as you want during warmup, as the VTune program will filter out any data that does not meet test conditions.

Note: Lambda calibrations will automatically show a MAP axis rather than a TPS axis.
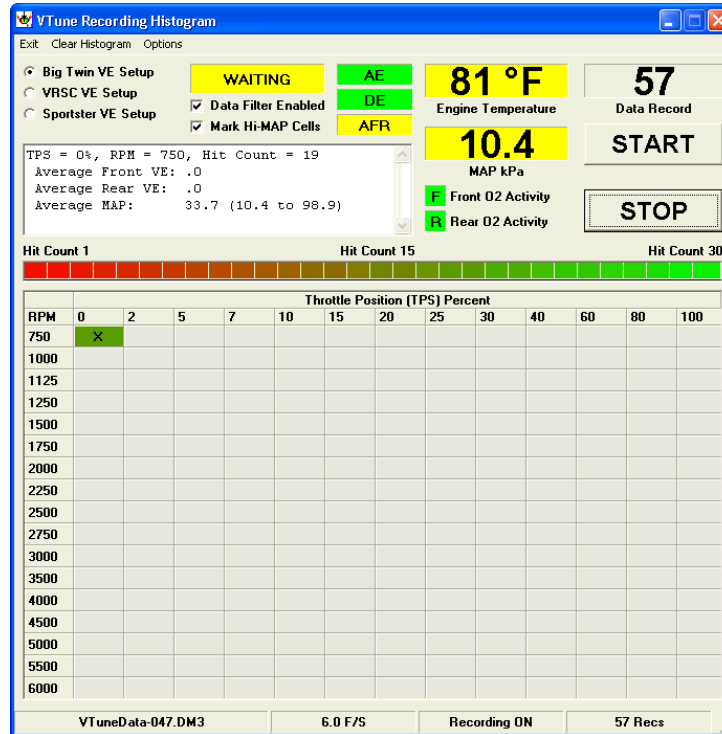
Figure 4-11: VTune Recording Histogram

4.6.   Collecting VTune Data

Once the vehicle is warmed up and ready, all the indicators will turn green and you are ready to ride and collect your VTune data. The "green" temperature will vary based on the model that is selected:

- Big Twin = 75 to 155 °C (167 to 311 °F)
- VRSC = 85 to 120 °C (185 to 248 °F)
- Sportster = 145 to 230 °C (293 to 446 °F)

Also, the MAP reading must be between about 26 and 85 kPa, or else the MAP display will be yellow and valid data will not be collected.
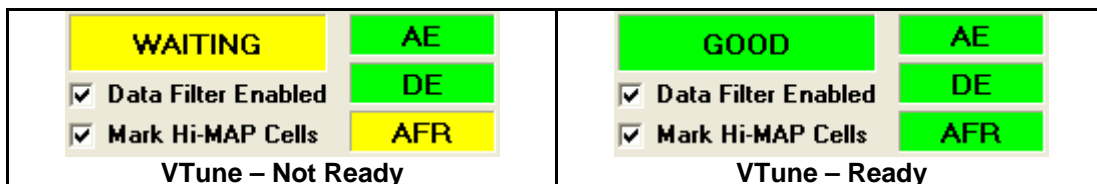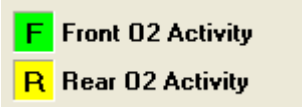
Figure 4-12: VTune Data Status

4.6.1. Start Data Collection and Verify VTune Ready Status

Click the "Start" button to begin data collection. Verify that good data can be collected by noting the "Waiting – Good" indicator has turned green. (This is available with DataMaster version 139 and newer)

F Front O2 Activity **R** Rear O2 Activity	Watch the O2 sensor activity monitor - If the O2 sensors are operating normally, both indicators will flicker between green and yellow at about the same rate.

If one of the indicators is "stuck" or sluggish, it indicates a problem with that O2 sensor. In this case, the "Waiting" status may be indicated and/or good VTune data may not be collected. This problem should be corrected before VTuning the vehicle.

4.6.2. Secure Laptop to the Bike

Close the lid on the laptop and secure it to the bike. Make sure all cables are tied up and will not interfere with vehicle operation!

4.6.3. Ride the Bike Collecting VTune Data

For safety reasons, VTune data collection should be done while riding on a closed course. When riding the vehicle, use a smooth driving technique and keep a steady hand on the throttle. The goal is to operate the bike in each load region for 5-10 seconds to collect stable data at each throttle position and RPM cell in the VTune histogram display. You can apply a bit of brake to increase the throttle percentage at a given RPM to collect data for higher load cells. DO NOT blip the throttle excessively, each blip will disable good data collection for several seconds!

The goal is to turn as many cells on the screen green as possible, which indicates enough data has been collected at each load point.

4.6.4. Stop VTune and Shut Off the Bike

When you have finished your ride collecting VTune data, stop VTune data collection and save the VTune file before shutting off the bike.

A typical VTune screen after 30 minutes of riding is shown below, Figure 4-14. For comparison purposes, a VTune run taken on a dyno is also shown. The Dyno run allows access to regions that are difficult to get and maintain during closed course riding – but, a closed course VTune session will cover 95 percent of your normal riding conditions!

After saving the DataMaster VTune file, exit the DataMaster application.

Tip: You can reload the file into DataMaster at any time and playback your histogram to see how your driving technique worked!
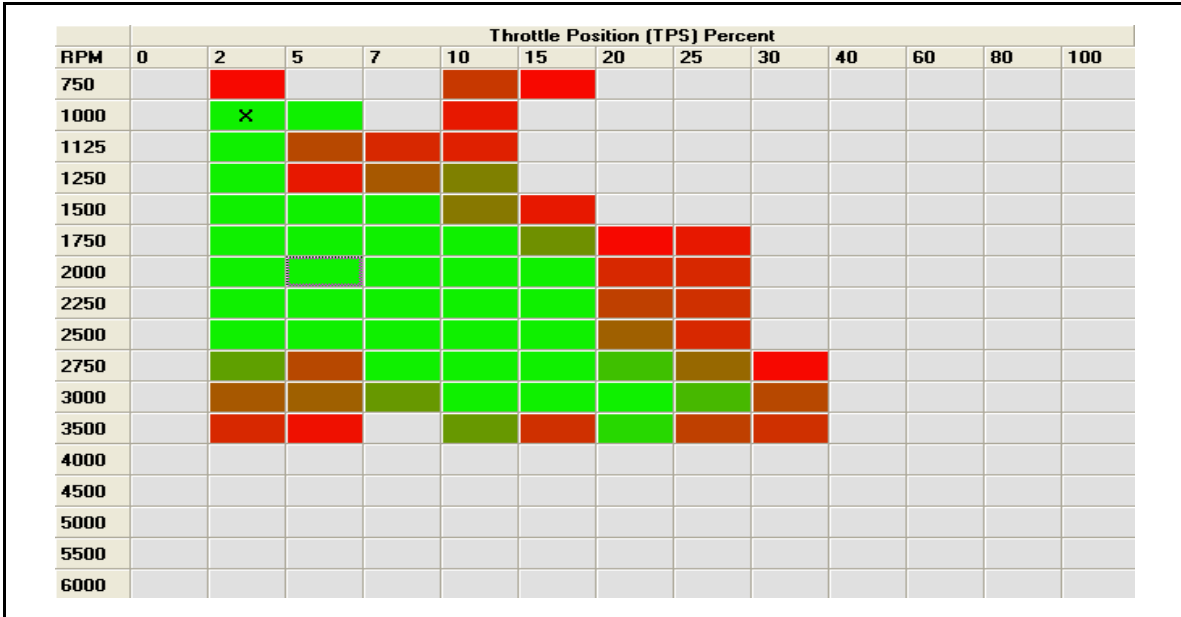
Figure 4-13: Closed Course VTune Data
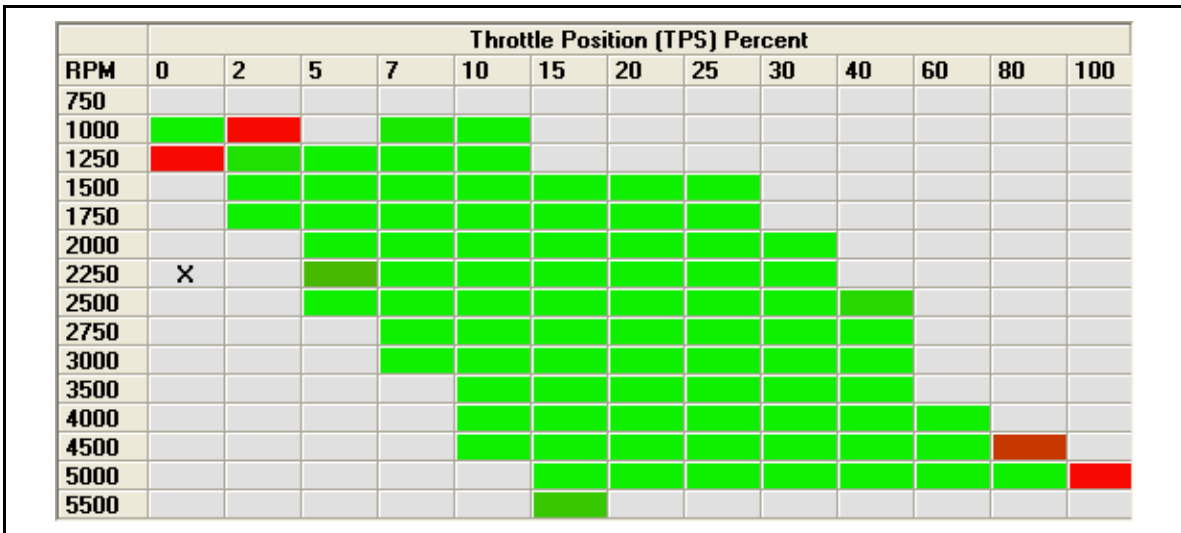
Figure 4-14: Dyno Generated VTune Data

4.6.5.   Note on VTune TPS and MAP Relationship

Notice that the VTune data does not include the lower-left and upper-right quadrants. This is completely normal! These are load areas the engine will not get to unless placed on a 'motoring' dyno. These areas of operation are rarely if ever accessed during riding.

When collecting VTune data, you will find it is not possible to get data in the upper right quadrant. The reason for this is that VTune data is not good when the MAP is above 85 kPa (this varies slightly with different calibrations). At low RPMs, the throttle only needs to be partially opened for the MAP to exceed this value. This results in the 'gray' cells in the upper right quadrant.

For similar reasons, it is not possible to collect data in the decel region, which is the lower left quadrant. In this case, VTune data is not good when the MAP is below 25 kPa (again, this varies slightly with different calibrations). As the RPM increases, it takes greater and greater throttle opening to keep the MAP above this limit. This results in the 'gray' cells in the lower left quadrant.

4.6.6.   Mark Hi-MAP Cells:

DataMaster v136 and later now shows the average MAP for any cell that is clicked on, and optionally marks cells if the average map is greater than approximately 80 kPa. This aids in quickly identifying if the maximum MAP was reached for each RPM row. A cell requires a minimum of 2 hits before it will be marked.
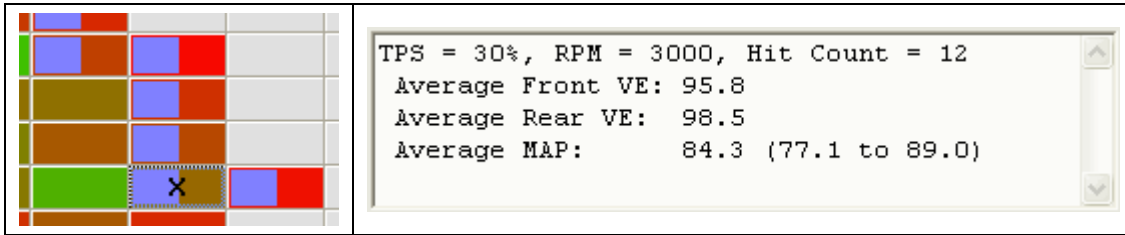
Figure 4-15: Histogram Cell Hi-MAP Marking

Figure 4-15 illustrates cells that have been marked with a purple band as having met the high MAP setting. Clicking on these cells will show the user the average, minimum and maximum MAP values recorded.

4.6.6.1.   Multiple Marked Cells in a Row:

The MAP value at a given throttle opening will vary somewhat based on engine load, i.e. uphill, downhill, wind, altitude etc. Because of this, it is normal to have multiple cells at the end of a row marked as shown in Figure 4-15. Click on each cell to display the actual MAP average for each cell. In the instance above, this yields the following results: (Blue text corresponds to 'marked' cells)

RPM	Throttle Position – MAP kPa		
	25	**30**	**40**
2250	**81.8 / 8 hits**	**88.6 / 2 hits**	no hits
2500	76.9 / 14 hits	**86.0 / 6 hits**	no hits
2750	72.2 / 11 hits	**85.3 / 9 hits**	no hits
3000	69.3 / 22 hits	**84.3 / 12 hits**	**86.4 / 2 hits**

If a cell only has a few hits, the values reported may represent transient events and are not representative of the stable longer term average. If the value looks out of order or is not following the data trend, you should not rely on it.

Section 4.11 contains details on how this information is used to finalize the VE tables.

4.6.7. Lambda-based VTune Data

When collecting VTune data for a Lambda-based calibration, the VTune axis will automatically reconfigure to use MAP as soon as data collection is started. This is because Lambda calibrations use MAP instead of TPS for the VE table calculations.

Manifold Pressure (MAP) kPa										
RPM	15	20	30	40	50	60	70	80	90	100
750										
1000			X							
1125										
1250										
1500										
1750										
2000										
2250										
2500										
2750										
3000										
3250										
3500										
3750										
4000										
4500										
5000										
5500										
6000										

Figure 4-16: VTune data for a Lambda-based Calibration

This particular example was collected on a Dyno. Note that with the Lambda calibrations, it is possible to fill in almost the entire rectangular area with good data!

4.7.   Generate New Calibration using the VTune Application

The next step is to use VTune to combine your VTune data with the calibration that is in the ECM to generate a new corrected calibration.

4.7.1.   Open VTune and Load DataMaster and MasterTune Files

Click on the VTune icon to launch the VTune program. This will present a window requesting two file names:
- The DataMaster (DM3) VTune file you just collected
- The MasterTune calibration that is currently programmed into the ECM

	Click the **"..."** buttons to the right of the file entry form to open the file browser where you can select your MasterTune and DataMaster files. Next, click the **Generate Tune** button to calculate the VE table correction based on this data.
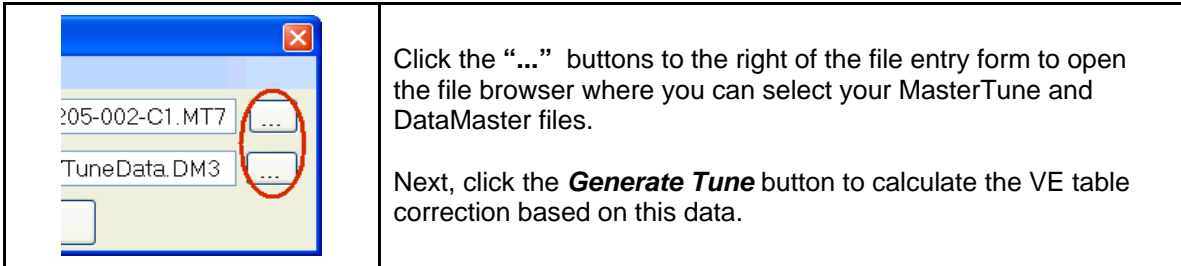
Figure 4-17: VTune File Selection
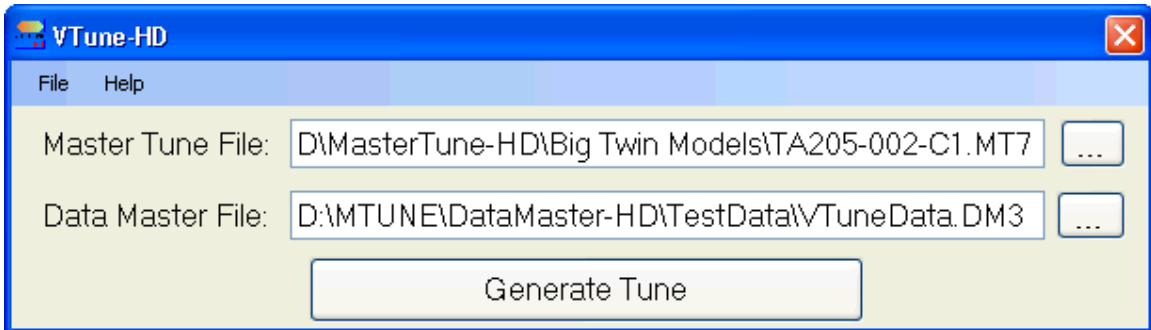
Figure 4-18: Loaded VTune Data Files

4.7.2.　View the VTune Correction Data

When the tune is generated, a window will be opened showing the proposed corrections to apply to the existing VE table. When the first VTune correction is made, there will usually be considerable correction to apply as indicated by the **red** cells in the window:
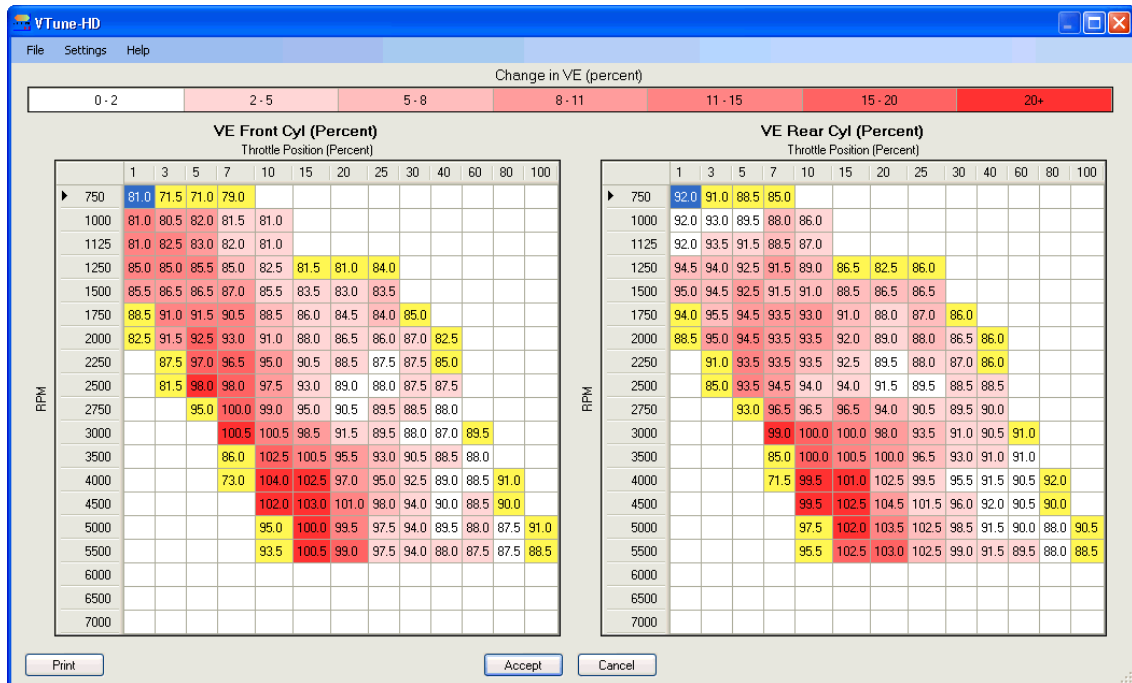
Figure 4-19: VTune Initial Correction Data

Starting with VTune version 1.3.3, a yellow color has been added to mark cells where not enough data was collected for a proper correction. What this means is that some correction has been applied, but it is not enough to get to the final VE value the cell should have. The Tuner should use this information in conjunction with observing the shape of the data graph in MasterTune to determine how to smooth or extend the VE data into these cells.
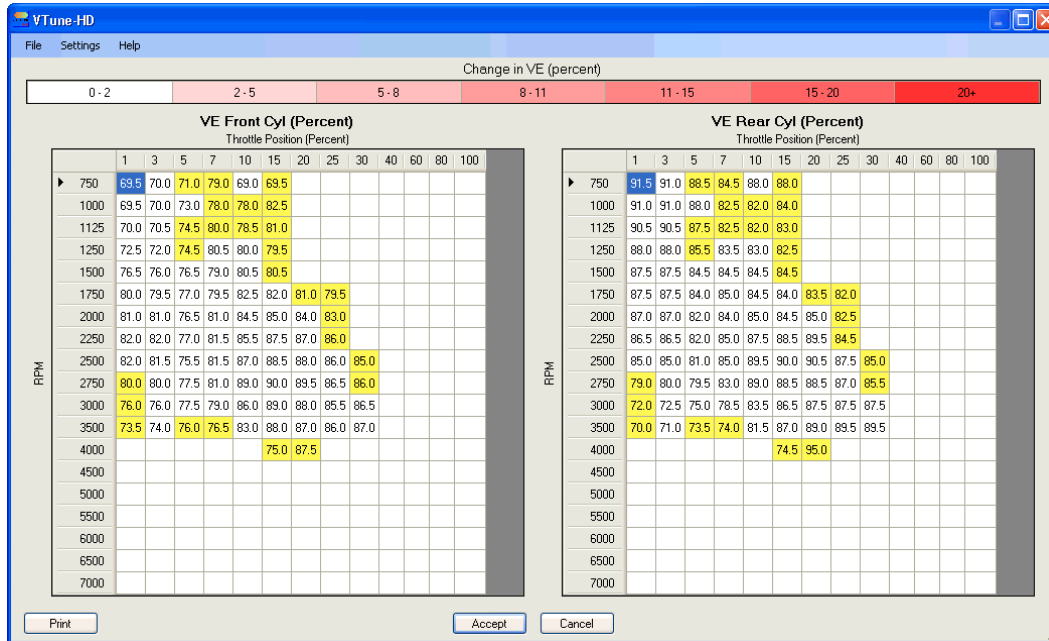
Figure 4-20: VTune Final Correction Data

For comparison purposes, the final VTune run is also shown here after several VTune iterations. The final result is very close to ideal. Note that the yellow indicates the Tuner should look closely at the VE data in those cells to make sure it is a smooth fit with the expected VE data trend in that region.

There is no hard and fast guideline for what constitutes a "good" data run, but in general a good data run will only have yellow cells on the edges of the collected data. The following VTune result (Figure 4-21) shows a high percentage of yellow cells, extending beyond the edge and into the middle of the collected data area. **A data run with this pattern has insufficient good data and should not be used to generate a VTune calibration**.
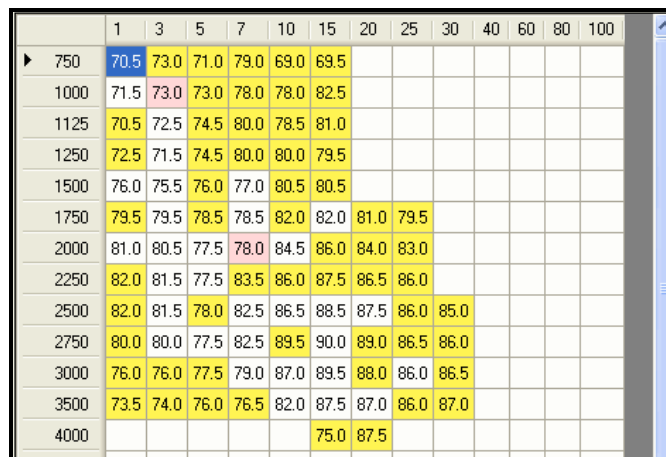
Figure 4-21: Poor VTune Data Example

4.7.3.   Print and Save the New VTune Calibration

Expand the form such that it shows all the cells that VTune has changed, and use the Print button to print a screen shot of your VTune changes. This is not always necessary, however it gives some data that can be used later to estimate your VE values in areas outside of the area corrected by VTune.

Click the *Accept* button to generate a new MasterTune calibration file. Give this file a name you will remember, as you will be programming it into the ECM as your next step!

4.8.   Program the New Calibration into the ECM

The final step is to program the NEW calibration you just generated with VTune back into the ECM. This will become your NEW starting calibration! Follow the same steps outlined in section 2.6 and program the new calibration into the bike. This will be the NEW starting point for your next VTune session!

4.9.   Repeat the VTune Procedure 2 to 3 times

Repeat steps 4.5 through 4.8 until the VTune correction is in the 2 percent region. This will usually take two to three more sessions. It is normal to have 2 percent fluctuation or so between your VTune runs and when your correction is less than 5 percent it is acceptable.

4.10. Restore the AFR and PE Settings to Original

When you have completed your final VTune correction, you **MUST** restore the original AFR table that was supplied in the calibration. Otherwise, the engine may run too lean for extended high-load operation.

1.   Load the final VTuned calibration into MasterTune
2.   Select the **AFR** table
3.   Click on the upper left corner to select the entire table
4.   Click the "*Set to Original*" button

Next, under *Table Selection*, select the "*ECM Tuning Constants*". On the tabbed dialog in the right pane, select "**PE Mode**" and set the RPM to back to its original value by pressing the "*Set to Original*" button. This is typically 4500 RPM. Note that Sportster cals do not currently support this option.

These are the only two items that need to be returned to their original settings.

At this point, save your final file edits and program it into the bike. Enjoy your VTuned ride, or proceed with the optional steps if desired.

4.11. Optional: Finalize the VE Table Values

For those who wish to fill in areas of the VE table not covered by the VTune procedure, use this method to estimate the remaining VE table cells. Apply this technique to BOTH the front and Rear VE tables.

Now, understand if you could not get the motor into these regions during your VTune riding, does it really matter what is in those cells? This is for the people who want to get everything they can, and by using the last known good value from V-tune you will be extremely close.

This requires using DataMaster to review the final VTune data log and MasterTune to edit the resulting VTune calibration as follows. This requires using your **last** VTune data and Calibration File pair.

1. Load the final VTuned calibration into MasterTune
2. Load your last VTune recording into DataMaster
3. Select the front VE table, then select the **Compare Edits to Original** option. This will show the corrections that VTune made to the original TTS calibration. You can also use the VTune Screen Prints you saved in step 7.
4. Look at the right-most cell in each RPM row corrected by V-tune. Scroll through your VTune recording looking for that RPM and TPS region and determine if the MAP has reached 80 kPa or above.
5. If the kPa at that RPM and TPS setting is 80kPa or above, take the last VTuned cell value and fill in the remainder of that RPM row. If there is a "trend" to the data here, you can just follow the trend out to the end of the RPM row.
6. When your edits are finished, save the file and program it into the bike. Enjoy your ride!

Tip: The DataMaster VTune histogram now has an option to show the average cell MAP values that occur during a VTune run, and mark all cells which get up to the 75-80 kPa range. Use this information to aid in determining the TPS for each row that gives you the 80 kPa value.

Example of Right-Extending the VTune Row Values
In this example, the **highest** TPS VTune row value for the first 4 RPM rows are as follows:

RPM	VE	TPS Percent
750	69.5	15
1000	82.5	15
1125	81.0	15
1250	79.5	15

This shows the final VTune values that were applied to the calibration.

Next, view the final VTuned calibration and locate the right-most cells in each row that VTune corrected, Figure 4-23. In this example, this will be at 15% throttle position.

Figure 4-22: Final VTune Correction Screen

Figure 4-23 shows the VTuned file loaded into MasterTune:

RPM	Throttle Position (Percent)												
	1	3	5	7	10	15	20	25	30	40	60	80	100
750	69.5	70.0	71.0	79.0	69.0	69.5	81.5	81.0	80.5	79.5	79.0	79.0	79.0
1000	69.5	70.0	73.0	78.0	78.0	82.5	82.0	82.0	82.0	80.5	79.5	80.0	81.0
1125	70.0	70.5	74.5	80.0	78.5	81.0	83.0	83.0	83.0	81.5	80.5	81.0	82.0
1250	72.5	72.0	74.5	80.5	80.0	79.5	79.0	84.0	84.0	83.0	82.0	83.0	84.0

Figure 4-23: VE Table in MasterTune Before Row Extend

In Figure 4-24, the 4 rows have been extended from the 15% column all the way to the 100% TPS column. Because the data trend for each row is fairly flat, the last VTune value is used to fill each TPS position moving right.

NOTE: Only extend the row from the cell where the kPa is 80 kPa or above(75 kPa for Lambda-based cals)!

RPM	Throttle Position (Percent)												
	1	3	5	7	10	15	20	25	30	40	60	80	100
750	69.5	70.0	71.0	79.0	69.0	69.5	69.5	69.5	69.5	69.5	69.5	69.5	69.5
1000	69.5	70.0	73.0	78.0	78.0	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5
1125	70.0	70.5	74.5	80.0	78.5	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0
1250	72.5	72.0	74.5	80.5	80.0	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5

Figure 4-24: VE Table in MasterTune After Row Extend

To determine where the MAP values exceed 80 kPa, load the final DataMaster VTune recording and select the *View - VTune Histogram* menu. Press the start button and let the entire file playback, filling in the histogram. When finished, cells that exceed the Hi-MAP threshold will be marked with a purple bar. This gives a quick indication of where to look in the VE table for the value to row-extend. Click on the cell in the DataMaster VTune histogram to give you the average MAP in the information window.


```
TPS = 30%, RPM = 3000, Hit Count = 12
 Average Front VE: 95.8
 Average Rear VE:  98.5
 Average MAP:      84.3 (77.1 to 89.0)
```
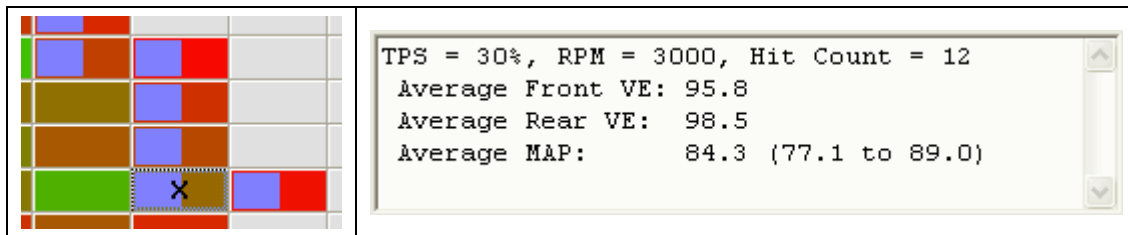
Figure 4-25: Histogram Cell Marking and Statistics

The MAP value at a given throttle opening will vary somewhat based on engine load, i.e. uphill, downhill, wind, altitude etc. Because of this, it is normal to have multiple cells at the end of a row marked as shown in Figure 4-25. When there are multiple cells marked, look at the hit count and the associated VE table values for the cells. Giving more relevance to the high hit count cells, look at the VE data trend for the marked cells and from that you can estimate what a good VE value to extend is.

After you do this a few times, it will become intuitive what to do!

Note that both the front and rear cylinders must be independently blended – each table applies to only that cylinder.

4.12. Using the VTune Auto-Extend Option

Starting with VTune version 1.6.0, an option has been added to automatically right-extend VE table rows if enough 'good' data is collected. This option is presented after the "Generate Tune" button has been pressed:
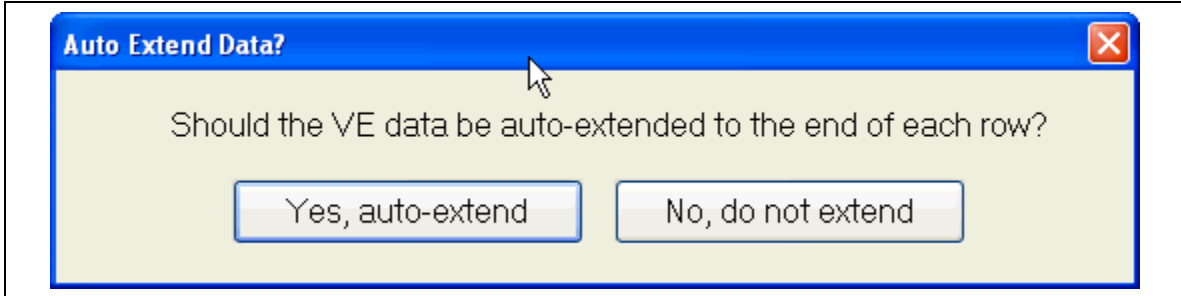
Figure 4-26: The Auto-Extend Dialog

Press **Yes** to Auto-Extend the VE data rows. VTune will examine the data collected in each row, and if the cell data has reached 80 kPa and there are enough "hits", the cell value will be automatically extended to the right edge of the table. Note that the color of the extended cell is maintained throughout the extended region.

The following screen capture illustrates a typical VE table before and after row extension:

Figure 4-27: VE Table Auto-Extend Result

Here is the DataMaster VTune histogram data that created the above VE table:
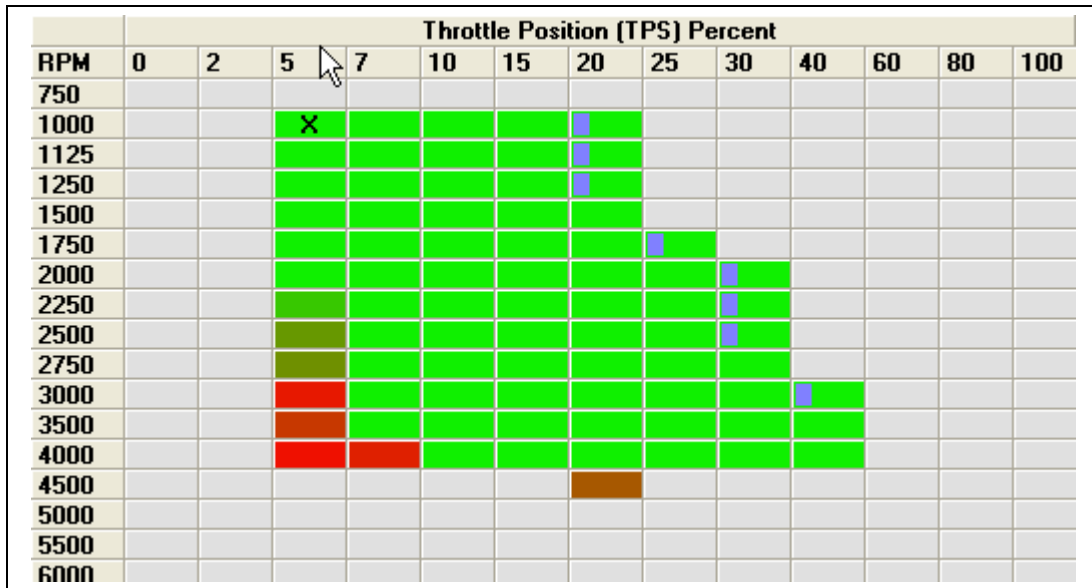
Figure 4-28: DataMaster VTune Histogram Data

Notes:
VTune uses a 2-D data interpolation scheme when populating the VE table. For this reason, data may be shown in VTune cells where DataMaster does not show any data was collected. For instance, in the above example the DataMaster histogram does not show any data in the 750 RPM row, while VTune has no problem making corrections and filling in the values for that row. **This is because VTune corrections are applied to <u>ALL</u> the nearest cells at the actual RPM and TPS/MAP the data was recorded at!**

The row at 2750 RPM **WAS NOT** extended. This row did not get enough data at 80 kPa to allow extension.

The row at 1500 RPM **WAS** extended, even though the DataMaster histogram shows no 80 kPa cell marker. Again, this is because VTune applies corrections to all adjacent cells, and has determined there is enough data to allow the extension.

4.13. Optional: Make AFR and Timing Adjustments

When the VTune process has been completed, the VE tables now accurately model the engine's air flow. The user can now adjust the AFR table for richer or leaner mixture in the various load regions. This way, the desired balance of economy and performance for this engine build can be obtained. After AFR is set, the user can then move on to fine-tune the timing.

Note: If you change any AFR cell to a value other than 14.6, the ECM will not be in closed loop for that cell region! For Lambda cals, a cell in closed loop will be marked by bold text and a vertical bar on the cell's left edge.

4.13.1.   Calibrating the Main Spark table

The Main Spark table can be calibrated using DataMaster to monitor for knock retard.   The Delphi ECM uses "Ion Sense" technology to detect knock even before there is an audible "ping". When knock is detected, the Fast Knock Retard will remove several degrees of timing advance. If the knock continues, the system will continue to remove timing until the maximum knock retard limit is reached, typically 8 degrees.

Adjusting the spark from a DataMaster log works very well but it requires some trial and error. Basically, one looks for any knock and then makes a slight timing adjustment to make it disappear.

Before starting, set the **Adaptive Knock Retard** table (Figure 3-29) to zero to prevent interference with this procedure. Program this calibration into the bike, and begin your testing.

First, make a data run monitoring for any signs of knock retard. Review the DataMaster log, and remove timing in any MAP / RPM regions that shows spark retard activity.

Next, add 2 degrees timing everywhere below 80 kPa. Make another data run and make the necessary adjustments where knock occurs. As you add and remove timing from the areas that ping you will begin to shape the spark curve to what your bike wants/needs. Once you get to where it just barely wants to ping at most settings, reduce spark by 3 degrees across the board, this is your safety margin.

This will let you tune without a dyno but doesn't adjust above 80kPa. Once you have the spark map close, take the values you have at 80 kPa and extend them over to the right on the map following the existing trend. Go make your WOT runs and adjust what you see based on the knock retard. This will get you 95% complete, and the last 5% is best done on a dyno. As the weather warms up and you note some pinging, go to the Spark Temperature Correction table and remove some timing from the proper cells. This will give you the best possible tune under all conditions.

It is best to not have any retard at all because the system will tend to take out more timing than is necessary and hold it out for several seconds.

Example: The retard system shows 4 degrees of retard happening. The tuner removes 1 degree of timing from the main spark table and this completely stops the knock retard from occurring. So, your net gain is 3 degrees timing advance compared to what the retard system did. This 3 degree improvement will give a nicer running engine and better fuel economy.

After finishing the spark table adjustments, restore the **Adaptive Knock Retard** table to the original settings.

Once you've finished the spark adjustments go back and run V-tune one more time as the correct spark can cause the mixture to change a small amount. Using this method you can generally get to within 3 HP of what we get using a dyno.

4.13.2.   Note for Sportster Spark Table calibration

Sportsters do not have a knock retard system. Knock detection must be "by ear" on these bikes. When logging data, you need to find a way to mark the area when you heard the pinging. One way to handle this is when you hear the ping, pull in the clutch and quickly free rev the motor. When you get back from the test ride, look at the data and follow along looking for the rpm to jump up and you know that the ping you heard was just before that. Look at the MAP and RPM, and adjust that part of the spark table. Once you get the hang of it, it goes quickly.

4.14. VTune Flow Chart

1 Select Starting Calibration

2 Load Selected Calibration into MasterTune

3 AFR or Lambda Cal?

AFR

Lambda

4A Select *'AFR'* table and set to highest value possible (mostly 14.6)

4A (Lambda) Select *'Main Lambda'* table and set all values that allow to 0.981

4B Select *'Closed Loop Bias'* Table(s) and set to desired level

4C Select *'Accel Enrichment'* Table and set all values to zero

4D Select constant *'PE Mode'* and set RPM to 10000

4E Make any other changes required for your setup

4F Save the calibration file under a new name of your choice

5 Program the new Calibration file into the bike and close MasterTune

6 Open DataMaster and select *File – Record Vtune Data*...

7 Create a VTune file name or use the Default file name

8 Set COM port number and with the key on click *Get ECM Info*

9 Reduce the Data Recording Control window by clicking the '-' button

10 Start the motor and click the *Start* button on the Vtune Recording Histogram Window

11 Dyno test or ride motorcycle to gather data in the Vtune recording

12 When finished gathering data, click *Stop* and exit DataMaster

13 Open Vtune Program

14 Click button and load MasterTune file from step **4F**

15 Click button to load DataMaster File from step **7**

16 Click the *'Generate Tune'* button

17 Review the generated VE tables and click the *'Accept'* button

18 Name and Save your new calibration with a NEW name

19 Repeat process from step 5 onward until change in VE values are 5% or less

Change less than 5%?

NO

YES

20 Restore changes made in sections **4A, 4C, 4D** to original values

21 Save final calibration file and program into motorcycle

Figure 4-29: VTune Flow Chart

5. Using the CamTune Feature

5.1.   Introduction

Beginning with MasterTune version 1.7, the "CamTune" feature was added to aid the tuner in setting up a calibration for use with different camshafts. This is done by adjusting settings for the Intake Valve Opening (**IVO**) and Intake Valve Closing (**IVC**) timing.

NOTE: CamTune is only available when using MT8 calibration files; at this time only the BigTwin calibrations have enabled this feature.

The CamTune feature is accessed using the ***ECM Tuning Constants*** menu selection and selecting the ***Cam Selector*** tab:

Figure 5-1: CamTune 'Cam Selector' form

For BigTwin engines, there are 7 possible settings for the IVO timing, and 3 possible settings for IVC timing.

Note: The available settings may change with different calibrations and engines.

To help determine which settings to use, use the built-in estimator by clicking the ***Estimator*** button:
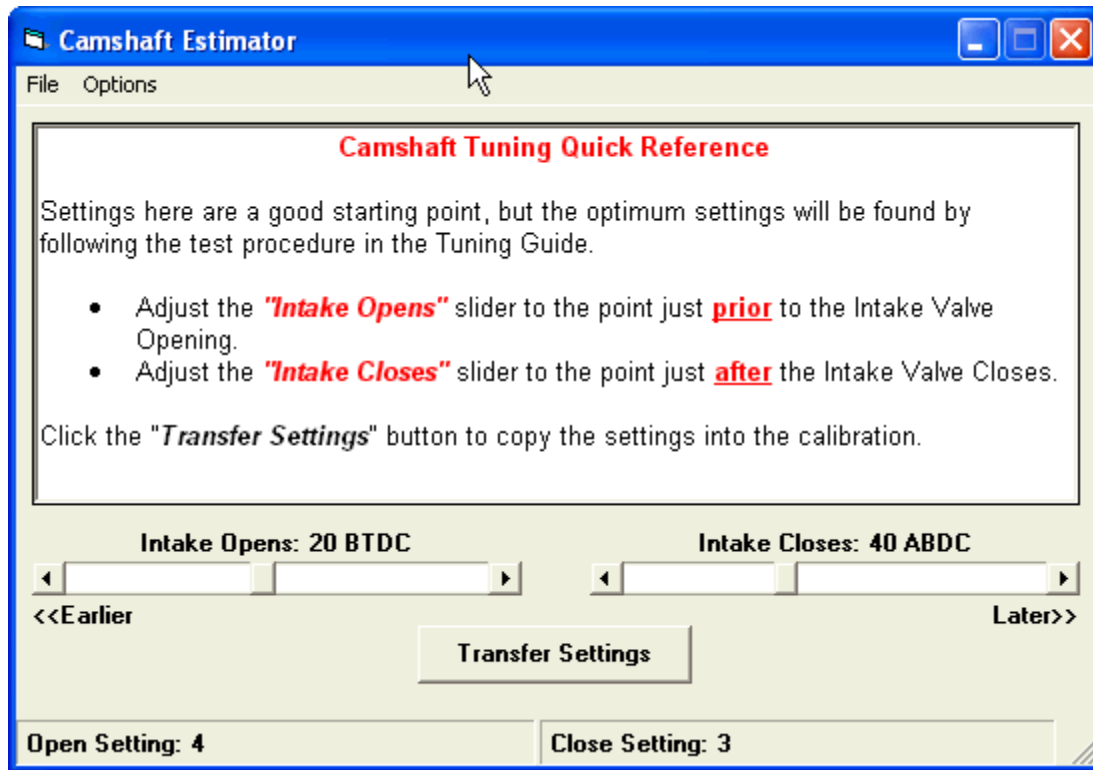
Figure 5-2: The Camshaft Estimator Form

The camshaft estimator provides a starting point for determining the best CamTune settings; however, due to the great variety in camshaft designs (and related engine components) there is no hard and fast correct setting to use.

- Adjust the *"Intake Opens"* slider to the point just **prior** to the IVO event
- Adjust the *"Intake Closes"* slider to the point just **after** the IVC event

The Open and Close settings are indicated on the bottom status bar - Click the **Transfer Settings** button to copy the settings to the calibration.

The estimator will get you in the ballpark; then use DataMaster CamTune data collected on the Dyno to finalize the settings.

Note:
These settings affect airflow and pressure calculations within the ECM, so when changes are made the VE, AFR and Spark table settings need to be verified. One of the goals of changing the camshaft settings is to flatten out the higher load regions of the VE table; VE MUST be recalibrated when CamTune setting changes are made.

5.2. Setting-up to Record CamTune Data
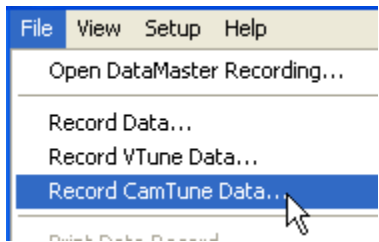
To record CamTune data, it is recommended that the user select the Record CamTune Data from the main form menu. This will preset all data recording options to the correct values for recording CamTune data.

A File Dialog form will be presented, and the user must select a file for saving the CamTune data to. Note that the file dialog will automatically generate a sequential filename in the form of **CamTuneData-xxx.DM3**, where **xxx** is a sequential 3-digit number. Each time CamTune data is recorded, the next sequential file number will be used.

By default, CamTune data is saved in the users' *My Documents\TTS\HD\DataMaster-HD\CamTuneData* folder.

Upon accepting the filename, the standard Data Recording Control form will be opened. The Data Recording Control will be correctly configured unless a COM port has not been selected (refer to Selecting The Com Port). To manually configure the Data Recording Control for CamTune data, see the section below "Manual CamTune Data Configuration".

Note: CamTune data requires that an appropriate MT8 calibration be installed in the vehicle. If the MT8 calibration is not present, any collected data is invalid.

There are two basic types of CamTune recordings that need to be made, one for determining the Intake Valve Opening (**IVO**) setting and the other for Intake Valve Closing (**IVC**) settings. Both these recordings use the identical DataMaster data, but the bike is operated differently for each.

5.2.1. Manual CamTune Data Recording Configuration:

If the user desires to manually collect CamTune data, the following recording options must be selected:

- *Data Type* is set to *Cam Tune Data*
- Recording Speed is set to 20 Frames/Sec
- *Options - Collect Set DTC's during Data Recording* is **NOT** checked
- *Options - Advanced - Allow DataMaster Exclusive Bus Access* is **NOT** checked
- *Options - Advanced - Notify if OS and Data Type Selection Mismatch* is **NOT** checked

5.3. Intake Valve Opening (IVO) Data

5.3.1. Recording IVO Data:

IVO data is recorded with a stationary bike during warm idle. The bike should be at normal operating temperature when the recording is made. The idle speed must be between **900** and **1100** RPM to collect valid data. The rider should collect data for a few minutes, then stop the recording and turn off the bike. The recorded data should look similar to the following picture:
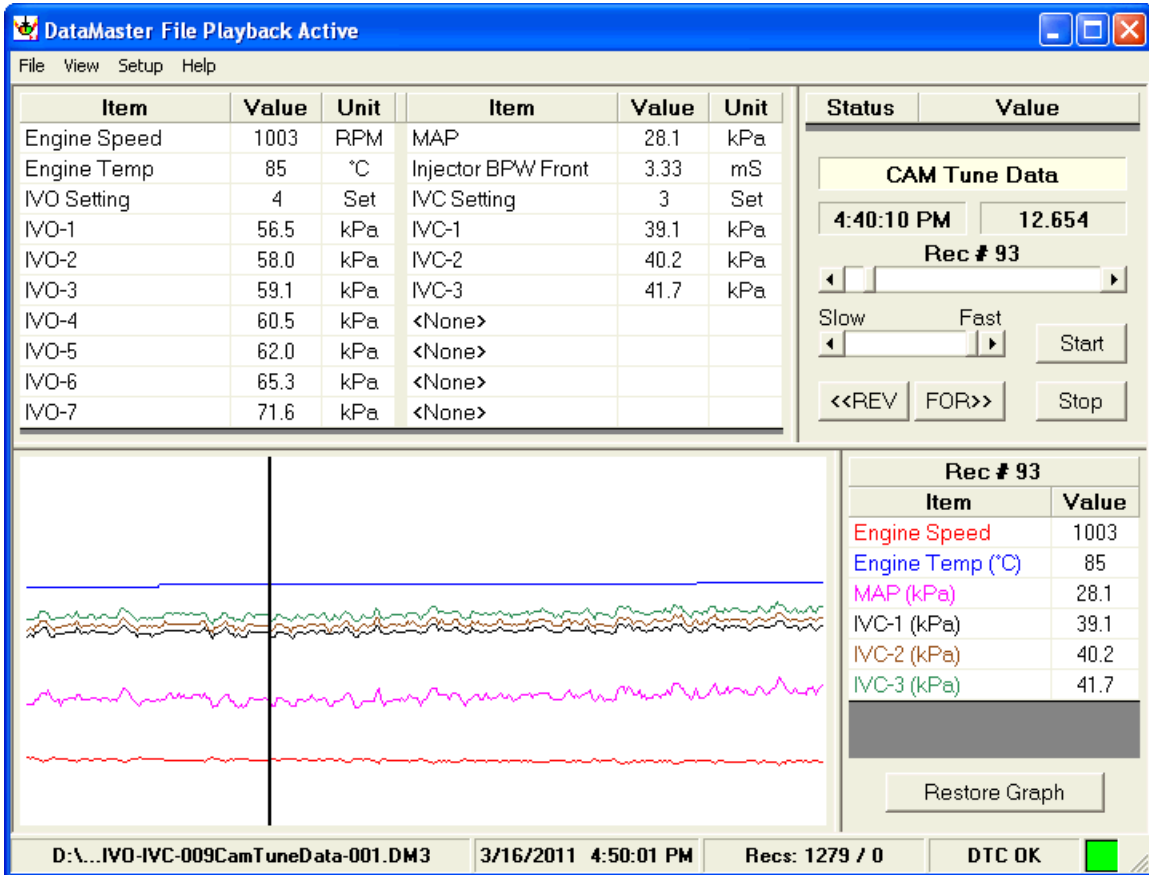
Figure 5-3: CamTune "IVO" data recording at idle

5.3.2. Analyzing IVO Data:

To analyze the IVO data in this run, select the View - Camshaft Analyzer – Opening menu:
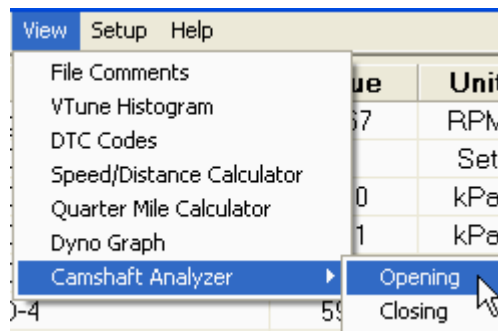
Figure 5-4: Camshaft Analyzer Opening Menu
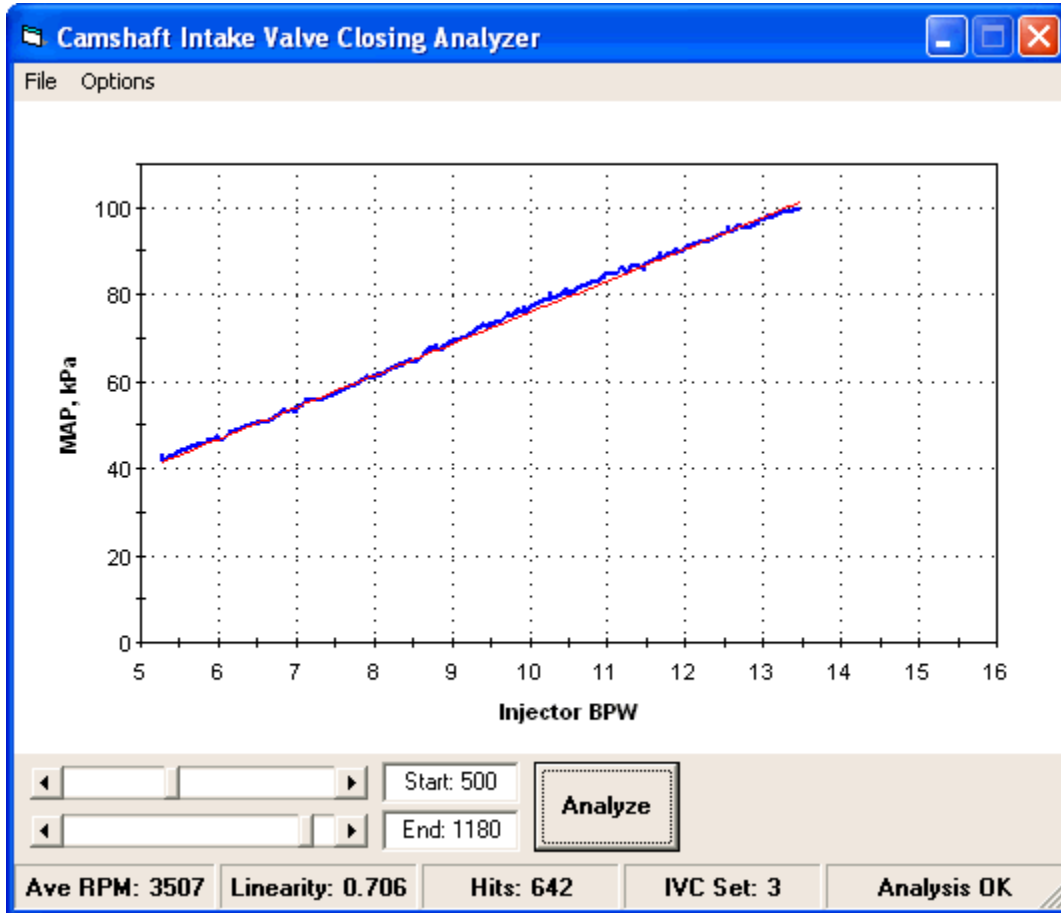
This will bring up the IVO analysis form:
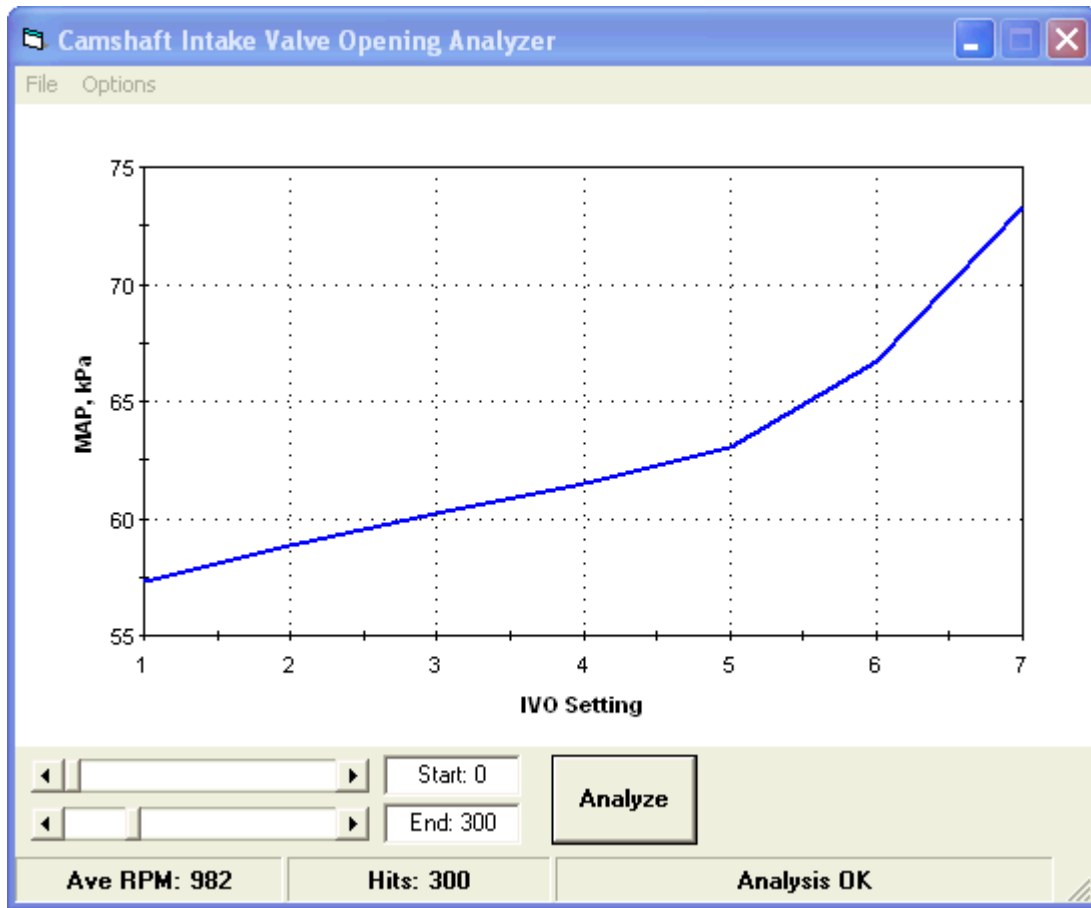
Figure 5-5: IVO Data Analysis Graph

Select the starting and ending record of the recording you desire to analyze, or use the default which selects all records. Click the Analyze button to analyze and plot the data. The analysis will automatically filter out any records with RPM outside of the 900 to 1100 RPM range.

5.3.3. Determining Intake Valve Opening (IVO) Setting:

To determine the optimum IVO setting, view the above graph and find the point at which the curve "breaks" and begins to head up at a steeper angle. That point should be the optimum IVO setting to use in the calibration. Note that in this example, the optimum setting is 5 as that is the "Inflection Point" at which the graph first heads upward. It is also permissible to set this one less (i.e. 4) using your judgment.
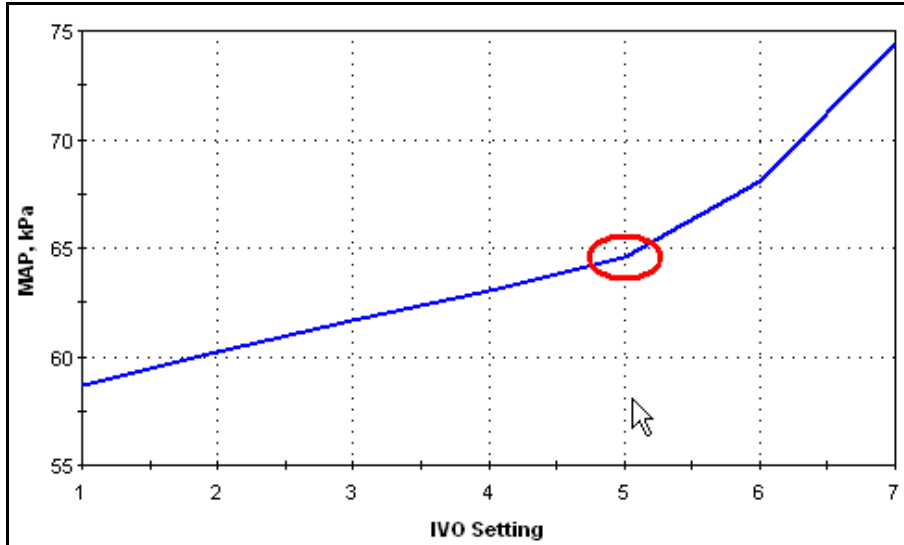
Figure 5-6: IVO Setting "Inflection Point"

5.4.   Intake Valve Closing (IVC) Data:

IVC data is recorded with a stationary bike under load on a dyno. The bike should be at normal operating temperature when recording is made. Separate recordings must be made for **each** of the three IVC settings the calibration allows.

Calibrations **must** be set-up for open-loop at an AFR setting of 13.0 (Lambda = 0.886) and the VE tables properly calibrated to give this AFR across the entire test load range. Once this is done, CamTune data is recorded at a constant RPM of 3500 RPM (±50 RPM), varying the load on the dyno such that the MAP kPa ranges from about 60 kPa to 100 kPa. Collect data in load steps of 3-5 kPa holding the load constant at each point for roughly 3 seconds. Continue this sweep until 100 kPa is reached. The recording time will require 1-2 minutes.
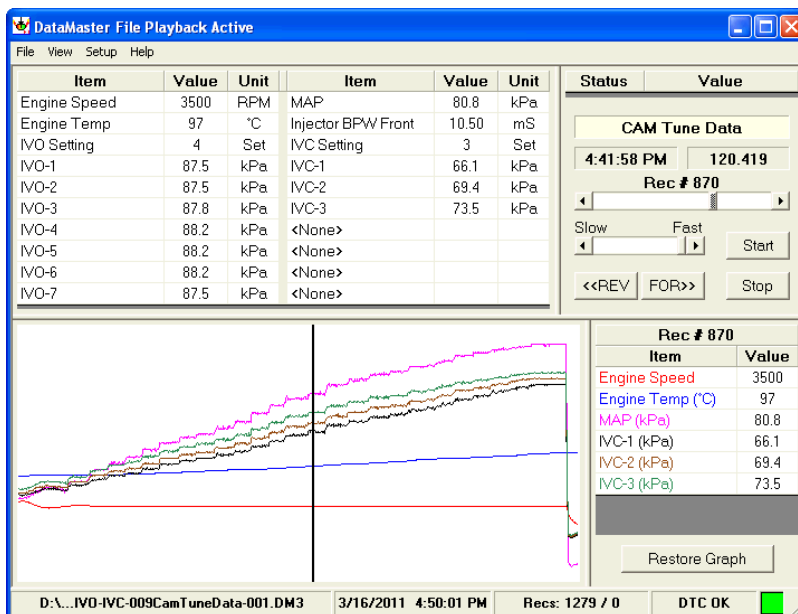
Figure 5-7: CamTune IVC Data Recording on Dyno

Perform this recording for each ICV setting the calibration allows. Note it is critical that EACH calibration be set-up for a true 13.0 (or Lambda = 0.886) setting. Each calibration must be individually validated for AFR when the IVC setting is changed.

5.4.1. Analyzing IVC Data:

To analyze the IVC data in this run, select the **View - Camshaft Analyzer – Closing** menu. This will bring up the IVC analysis form:

Figure 5-8: IVC Data Analysis Graph

Select the starting and ending record of the recording you desire to analyze, or use the default which selects all records. Click the Analyze button to analyze and plot the data. The analysis will automatically filter out any records with RPM outside of the 3500 RPM (±50 RPM) range and with BPW less than 5.0 mS.

Print a copy of the graph using the IVC **File – Print** menu. You will need this to visually compare the IVC settings.

5.4.2. Determining Intake Valve Closing (IVC) Setting:

After all the IVC calibrations have been recorded, the three graphs are compared for linearity in the 10 to 16 mS BPW range. On the graph, the thin red line is the best straight-line fit of the collected data, and the thicker blue line is the actual data that was collected.

Compare the three graphs you printed out, and determine which one shows the straightest fit to the red line in the 10 to 16 mS BPW region. The setting that generates the straightest line in this region is the optimum IVC setting for the calibration.

The status bar *Linearity* panel indicates the overall linearity of the data; lower numbers indicate a better fit of the data.

<<< GRAPHIC NEEDED >>> A: IVC = 0 Setting	<<< GRAPHIC NEEDED >>> B: IVC = 1 Setting	<<< GRAPHIC NEEDED >>> C: IVC = 2 Setting
Figure 5-9: IVC Setting Graph Comparison		

In this example, the "A" IVC = 0 setting shows the best linearity, so this is the optimum setting for this calibration.

6. Common Tuning Problems

6.1. VE Table Entries Maxed Out:

When calibrating the VE tables, occasionally the table values will max out. The best way to handle this problem is to increase the engine displacement setting constant. This affects many other settings, so if you anticipate this problem make the change early in the tuning process. Do not change the displacement any more than necessary to get the VE table into range. A good starting place would be to increase the displacement by 5 percent, and decrease both VE tables by 5 percent across the board. Rerun the VE table calibration and verify that the peak VE is now under the maximum limit.

If you are using a calibration that supports the EGR Effect tables (these are MT8 or later files) and the high VE values are at 60kPa or less, the recommended procedure is to adjust the EGR tables to reduce the VE value **PRIOR** to making any engine displacement setting changes. Refer to section 3.13 for further information.

6.2. Exhaust Popping on Deceleration:

Exhaust popping on deceleration is due to a too lean or too rich mixture in the exhaust. This can be caused by a leaky gasket, or by the AFR being set incorrectly by the ECM. Most commonly, the mixture will be too lean.   The ECM has three tables which affect this: The Decel enleanment, the AFR table, and the VE table.

The Decel Enleanment table only acts for a short time (ie 1-2 seconds) after the throttle is closed. To richen the mixture during this time, decrease the value in the table at the temperature the problem occurs.

To richen or enlean the mixture during the entire decel event, the recommended way is to change the AFR table in the in the first column (20 kPa between 1750 and 3500 RPM by 5 to 10 percent. Some experimentation here will find the sweet spot that eliminates the popping.

In the past, others recommended to change the VE table values to eliminate this popping. This will also work, however since changing the VE table has many other effects on engine operation, we do not recommended it.

Tip: To determine the MAP and RPM that is causing the popping, use the following procedure to "mark" the data recording.

1. Set-up DataMaster to record generic or O2 data
2. When you are riding and the popping occurs, pull in the clutch and let the engine revs drop to idle
3. When you play back the data, look for the idle spot at speed. The MAP and RPM that caused the popping are right before this.

Another way to mark a recording is to pull the clutch in and rev the motor twice quickly. Find a method that works best for your situation!

6.3. Engine Runs Hot at Idle

Many late model bikes run very hot at idle, and will overheat if stationary for too long a period.

The latest MasterTune calibrations have significantly improved heat management capability over the earlier and stock calibrations. It is recommended to use these cals wherever possible, and enable the EITMS system if heat buildup during idle is a problem.

The EITMS system is an option on most calibrations. The EITMS system was developed to reduce heat buildup during prolonged idling times and controls heat buildup in two stages:
1. Mode 1 – AFR Enrichment
2. Mode 2 – Skip Fire

Mode 1 will be activated under the following conditions:
1. The engine temperature exceeds 142 °C (Sportsters 230 °C)
2. The Engine RPM is less than 1200 RPM

Mode 2 (Big Twins only) activates if Mode 1 is active AND
1. The engine temperature exceeds 155 °C
2. The vehicle speed is less than 1-2 KPH

Note that Sportster temperatures are much higher due to the location of the temperature sensor and only uses EITMS Mode 1 (AFR enrichment).
to use these cals wherever possible.

If this is not sufficient, turn off EITMS (EITMS takes over AFR control) and make adjustments to the AFR and timing as follows:

First, try adding additional timing advance in the idle region. This can have a significant impact on heat build-up.

If the vehicle is in closed-loop mode when the problem occurs, try adjusting the O2 Bias table higher in the idle region (1000 – 1500 RPM and 30 – 45 kPa).

If running open loop during idle, the AFR table can be set for a richer mixture in the idle cells. The idle cells can be identified by monitoring the engine using DataMaster.

6.4.   DBW Bike High Idle Speed

The 2008 and later Drive-by-Wire (DBW) bike can develop a high idle speed over time. This is caused by the "auto learn" feature in the ECM that learns the Twist Grip Sensor (TGS) zero position when the bike is shut off. Many riders just flip the switch on the handle bar with their right thumb with the rest of the hand still on the throttle grip. This causes the Twist Grip Sensor to not be at zero and the ECM learns the new position, and little by little this causes the high idle issue.

To prevent this problem, always turn the bike off using the tank switch with your right hand. By removing your hand and shutting down using the tank switch you have to let go of the Twist Grip so it returns to the proper zero position prior to the power shutdown.

7. When Things Go Wrong

This section addresses some of the most common problems that occur when using MasterTune or DataMaster. The answer to your question may also be found in the FAQs, chapter 8.

7.1.   Communication Problems

Communication problems fall into three basic categories:
- The COM port number is wrong
- USB driver configuration
- You can connect to the ECM but an error occurs when programming or uploading

7.1.1.   COM Port Number

MasterTune and DataMaster communicate to the vehicle interface using the PCs serial COM port. These are called COM1, COM2 .... on up to COM255. MasterTune and DataMaster requires that the COM port number be assigned between COM1 and COM16.

7.1.2.   Selecting Physical COM ports

Older laptops usually have one "physical" serial COM port (a 9-pin connector) on the back of the laptop. This is assigned to either COM1 or COM2 in the system BIOS setup. Consult the PC manufacturer for details on configuring the COM ports in the BIOS.

The COM port is selected from the MasterTune *Save and Restore* or *ECM Programming* windows. On DataMaster, the selection is made on the *Data Recording Control* window.

COM ports are also used by Bluetooth adaptors, infrared (IR) ports and occasionally graphics cards. For this reason, many available COM port selections may be shown in the drop-down menu.

In this example, the PC has 3 COM ports available: COM1, COM3, and COM14. COM14 is selected as shown by the check mark. If a COM port is not available on the PC, it will be grayed-out in the menu.

Figure 7-1: COM Port Assignment

If the wrong COM port is selected, MasterTune and DataMaster will be unable to communicate with the vehicle. This is checked by pressing the 'Get ECM Info" button. If the correct COM port is selected and the vehicle's handlebar and tank switch are on, information from the ECM will be displayed. If there is a problem, the following error message is shown, Figure 7-2.
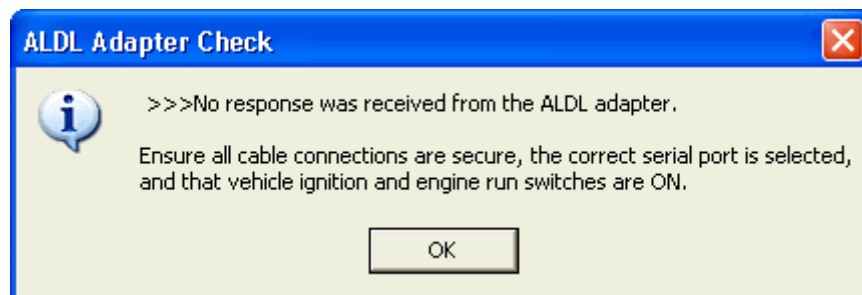
Figure 7-2: No ECM Communication

If you get this message, the first thing to try is selecting the other COM port numbers and repeating the test. If none of them respond, and you are **not** using a USB serial adaptor then there is probably a problem with the cables or the COM port is not enabled in the BIOS. Configuring the COM port in the BIOS is beyond the scope of this section and the user should contact the PCs manufacturer for instructions on how to do this.

7.1.3.   USB COM ports

Newer laptops have eliminated the physical COM port. For these systems, a USB to serial adaptor must be used. These adaptors come with their own drivers that must be installed on the system prior to use.

NOTICE:
TTS has found that many USB adaptors fail to operate correctly when transferring large blocks of data required for programming. For this reason, it is recommended that the TTS USB serial port adaptor be used, as this is extensively tested with all Windows versions.

NOTICE:
Always install the USB drivers prior to connecting the USB adaptor to the PC for this first time. This way, when the interface is first connected it will automatically be detected and will not prompt you for a driver installation disk.

The USB drivers for the TTS interface are included on the distribution CD, and are installed by selecting the Prerequisites and Drivers button. These can also be downloaded from the FTDI website at http://www.ftdichip.com/FTDrivers.htm. When downloading, select the VCP (Virtual Com Port) driver type.

7.1.3.1.   *Installing the USB Driver for Win XP through Win7:*

To install the USB drivers, insert the TTS installation CD and browse to the ***Prerequisites and Drivers*** page. Then, press the ***USB Driver 2K-XP-Vista-WIN7*** button to invoke the install process. This will automatically install the drivers for all versions of these OS. Installation may take a minute or two to complete.

Figure 7-3: Windows Driver Install

7.1.3.2.   *USB Driver Install Failure:*

If the automatic driver installation fails for any reason, the drivers can be installed using a manual process. In this case, connect the interface to the PC, and when prompted by the Add New Hardware wizard, browse to the TTS installation CD folder; assuming D is the CDROM this will be "***D:\USB_Drivers\Windows_2000_XP_Vista\CDM_2_08_14_Unpacked***" and enter **OK**. Follow the wizard prompts to complete the installation process.

7.1.3.3. Configuring the USB Driver:

MasterTune and DataMaster require the COM port be between COM1 and COM16.   In some cases, it is necessary to reassign the COM port that the USB driver automatically selects. The following sections show how to do this using Device Manager.

7.1.3.4. Windows XP Com Port Reassignment:

Notes:
- You must be logged in as an administrator to make changes with Device manager!
- The USB interface must be connected to the PC in order to perform the following configuration.

7.1.3.5. Invoking Device Manager:

To launch device manager in Windows XP, go to **Start - Settings – Control Panel** and click on the **System** icon. This will open the Systems Properties dialog. Select the "**Hardware**" tab and then press the "**Device Manager**" button.

Tip: A shortcut to access Device Manager is to open **devmgmt.msc** from the **Start -Run dialog**:
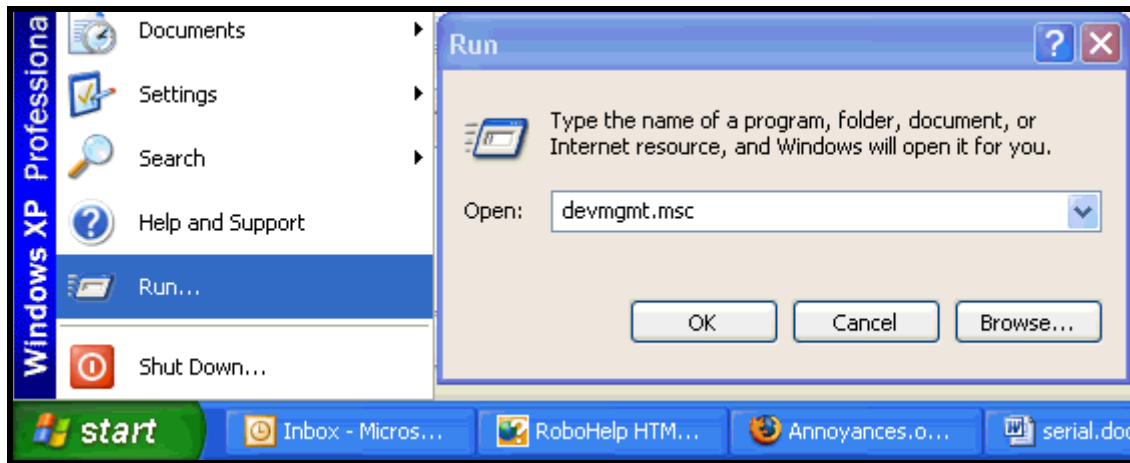
Figure 7-4: Invoking Device Manager

This will bring up the device manager dialog. Go to the section labeled "**Ports (COM & LPT)**" and press on the "+" symbol to view the port assignments:
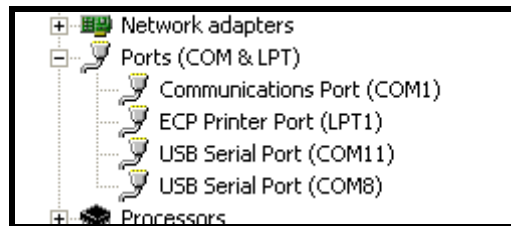
Figure 7-5: Windows XP Ports Display

To reassign the COM port number, double click on the USB Serial Port selection to be changed. This will bring up the driver configuration dialog:
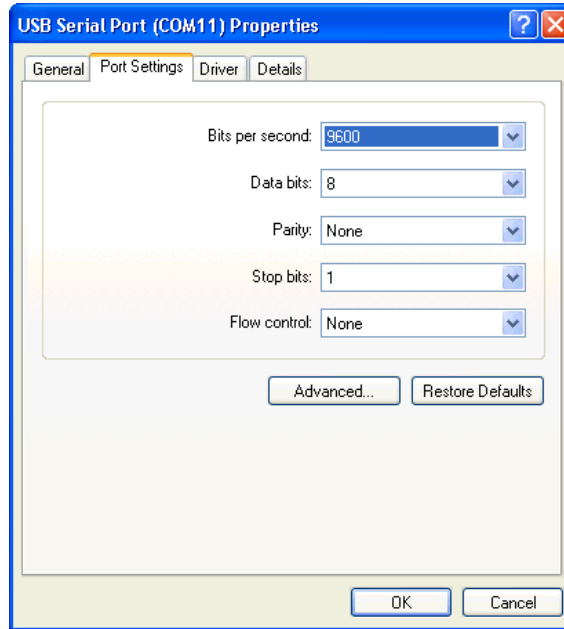
Figure 7-6: USB Driver Configuration Dialog

Select the Port Settings tab, then press the "Advanced" button: This will bring up the Advanced Port Settings dialog. In this example, note COM1 through COM10 are already "In Use" by other devices.
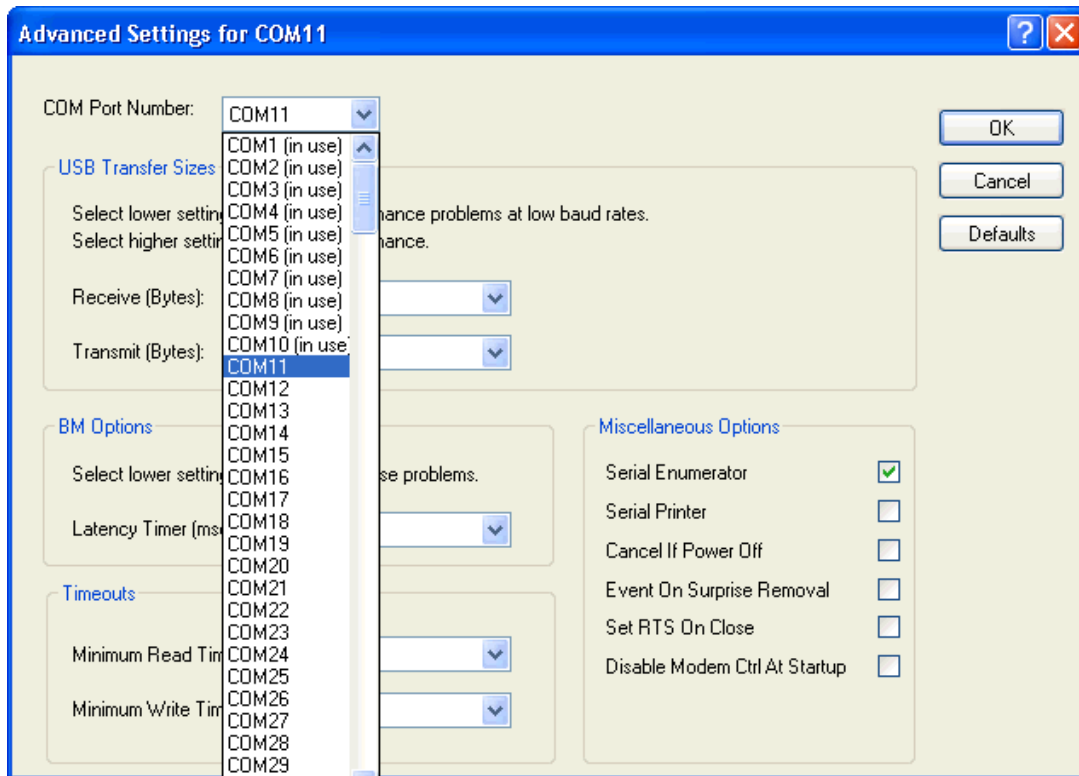
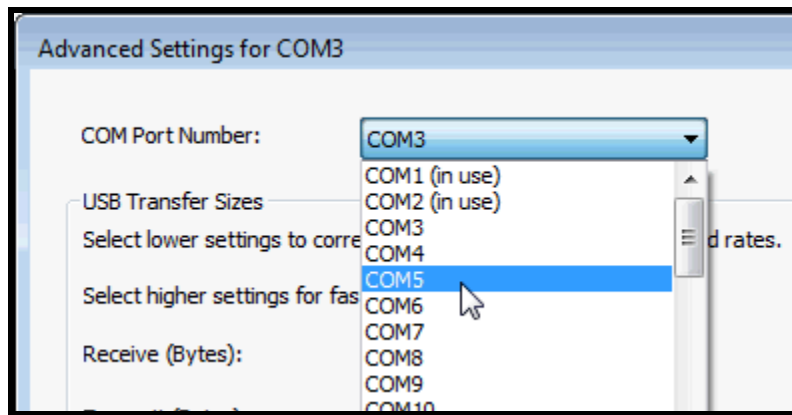**Figure 7-7: Advanced COM Settings**

The TTS USB port must be assigned between **COM1** and **COM16**. If all these port assignments are already in use, (which often happens with wireless laptops), make a new selection between **COM5 and COM16** (COM1 - 4 are usually the Laptop hardware such as IR or Modem connections) - You will receive the following warning:
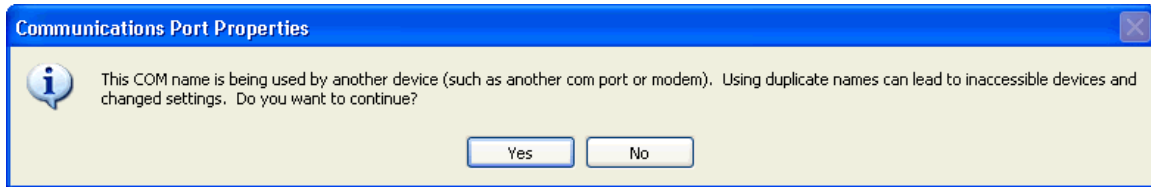
Figure 7-8: COM Name In Use Warning Dialog

Click "*Yes*" to accept the new assignment. This will generally not cause any problem - however the selection can be easily changed at a later time if necessary.

Make a note of the port number you selected, and select OK to apply the changes. When you open MasterTune or DataMaster and select the serial Com port, use this port number.

Note: Occasionally you will need to restart the PC in order for the COM port reassignment to take effect.

7.1.4.   Windows Vista / Win7 Com Port Reassignment:

Notes:
- You must be logged in as an administrator to make changes with Device manager!
- The USB interface must be connected to the PC in order to perform the following configuration.

7.1.4.1.   *Invoking Vista Device Manager:*

The Windows Device Manager application must be used to configure the USB serial port connection. There are two ways to invoke device manager:

The Windows Device Manager application must be used to configure the USB serial port connection. There are two ways to invoke device manager:

Type **devmgmt.msc** into the windows Search box:

Figure 7-9: Invoking Vista Device Manager using Run

-OR-

From the start menu, right-clicking on Computer and selecting Manage:
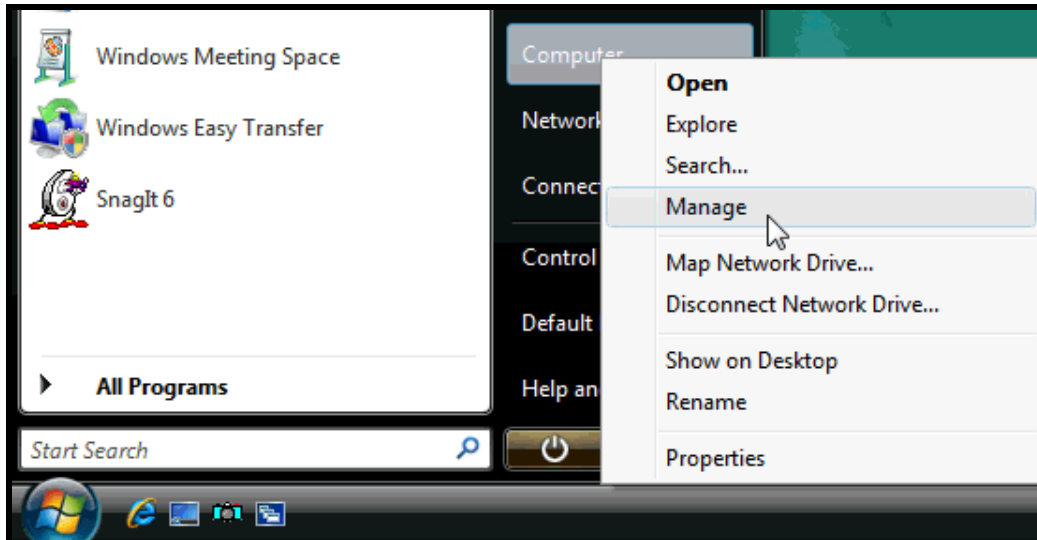
Figure 7-10: Running Vista Computer Manager

You will receive the message "Windows needs your permission to continue". Press the Continue button.

Click on "Device Manager" in the left-hand tree:
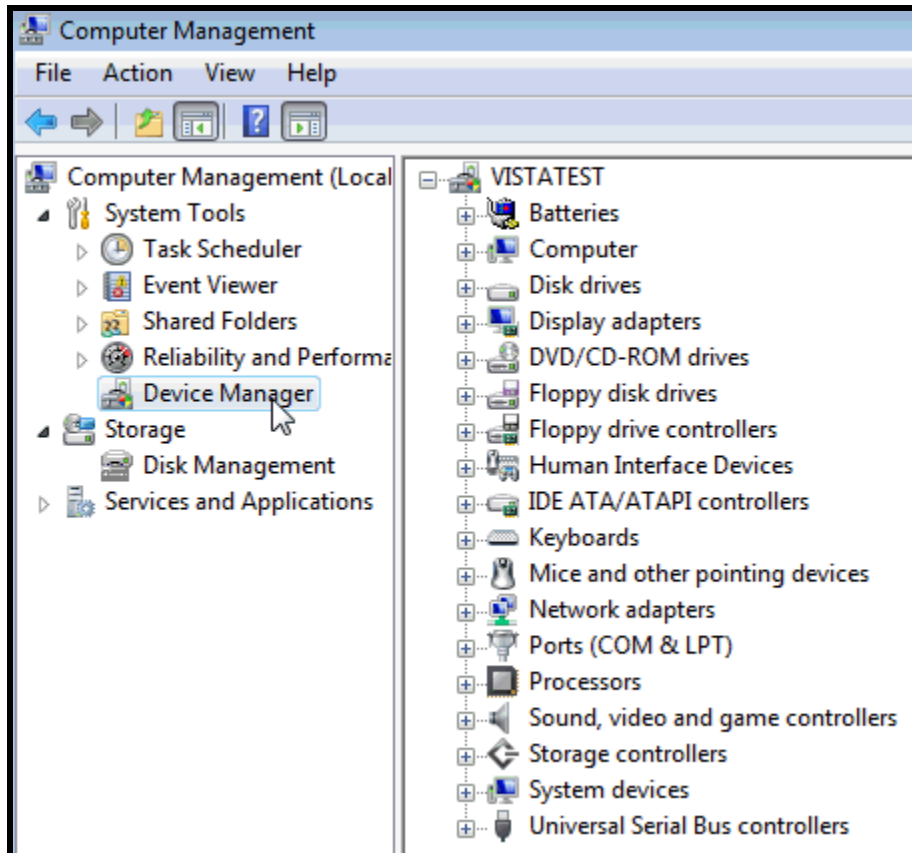
Figure 7-11: Vista Computer Management

The right hand pane will show a list of all devices. Click on the "Ports (COM & LPT)" in the right hand pane. This will show a list of all the available COM ports:
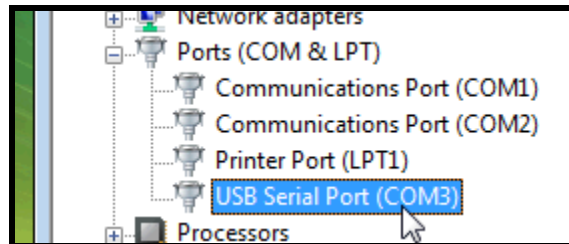
Figure 7-12: Vista Ports Selection

Double click on the USB Serial Port open the driver properties dialog:	Next, click on the "Port Settings" tab:
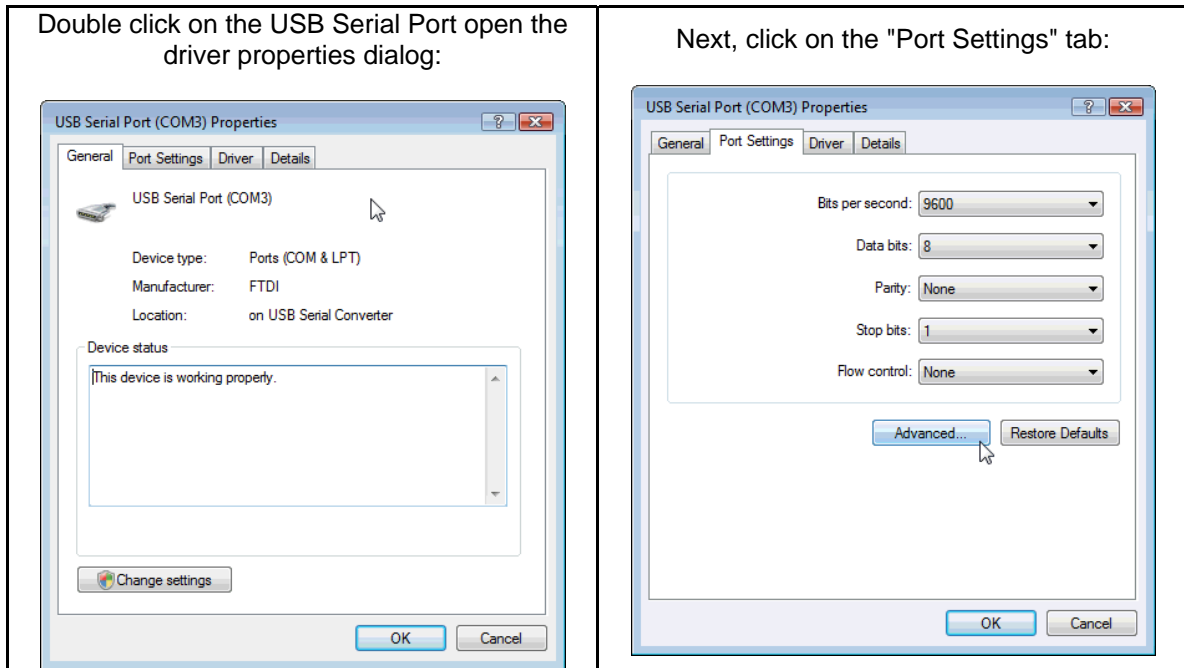
Figure 7-13: Vista / Win7 USB Serial Port Properties

Press the "Advanced" button to access the advanced port settings dialog. From this dialog, select the new COM port number:

Figure 7-14: Vista / Win7 Advanced COM Port Settings

The TTS USB port must be assigned between **COM1** and **COM16**. If all these port assignments are already in use, (which often happens with wireless laptops), make a new selection between **COM5 and COM16** (COM1 - 4 are usually the Laptop hardware such as IR or Modem connections) - You will receive a "***Port Name In Use***" warning.

Click "Yes" to accept the new assignment. This will generally not cause any problem - however the selection can be easily changed at a later time if necessary.

Make a note of the port number you selected, and select OK to apply the changes. When you open MasterTune or DataMaster and select the serial Com port, use this port number.

7.2.   Bootloader Error when Programming or Uploading:

If you receive a message "**Error Installing Bootloader**" when programming or uploading the ECM, but you are able to read the ECM info using the "**Get ECM Info**" button, then most likely cause is a non compatible USB interface. For this reason, TTS recommends using the TTS supplied interface, as this is extensively tested and qualified with all versions of Windows.

This can be also be caused by a defective serial cable that connects from the TTS Interface to the USB or Laptop connection. Make sure there are no bent or missing pins, and try a different cable.

7.3.   Programming Stops Partway Through:

Occasionally programming will stop when partially completed. Should this occur there are two recovery options to try:

First, just try re-running the programming session by pressing the **Program ECM** button again. Generally, this will solve the problem. You cannot harm the ECM by trying this multiple times if necessary.

If this is unsuccessful, then you will need to restore the original code that you saved from the ECM. Close the programming window, and open the **Save and Restore** window. From the command menu select **Restore ECM Calibration**. Click the **Restore ECM Calibration** button and a file dialog will be presented. Select the **MTE** file that you uploaded (you **DID** save the ECM before you started tuning, right!!?). Verify the MTE file you selected is the correct one and Click the **OK** button to begin the restore process.

Aftermarket products that connect to the diagnostic bus sometimes cause interference during programming. In these cases, disconnect these devices (i.e. gauges or Power Commander type devices) and retry the operation.

If programming problems persist contact your supplier or TTS for additional options and support.

7.4.   Upload Fails with Error -50:

This error can occur when there is another device on the diagnostic bus interfering with data transfer. Most commonly, this is due to an aftermarket digital gauge, or in some cases the OEM digital speedometer. To solve this problem, remove the fuse powering the gauges or speedometer assembly. This is usually the Accessory or Instrument fuse located under the seat. Consult your manual to identify the fuse location.

Figure 7-15: Typical Location of Accessory Fuse

8. MasterTune FAQs

8.1. AFR Tuning Questions :

Q: What is the best AFR for power?
A: Keep in mind that every motor is a bit different and that gas composition can vary substantially.   In general, we find the best AFR for WOT power is between 13.0 to13.5:1 AFR. However, these settings can build a lot of heat so it is best to go a bit to the rich side. For street use, using a AFR setting of 13.0 is a good compromise between power and economy. Keep in mind that alcohol fuel blends require a lower AFR for maximum power than straight gasoline. Also, if heat is a problem it will be better to run a lower AFR

Q: I set the AFR table to a new value, but the measured AFR does not agree. What is the problem?
A: The AFR table is only accurate if the VE table has been calibrated to the engine. Also, during warm-up and transient conditions, the AFR will be altered from the targeted value. Transient adjustments generally affect the AFR for several seconds after the event.

Q: How do I know if I need larger injectors?
A: By using DataMaster to monitor the injector pulse width. The injector should open no more than 80% of the time. Chart Table 8-1 shows the injector duty cycle for various engine RPMs. For example, at 6000 RPM, the injector pulse width should be 16 mS maximum. MasterTune has an injector calculator under the *Tools* menu which will aid in evaluating injector sizing.

RPM	Time, mS	80% DC mS	RPM	Time, mS	80% DC mS
1000	120.0	96.0	7000	17.1	13.7
1500	80.0	64.0	7500	16.0	12.8
2000	60.0	48.0	8000	15.0	12.0
2500	48.0	38.4	8500	14.1	11.3
3000	40.0	32.0	9000	13.3	10.7
3500	34.3	27.4	9500	12.6	10.1
4000	30.0	24.0	10000	12.0	9.6
4500	26.7	21.3	10500	11.4	9.1
5000	24.0	19.2	11000	10.9	8.7
5500	21.8	17.5	11500	10.4	8.3
6000	20.0	16.0	12000	10.0	8.0
6500	18.5	14.8	12500	9.6	7.7

Table 8-1: Injector Duty Cycle V.S. RPM

Q: How much horsepower are my injectors good for?
A: Use Table 8-2 to estimate the maximum HP per cylinder for your injectors.
   Max HP from the on-line calculators are very optimistic.
   Crank HP at the crankshaft assume 6000 RPM, 80% DC, 0.5 BFSC, and 55 PSI
   Wheel HP at the rear wheel include drivetrain losses assumed to be 10%

gm/sec	lb/hr	Max HP	Crank HP	Wheel HP
3.91	31.03	62.1	55.7	50.1
4.35	34.52	69.1	62.0	55.8
4.89	38.81	77.6	69.7	62.7
5.32	42.22	84.5	75.8	68.2

Table 8-2: Injector HP per Cylinder

Q: Can I change the AFR over the entire table by changing the injector flow constant?
A: Yes, but only for the cells that are in open-loop mode. Closed loop cells will compensate for injector changes. Note that changing the injector constant will also change the mixture for **ALL** other fuel-related tables – it is a global change!

8.2.   VE Table questions:

Q: The VE table is maxed out. How do I fix this?
A: The best way to handle this is to set the engine displacement larger. This affects many other settings, so if you anticipate this problem make the change early in the tuning process. Do not change the displacement any more than necessary to get the VE table into range.

Q: The ECM is not responding to changes in the AFR table at full throttle. What is the problem?
A: At throttle openings greater than roughly 80% and RPMs greater than the Power Enrichment (PE) RPM setting, the ECM enters PE mode and uses the "PE Air-Fuel Ratio" table (Figure 3-19) to control the AFR. This can cause problems when calibrating the VE tables during WOT. During this procedure, the AFR will track the PE AFR values and the main AFR table will be ignored.

Q: Why are the VEs different for the front and rear cylinders?
A: The VEs will never be identical because of differing intake length, exhaust pipe length, reversion, timing, cooling and other factors.

Q: Can I run the TTS VTune program riding 2-up?
A: You ride anyway you like. If you do it 2-up it will cover more of the cells on the map as you will have a larger load on the bike but it might miss some of the lighter load areas you can get by riding solo. A few runs each way will give you the best of both worlds!

8.3.   Closed-loop Operation Questions:

Q: I installed a Hi-flow air cleaner. Do I need to update the calibration?
A: Closed-loop bikes will compensate for minor changes if you give the system time to learn. It can be made to run better with tuning, but it is not necessary. If you change more than the air cleaner, then you will need the tuning changed

Q: I changed my exhaust system. How does this affect my tuning?
A: Exhaust can drastically change the airflow through the motor due to reversion (pressure waves) during the valve overlap period. This affects the cylinder fill and mixture dilution based on RPM. This requires adjusting the VE tables to best match your engine combination.

Q: Does MasterTune clear the adaptive fuel values (AFV) when programming?
A: Yes. The AFV cells are cleared during each programming session. They can also be manually reset at any time using DataMaster.

Q: What are the "AFV" cells and why do they need to be cleared?
A: The AFV cells store the long-term learned fuel correction ("trim") over the closed-loop operating range. When a calibration is flashed into the bike, these cells need to be cleared so they do not influence the calibration. The goal is to get the calibration very close to the optimum values so very little trim is needed. MasterTune clears the AFV cells every time a calibration is flashed into the vehicle.

Q: What does "Stoichiometric" mean?
A: Stoichiometric mixture is the air-fuel ratio (AFR) that generates the most complete combustion. This is typically measured using a "lambda" (oxygen) sensor which measures the oxygen content of the exhaust gas. Note that Stoichiometric AFR is dependent on the fuel composition. Today's gasoline varies from 14.28 to 14.68; alcohol blends trend lower. Table 8-3 shows approximate Stoichiometric AFR for some Common Fuels. Also refer to section 3.5 for additional information.

Fuel	Stoichiometric AFR
Gasoline Blends	14.3 to 14.7
Ethanol	9.0
Methanol	6.4
Diesel	14.6
Propane	15.5
E85	9.8
E10	14.1

Table 8-3: Stoichiometric AFR of Common Fuels

8.4. Calibration Questions:

Q: I can't find any MT7 or MT6 calibrations, only the MT8's are showing!
A: The File Dialog filters the file types which are shown such that only one type of calibration is shown at a time. Use the "**File Type**" selection on the bottom of the file dialog box to select the type of calibration you want to open: MT6, MT7 or MT8.

Q: How do I decide which calibration is best for my Bike? Can I swap calibrations around?
A: As a starting point, select the cal that best matches the components on your bike. Most of the Twincam calibrations can be swapped around without too much trouble. Refer to section 2.5 for calibration selection guidelines.

Q: I installed a calibration but still have exhaust "popping" during decel. How do I fix this?
A: Exhaust popping is caused by too rich or too lean a mixture during overrun conditions. If the popping happens immediately after the throttle is closed, adjust the "Decel Enleanment" table lower (= richer) for the temperatures where the problem occurs. If the problem lasts for a longer period of time, try changing the AFR table 4 to 10 percent in the region the popping occurs.

Adjusting the Closed Throttle Spark table may also help reduce the popping. Note this will also affect the timing at idle!

Tip: Use DataMaster to log data and "mark" the popping region by pulling in the clutch and giving a quick blip of the throttle. Refer to the data log to find your "mark" and identify the AFR MAP and RPM region to adjust.

Q: How long does the Warmup Enrichment AFR table stay active?
A: The Warmup enrichment table is gradually phased out over about 90 seconds at each key-up. Also note, the Warmup Enrichment is phased out if the MAP is greater than 40 kPa.

Q: How long does the Acceleration Enrichment table stay active?
A: It takes about 20 engine revolutions to decay the AE value to zero. For example, at 2000 RPM, this is 0.600 seconds

Q: How does the ECM "sync up" to the engine phase when there is no camshaft sensor?
A: The ECM monitors the manifold pressure pulses and the crankshaft rotational speed during cranking to determine which stroke the engine is on. The MAP reading determines the intake stroke, while the rotational speed determines the compression stroke. This information is combined to determine the engine phasing.

Q: When knock retard occurs, how long is it active?
A: When knock is first detected, the timing is immediately retarded up to 5 degrees (controlled by the **Adaptive Knock Retard** table). The ECM decays the retard back to zero over a 10 to 20 second period (assuming there is no additional knock detected).
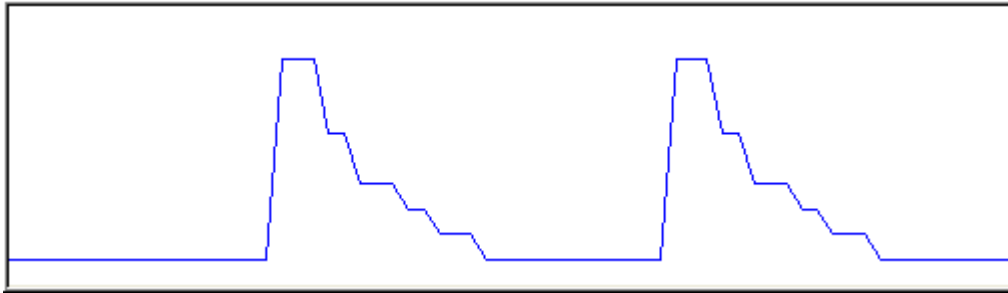
Figure 8-1: Spark Retard Event

Q: Can I view/edit the uploaded calibration that is currently installed in my ECM?
A: No, not at this time. The uploaded calibration "MTE" files are only intended for saving and restoring of any existing calibration in the ECM.

Q: Can the dealer tell if I have installed a TTS calibration in the ECM?
A: The dealer tool reports the calibration part number that the user sets in MasterTune. By default, this is the TTS calibration part number.

Q: The ECM shows same CAL number after programming. What is the problem?
A: The user must enter a new calibration number from the main editing screen prior to programming. Under the **Edit** menu, click on **Edit Part Number**. This will bring up the form that allows you to edit the calibration number.

Q: When coasting to a stop with the clutch pulled in, the idle speed is higher than my setting. What is the problem?
A: The Idle RPM setting is only active when the vehicle is stopped.

Q: Does the fuel I'm running make any difference to my tune?
A: Yes, changes in the fuel quality will change the tune. For best results, always tune with fresh fuel that you normally use for riding.

Q: My speedometer reading is off. How much do I adjust this?
A: You make this adjustment when programming the ECM when the Vss dialog is presented. If you know how much the reading is off, you can make the adjustment as follows:

$$Vss(new) = \frac{Vss(old) \times Spd(reading)}{Spd(actual)}$$

You can also use the Vss calculator or actually measure the tire rollout as detailed in the on-line help file.

Note: Increasing the Vss value Decreases the speedometer reading (and vice-versa).

8.5. Computer, Communication, USB, and Locking Questions:

Q: Is the MasterTune software Vista or Windows 7 compatible?
A: Yes, the software will work with all versions of Vista and Windows 7 including 64-bit versions.

Q: I get error 4121 during the .NET framework install. What is the problem?
A: The .NET 2.0 framework requires Internet Explorer 6 or later be installed on the system. IE6 can be downloaded from Microsoft at
http://www.microsoft.com/windows/ie/ie6/downloads/default.mspx

Q: Can I use my SERT or SEST vehicle cable with MasterTune?
A: Yes, the MasterTune vehicle interface is compatible with the **original** SERT cable. 2011 and later CAN protocol bikes use a completely different incompatible cable with a 6-pin vehicle connector.

Q: What programs do I get when I purchase MasterTune? Does it include VTune?
A: When you purchase MasterTune, you also receive the VTune, DataMaster and the Updater Software.

Q: I installed MasterTune, but I can't find any calibrations. Where are they?
A: You must run the TTS Updater utility to install the calibrations on your system. This will retrieve the latest calibrations from our server.

Q: Will my "brand X" USB serial adapter work with MasterTune?
A: Maybe, but many do not. We recommend that you use the TTS USB adapter which is fully tested and works with all windows versions from 98 through Win7. This is sold as a separate kit by TTS.

Q: MasterTune will read the ECM information but will not upload or program the ECM. What is the problem?
A: The most common cause of this is an incompatible USB serial adaptor. Try a different adaptor, or use the adaptor kit which is sold by TTS.

Q: How can I tell if a MasterTune interface has been used?
A: It is only possible to tell if the interface is locked to the vehicle it is attached to. From the programming screen, select "***Get ECM Info***". The Lock Stat display will show how many slots (i.e. vehicles) the interface supports, and if it is locked to the attached vehicle.

Q: I receive a message "Unable to determine the interface type". What is the problem?
A: Most likely, the wrong COM port is selected, or the ignition/handlebar switch is off. Verify the switches are on, and if the problem persists check the COM port number. If the interface does not appear for any COM port number, and this is a USB adaptor, refer to the section 7.1.3 on Configuring the USB Driver for further information.

Q: I get a VIN Not Found error on my bike.   What is the problem?
A: This most often happens with 2001 and 2002 bikes. Some of these bikes left the factory without the VIN being programmed. MasterTune now allows repairing these VINs so the calibration will program correctly.

Q: When programming an ECM the program stops and reports a VIN check 10 error. What is the problem?
A: The VIN in the vehicle indicates a different engine type than the calibration file is designed for. Verify that the correct calibration file is loaded. If everything appears correct and the error persists, please upload the original calibration and send the MTE file to TTS for evaluation.

Q: I get an Access Violation when starting MasterTune or DataMaster under Vista, or the program will not launch under Windows XP/Vista/Win7.   What is the problem?
A: This is due to the "Data Execution Protection" (DEP) function in the operating system.   DEP must be set to allow MasterTune and DataMaster to run as an exception. Use the following procedure to fix this issue:
1. Log into the Administrator account.
2. From the *Start* menu, right click on *Computer* and choose *Properties*
3. Select the *Advanced System Settings* task in the left pane
4. Select the *Advanced* tab, then click the *Settings* button in the performance section
5. Select the *Data Execution Prevention* tab
6. Add the MasterTune-HD.exe and DataMaster-HD.exe programs to the exception list. This is done by browsing to Program Files\TTS\HD\MasterTune-HD\ MasterTune-HD.exe and Program Files\TTS\HD\DataMaster-HD\ DataMaster-HD.exe
7. Click *Apply* to save the changes
8. Click OK on the forms to exit
9. The computer may have to be restarted to complete the process.

For detailed Vista or Win7 instructions, go to the following Microsoft website:
http://windows.microsoft.com/en-US/windows-vista/Change-Data-Execution-Prevention-settings

Q: MasterTune or DataMaster are very slow starting up, and may show high CPU usage during this time.
A: This is commonly due to the Windows Defender program monitoring these programs as they start up. The solution is to place these two programs on the Windows defender exception list as follows:
1. Log into the Administrator account.
2. Select *Start – Programs – Windows Defender*
3. Select *Tools* and then *Options*
4. Scroll to the bottom of the page to *Advanced Options*
5. In the "*Do Not Scan these files or Locations"* box add the following entries:
     a. C:\Program Files\TTS\DataMaster-HD\ DataMaster-HD.exe
     b. C:\Program Files\TTS\MasterTune-HD\ MasterTune-HD.exe
6. Click *Save* to save the changes. Select OK if prompted to OK the changes
7. Close the Windows Defender application.

Note this problem may occur with other third-party anti-spyware programs. Follow the manufacturers instructions for adding MasterTune and DataMaster to their exception list.

Q: MasterTune stops with a message "Error Installing Bootloader, Quitting". What is the problem?
A: This is usually due to using a USB-Serial adaptor that is not compatible with the MasterTune interface. Try using a different brand of USB adaptor. If you are using the TTS USB to Serial converter and you receive this message, check that the cable from the interface to the USB adaptor is connected securely and not damaged.

If you are using a native serial port on the PC and receive this message, check the serial cable for damaged pins or a bad connection. Try another serial cable if possible.

Q: I get an error -50 when uploading or programming ECM. How do I fix this?
A: This has been traced to the digital speedometer installed in some models. To fix the problem, remove the fuse supplying power to the speedometer assembly prior to uploading or programming the vehicle.

This problem may also occur with aftermarket digital gauges. In this case, removing the fuse supplying power to the gauges will allow normal programming.

For Dakota Digital gauge MCL-3006, the problem can be resolved by disabling the fuel sender type setting in the gauge assembly. Follow the procedure outlined in Dakota Digital manual **mcl-30066-ot.pdf**, page 10 in the section "**Fuel Sender Selection DEFAULT OFF**". The manual is available from the Dakota Digital website.

Q: MasterTune stops during uploading (saving) or programming with an error -502. What is the problem?
A: This is due to corrupted communications on the ECM diagnostic bus. This can occur if third-party devices connected to the bus or ECM (such as a Power Commander or aftermarket gauges). Disconnect any such devices and retry the operation.
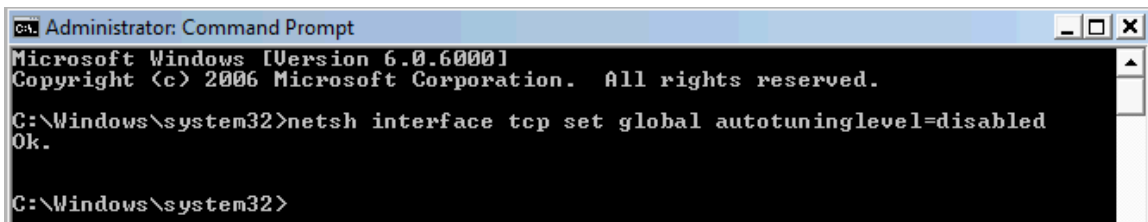
Q: Updater has very slow downloads and may stall out after 100K – 200K has transferred.
A: There are several possible causes for this issue. If downloads worked OK at one time and recently slowed down, check if your network card drivers were recently updated. If so, try rolling back to the previous driver version.

If your computer uses the Vista or Win7 OS there is a feature that controls network performance. This can cause very slow downloads from the internet. The following procedure prevents this problem from occurring:
1. Log onto an administrator account
2. Select *Start – All Programs – Accessories*
3. Right-click on *Command Prompt* and select *Run as administrator*
4. Vista/Win7 will need your permission to continue – Press *OK* and the command prompt will open
5. In the command prompt box type the following line exactly:
   netsh interface tcp set global autotuninglevel=disabled
6. Press the *Enter* key

If successful, the response will be *Ok.*, Figure 8-2. If there is an error, make sure the line is entered exactly as above and make sure the command prompt was started using *Run as administrator* option.


```
Administrator: Command Prompt                                    _ □ X

Microsoft Windows [Version 6.0.6000]
Copyright (c) 2006 Microsoft Corporation.  All rights reserved.

C:\Windows\system32>netsh interface tcp set global autotuninglevel=disabled
Ok.

C:\Windows\system32>
```

Figure 8-2: Administrator Command Prompt

Q: Occasionally the interface "locks up" when I first connect to the PC.
A: We have found that some PC serial ports will cause the interface to "lock up" if connected to the PC **after** the interface is powered up from the vehicle. If this occurs, unplug the cable to the vehicle to reset the interface. To prevent this problem from occurring, connect the interface to the PC serial port prior to connecting to the vehicle following the directions in section 2.4.1.

Q: I have everything connected up and powered on, but still can't communicate.
A: You may be plugged into the vehicle's accessory connector instead of the diagnostic connector. Refer to the vehicle manual to verify the location of the diagnostic connector.

On the late model touring bikes, the diagnostic connector is under the side cover which houses the fuses. *The connector under the seat will NOT work!*

Q: The computer quits recording during VTune sessions.
A: The most common cause for this is the laptop power save or hibernation has "kicked in" and shut down the laptop. PowerSave should be set to enable disk always, enable USB always and not allow hibernation. Refer to section 2.1.1 for details.

Some laptops have a "shock detection" system that turns off the disk if an impact (or rough road) is detected. This will prevent data collection. In these cases you may need to change (or disable) the detection sensitivity or mount the laptop in foam to reduce vibration.

The USB connector can also vibrate and terminate data collection. Secure the connection by using a thin plastic shim to tighten the connection.

Q: I installed the TTS software updater, but it fails with the message "Error checking for Updates".
A: This is usually due to a firewall setting blocking access to the TTS server. Make certain that your firewall allows the TTS updater internet access. Occasionally, we have seen this issue after a firewall product was uninstalled (such as Norton 360) but left behind a setting that causes the problem. The solution is to reinstall the product and reset its firewall to use the default Windows firewall settings.

9. Appendix A: O2 Conversion Parts List and Diagram

The following is a list of parts needed to convert the 2004 to 2006 Big Twin bikes to closed-loop operation. After O2 sensors have been added to the vehicle, you must install a level 176 closed loop calibration into the ECM.

NOTE: Model year 2004 vehicles must be equipped with a 2005 or newer ECM to allow closed loop operation. The ECM must be configured by the dealer for your bike prior to use by MasterTune. This includes the VIN, factory calibration and configuration settings.

Calibrations: To run a closed-loop calibration, select the level 176 calibration that most closely matches your bike's configuration as a starting point. You can now use VTune as on any newer bike for your tuning.

Table 9-1: O2 Conversion Parts List

Item	H-D Part Number	Qty
O2 Sensor, Short Leads	27719-07	2 Required*
O2 Sensor, Medium Leads	27683-07	
O2 Sensor, Long Leads	27683-06	
Socket Housing	72007-05	2
Socket Terminal, Gold	72611-07	4
Wire Seal #16-20 AWG/Yellow	72011-05	4
Pins (ECM Connection)	72076-00	2
18 Gauge Wire**	TXL 19 x 30 stranding	As Needed

 * Two O2 sensors are required; select the lead lengths that best fit your bike.
 ** TXL Wire is desired but any high quality automotive wire should be OK
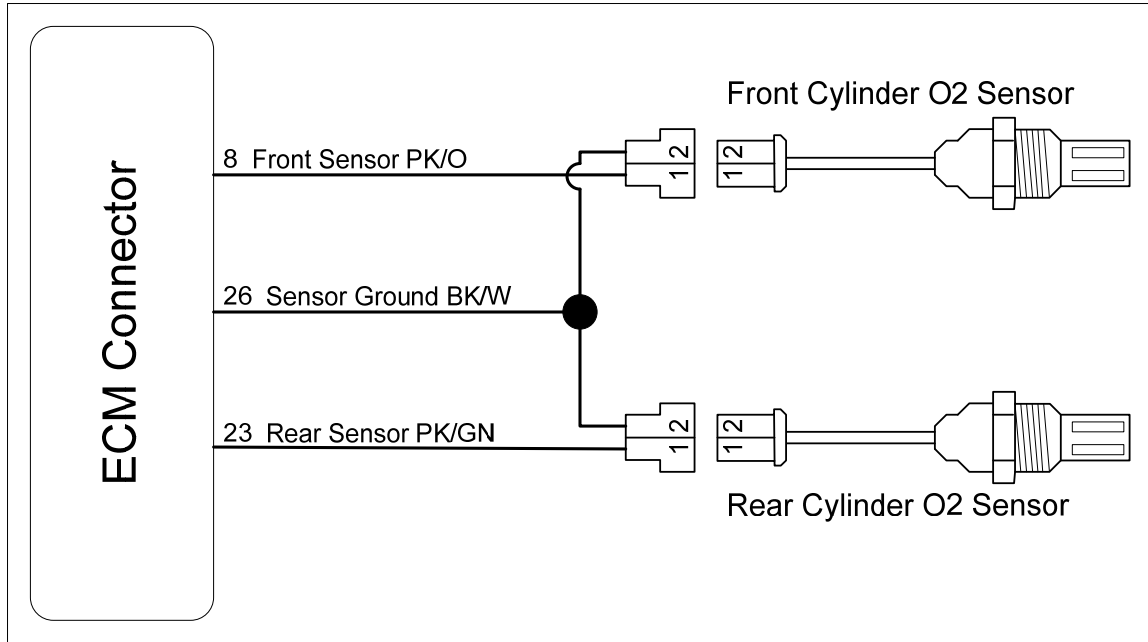
Figure 9-1: O2 Sensor Wiring Diagram

Table 9-2: O2 Conversion Signal Names

Signal Name	ECM Pin	Destination Pin	Comment
Front O2 Sensor Signal	8	Front O2 Pin 1	New wire, PK/O
Rear O2 Sensor Signal	23	Rear O2 Pin 1	New wire, PK/GN
Sensor Ground	26	F + R O2 pin 2	Splice into existing wire BK/W

OE Wire Color Code:
PK/O: Pink with Orange stripe
PK/GN: Pink with Green stripe
BK/W: Black with White stripe

10.   Appendix B: Table of Figures

11. Appendix C: Revision Log

Revision	Date	Comments
1.00	20-April-2009	Initial release
1.10	17-June-2009	4.7.2 – Added VTune info on yellow cell coloring
1.20	27-July-2009	Added Lambda calibration documentation Added O2 conversion parts list and diagram Update FAQs Update section 2.4.1
1.21	20-Aug-2009	Updated section 3.5 information 3.1.2.2 added info on AFR to Lambda calculator
1.22	22-Sep-09	Added note in section 2.4 Added DataMaster histogram MAP mark info in section 4.6.5 Added Lambda VTune illustration in section 4.6.7 Updated FAQs section 8.
1.23	24-Sep-09	Updated VTune instructions on using histogram MAP marker
1.24	19-Oct-09	Updated figure 3.14, 3.15 and typical closed-loop lambda values
1.25	02-Feb-10	Added info on O2 activity monitor section 4.6.1
1.26	27-Apr-10	Added note on Laptop HDD "Shock Detection" and USB power settings, section 2.1 Added section 6.4
1.27	16-Aug-2010	3.1.2 Clarify year for Lambda-based cals 3.3 Change IAC Warmup Steps calibration procedure 4.11 Add note on blending both front AND rear VE tables 6.x: Update max com port setting to Com 16 7.5 Add additional FAQs
1.28	31-Aug-2010	3.9 Updated Spark Temperature Correction Table
1.29	02-Dec-2010	4.12 add VTune Auto-Extend section
1.30	22-Mar-2011	3.3.3 Add Idle Speed Stabilization section 3.11.1 Add Skipfire Mode IAC offset description 3.12 Add section for Minimum TPS for Baro Correction table 3.13 Add section for EGR Effect tables 4.14 Add VTune flowchart 5.0 Add new chapter for CamTune
1.31	27-Apr-11	4.14 Update VTune flow chart
1.32	11-Jul-11	3.14 Add section on VTune Lo-MAP Highlighting feature
1.33	25-Jul-11	Many small changes made throughout for consistency