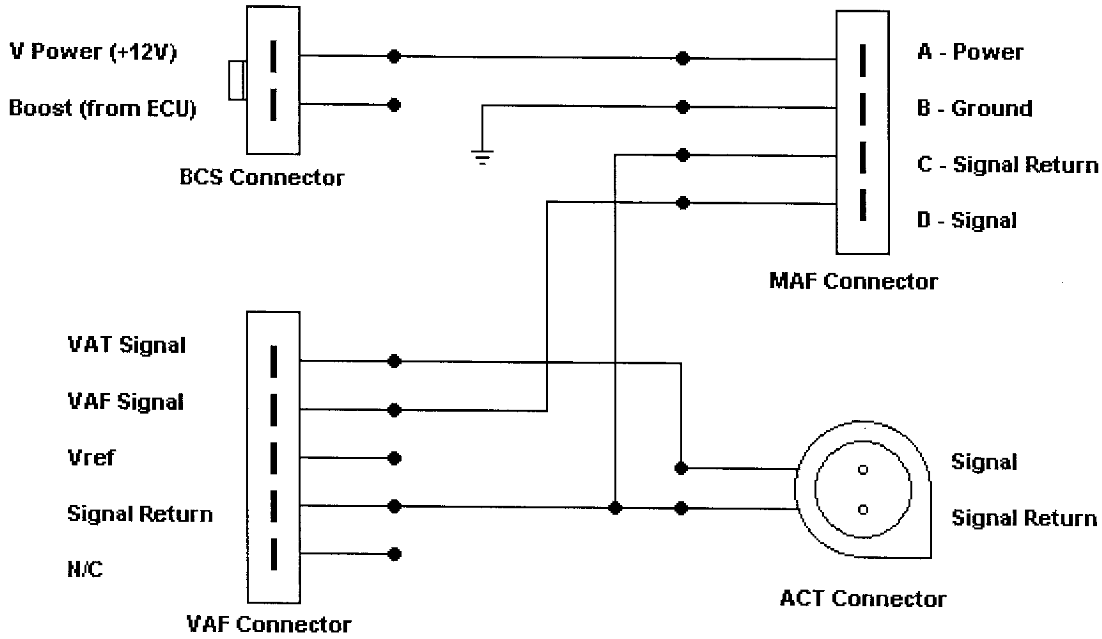
V Power (+12V)
Boost (from ECU)
BCS Connector
A - Power
B - Ground
C - Signal Return
D - Signal
MAF Connector
VAT Signal
VAF Signal
Vref
Signal Return
N/C
VAF Connector
Signal
Signal Return
ACT Connector

MAF Conversion Made Simple for P-Series Processors

Purpose Statement: The purpose of this project is to adapt a MAF meter to use on the 2.3T processor strategy in as simple a manner as possible using PCMX and an EEC-Tuner. I want to leave the stock fuel equation unaltered, but work around it as a means of implementing the MAF in lieu of the VAM. This rationale allows one to leave as much as possible unchanged, and (I believe) is infinitely more understandable for the novice tuner. I also want to change the stock airflow "cap" of 32 lbs/min, and use flow values that are best suited for the 2.3T EEC. I will assume those using this document possess a basic understanding of the 2.3T EEC's fuel strategy, and are reasonably comfortable working with PCMX. If you need to learn more about the fuel strategy, first read SAE paper #840251 ("Turbocharging the 1983½-1984 Ford 2.3L OHC Engine" by Dertian and Hutchison) that's in the tuner23 archives and then peruse my EEC fuel equations document. If you need to learn more about using PCMX, read through Kevin Timmerman's user's guide on the PCMX website (http://www.pcmx.net/pcmx/guide). The principle elements you'll need to adjust via PCMX are as follows:

- P_0404—Mass Air Flow Multiplier
- P_0408—VAF Sampling Average at Idle
- P_0520—VAF Low Limit
- P_0522—VAF High Limit
- P_1E08—Minimum VAF
- F_0A58—Max VAF vs. RPM
- F_0ED6—VAM (or for the current purposes "MAF") Transfer Function
- F_0FEE—Air Mass Transfer Function
- Hex Locations 0x2312 and 0x2313—MAF Cap

Those wishing to do the swap will also need the following hardware and data:

- A mass airflow sensor that works on a 5V scale.
- A detailed flow (preferably in lbs/min) vs. voltage map for the meter in question. I would think any really useable flow sheet would contain at least 20-25 data points. Pro-M has 48-point flow sheets for their meters listed on their website.
- A VAT sensor that has been extracted from a junk VAM for use as an IAT. There's been a lot of talk about adapting a later model IAT or ACT for use on our cars, but until someone perfects that swap I'll just advise you to stick with what we all know works. Hopefully I'll be able to amend this sentence before too terribly long. After all, the VAT is an ugly and fragile little booger and it's somewhat difficult to secure to the intake tract.

In all of the following calculations, I will round as little as possible until PCMX yields a "hard" number for me to work with. I think this is the most accurate way to do things using the tools at our disposal. Since John Baas has done an adequate job of describing the physical installation of a MAF sensor on one of our cars, I will not rehash that information in this document. My thanks go out to all those who have contributed to the MAF conversion thread over the past two years or so of the list's existence. If it weren't for the archives and some private pieces of correspondence, this document would have been impossible to compile. I might also say that I consider this a "work-in-progress," and hope you all will peruse it with an eye towards its perfection (i.e., any and all feedback is welcome).

Air Mass Transfer Value: The "Y" column numbers in the Air Mass Transfer function (F_0FEE) represent the values derived from the following equation in the 2.3T EEC's fuel strategy:

$$AMT=\sqrt{\frac{BAP}{VAT+460}}$$

Actually, the "Y" column values are just the square roots of the corresponding "X" column values. BAP and VAT values are derived from sensor inputs. Once the EEC determines the appropriate AMT value for current weather conditions, it uses a second equation to calculate metered air mass:

AMVAL (Air Metered Value)=Lbs/Min=CFM*.3187*AMT

The EEC uses the VAM to determine cfm value, and .3187 is a correction factor for Ford standard temperature and pressure (see P_05EC). Since a MAF provides a direct measurement of air mass, those wishing to convert from VAM to MAF need to bypass the AMT calculation step in the fuel equation. In order to do this, you'll have to select a set value for all of the "Y" column values in F_0FEE. I prefer .25 since it is a nice "round" number in PCMX, and more importantly because it is a half-scale value (i.e., the acceptable range in F_0FEE is 0-.5). Making all of F_0FEE's "Y" column values the same makes it impossible for variations in barometric pressure and ambient temperature to affect the EEC's AMVAL calculation via the BAP and VAT sensor inputs. You'll be leaving that task up to the MAF from now on.

Resultant AMVAL at 256 CFM of Airflow: 20.396484375 lbs/min. I arrived at this number by using the AMVAL equation and the corresponding "long" values in PCMX:

AMVAL=Lbs/Min=CFM*.3187*AMT=256*.318695068359375*.25

256 cfm is a good starting point for our calculations is because it is a nice "round" number in PCMX and because it is a half-scale value (the acceptable numeric range in F_0ED6 is 0-512). We will use this number to help scale the "Y" column values of the VAM transfer function so that they accurately represent flow in lbs/min.

Finding the Best Scalar for "Y" Column in VAM Transfer Function: Since we'll be using 256 cfm as our starting point for finding the correct scalar for F_0ED6, and since none of the "stock" "Y" column values are exactly 256, you'll need to change the final cfm entry from 361 to 256 for testing purposes. Once this is done, simply edit F_0ED6 by changing the "Y" column scalar value until the final "Y" column value is as close to 20.396484375 as possible. What you'll find is that whenever the "Y" column scalar for F_0ED6 is set to 1606.5, the function's airflow values most closely approximate the correct lbs/min values whenever AMT remains "fixed" at .25 and at the rest of the fuel equation (i.e., P_05EC) remains unchanged. However, since we will be using a P_0404 value of 2 (actually 1.99996948242188) in order to get around the initial MAF clip, we'll need to halve the "proper" scaling value to 803.25. Using this scalar value allows the tuner to enter the flow rates from his or her MAF flow sheet into the "Y" column of F_0ED6 in terms of lbs/min.

<u>Best Mass Air Flow Multiplier Value (P_0404)</u>: 1.99996948242188. This is the maximum value that PCMX will allow you to enter. Using this multiplier value helps the tuner "work around" a max air flow clip of 32 lbs/min, upping it instead to 64 lbs/min.

<u>Changing the MAF Sampling Average at Idle</u>: Changing the value in P_0408 from 1 to 3 can help improve idle quality.

<u>Changing the VAF Low and High Limits</u>: Because the VAM produces a voltage signal KOEO, the stock P-series code sets a VAF low limit of .1709V at P_0520 and a minimum VAF signal of .2179 at P_1E08. Since the MAF sensor does not produce any signal voltage unless the motor is running, you'll want to change both of these values to 0. Also, since most MAF meters are on a 5V scale, you'll probably want to bump the value of P_0522 a bit higher than 4.5 V. I set mine to 4.8V.

<u>Adjusting F_0A58 to Accept Higher Voltage Signals</u>: Since most MAF meters are on a 5V scale, you'll probably want to bump some of the "Y" column values in the Max VAF vs. RPM function to allow for higher readings. I changed all values >3000 rpm to 4.6V.

<u>Expanding the MAF Transfer Function to Include More Data Entry Points</u>: Some consider this to be an unnecessary step in the conversion process, and to an extent it is. Since the "stock" VAM transfer table only contains 25 rows, I worry that I'll lose a fair amount of meter resonance by shrinking a 48-point flow sheet to fit a 25-point table. There is, however, a fairly simple fix we can use to enlarge F_0ED6 to contain 32 or even 36 rows. This task requires a modicum of familiarity with using the hex editor in PCMX. Since the functions F_0EAA, F_0E9E, and F_0E92 aren't really utilized in the P-series strategy, we can all feel comfortable shrinking them for the sake of expanding F_0ED6 into their territory.

- Thankfully, there is only one place in the P-series code that "calls out" the table address for the MAF transfer function, and its hex location is 0x1E8E. Once you expand the MAF transfer function, you'll want to change this hex value from 2ED6 (the normal starting point for the VAM transfer function) to either 2EBA (for the 32-point table) or 2EAA (for the 36-point table).
- Point-by-point directions for building a 32-point table:
    - Step #1—Edit F_0ED6 by changing the function size to 32.
    - Step #2—Edit F_0ED6 by changing the "X" axis address to 0x0EBA.
    - Step #2—Edit F_0ED6 by changing the "Y" axis address to 0x0EBC.
    - Step #3—Edit F_0ED6 by changing the "Y" axis units to Lbs/Min.
    - Step #4—Edit F_0ED6 by changing the "Y" axis format to %5.2f.
    - Step #5—Edit F_0ED6 by changing the "Y" axis max to 33.
    - Step #6—If you like you can change the VAM transfer function's name to reflect it's new purpose and location (i.e., 0EBA MAF Transfer).
    - Step #7—Enter your 32 data points into your newly created MAF transfer function.
    - Step #8—Change hex location 0x1E8E from D6 to BA.
    - Step #9—Rename and save the .bin and .rdt files.
- Point-by-point directions for building a 36-point table: Constructing a 36-point table is a bit more involved since it requires emendations to four functions instead of one.

- Step #1—Edit F_0ED6 by changing the function size to 36.
- Step #2—Edit F_0ED6 by changing the "X" axis address to 0x0EAA.
- Step #2—Edit F_0ED6 by changing the "Y" axis address to 0x0EAC.
- Step #3—Edit F_0ED6 by changing the "Y" axis units to Lbs/Min.
- Step #4—Edit F_0ED6 by changing the "Y" axis format to %5.2f.
- Step #5—Edit F_0ED6 by changing the "Y" axis max to 33.
- Step #6—If you like you can change the VAM transfer function's name to reflect it's new purpose and location (i.e., 0EAA MAF Transfer).
- Step #7—Enter your 36 data points into your newly created MAF transfer function.
- Step #8—Change hex location 0x1E8E from D6 to AA.
- Step #9—Edit F_0EAA by changing its size to 4.
- Step #10—Edit F_0EAA by changing its "X" axis address to 0x0E9A.
- Step #11—Edit F_0EAA by changing its "Y" axis address to 0x0E9C.
- Step #12—Change the function's name to reflect its new location (i.e., 0E9A Load [TRI for M_08A5 KAM]).
- Step #13—Enter the values that were in rows 8-11 of F_0EAA in the stock file into rows 1-4 of the new function.
- Step #14—Edit F_0E9E by changing its size to 2.
- Step #15—Edit F_0E9E by changing its "X" axis address to 0x0E96.
- Step #16—Edit F_0E9E by changing its "Y" axis address to 0x0E97.
- Step #17—Change the function's name to reflect its new location (i.e., 0E96 KAM spark advance gain)
- Step #18—Enter the values that were in rows 5-6 of F_0E9E in the stock file into rows 1-2 of the new function.
- Step #19—Edit F_0E92 by changing its size to 2.
- Step #20—Rename and save the .bin file and .rdt files.

Upping the Max Air Flow Limit to 64 lbs/min: Change hex location 0x2312 from 01 to FF. Change hex location 0x2313 from 3A to FF. This change is necessary for those of us whose motors move more than 32 lbs/min worth of air.

Important Equations for the 2.3 Turbo EEC Fuel Strategy

Actual Injector Pulsewidth for Open Loop Operation: BASEPW * OLBF Multiplier (M_06AD) * WOTPW Multiplier (F_0C50).

AMT: Stands for "Air Mass Transfer;" $\sqrt{\dfrac{BAP}{VAT + 460}}$

AMVAL: Metered airflow rate in Lbs/Min. It's determined from the following sensor inputs and an equation.

- Volume airflow measurement as determined by the VAM voltage signal and the VAM transfer function (F_0ED6).
- Air inlet temperature measurement as determined by the VAT transfer function (F_0F5E).
- Barometric pressure measurement as determined by the BAP transfer function (F_0F7A).
- Calibration adders for development.
- Correction factor for Ford standard temperature and pressure; .3187 is the Ford correction factor (P_05EC)
- AMVAL = Lbs/Min = CFM * .3187 * AMT

AO: Injector slope value in lbs/sec. The EEC stores the injector slope in lbs/hr at P_04B2. To convert the value at P_04B2 to lbs/sec, simply divide by 3600 (the number of seconds in one hour).

ARCHG/Load: Engine airflow in mass air charge per intake stroke. Its value is determined by means of an equation. The EEC uses load and rpm amounts to determine what open loop base fuel multiplier value to use (M_06AD).

- ARCHG = $\dfrac{AMVAL}{2 * RPM}$
- The number 2 represents the number of intake strokes that occur for every 1 revolution of the crankshaft in a four-cylinder motor. In a six cylinder engine this number would be 3, in an eight cylinder motor this number would be equal to 4, etc.

BASEPW: Base injector pulsewidth in secs needed to achieve a 14.64:1 A/F ratio. It's calculated on the basis of the following equation.

- BASEPW = $\dfrac{ARCHG}{2 * AO * 14.64 * lambda}$
- In all open loop operation, lambda equals 1 (i.e., it has no effect on the equation). Lambda values only play a part in closed loop operation, and are dependent on HEGO sensor readings.

HP = $\dfrac{60 * AMVAL}{BSFC * A / FRatio}$

- Typical BSFC (brake specific fuel consumption) values range from .5 (naturally aspirated) to .6 (forced induction). BSFC rates an engine's efficiency in terms of fuel usage. More specifically, it is the measured fuel flow in pounds per hour divided by the horsepower. The brake specific rule of thumb says that a typical engine will burn one half pound of fuel per horsepower per hour, or .5 BSFC.
- I can use this formula in order to calculate the AMVAL value needed to support "x" amount of horsepower.

WOTPW: Injector pulsewidth in secs needed to satisfy the conditions specified by M_06AD and F_0C50.

- $\text{WOTPW} = \dfrac{ARCHG}{2 * AO * 14.64 * OLBFM * WOTPM}$
- OLBFM = M_06AD
- WOTPM = F_0C50

Desired A/F Ratio = 14.64 * (BASEPW/EFIPW) or in most cases, Desired air/fuel ratio = 14.64 (1/M_06AD * F_0C50)

Fuel Pulsewidth: This is just a combination of the equations for ARCHG and BASEPW. The product is the same as BASEPW.

- Fuel Pulsewidth = mass air flow/[(2*RPM)*(2*injector size*14.64)]

MAF via the EEC-Tuner

This document will go into detail on how I adapted a MAF unit onto my P-series EEC using the EEC Tuner.

Mark Proctor has covered the basics, and his document "MAF Conversion Made Simple" is considered required reading before going any farther.

Mark's document goes into detail on how to effectively disable VAM to MAF calculations; this document will show how to completely remove the calculations, and why.

In my opinion, this is the best way, mainly because it gets rid of unneeded calculations and tables. The only drawback is it requires a hex editing program to make the required changes for the initial setup.

Before I get started, I would like to thank Dan Covin, Randy Schlitz, Dan Stokes, and the Tuner23 list for all the help I've received up to this point

How the EEC gets a Mass Air value from the VAM, VAT, and BAP:

First, it reads in the Barometric Air Pressure (BAP) and multiplies it by 2097152

```
3E5C:  LDB R37, RA5          : R37 = BAP
3E5F:  CLRB R36              : R37:R36 = BAP * 256
3E61:  SHRW R36, 03          : R37:R36 = BAP / 8 => BAP * 32
3E64:  CLRW R34              : R35:R34 = 0X0000 => BAP * 32 * 65536
```

Second, it reads in the Vane Air Temp (VAT) and divides it by 2, adds 115, and multiplies it by 256

```
3E66:  LDB R31, R73          : R31 = VAT
3E69:  JNB R73, 7, 3E6E      : if bit 7 of VAT is clear, then goto 3E6E
3E6C:  NEGB R31              :  else negate R31
3E6E:  SHRB R31, 01          : R31 = R31 / 2 => VAT = VAT / 2
3E71:  JNB R73, 7, 3E76      : if bit 7 of VAT is clear, then goto 3E76
3E74:  NEGB R31              :  else negate R31
3E76:  ADDB R31, #73         : R31 = R31 + 115 => VAT = VAT / 2 + 115
3E79:  CLRB R30              : R31:R30 = VAT * 256 => VAT = (VAT / 2 + 115) * 256
```

Third, it divides the modified BAP by the modified VAT
Essentially: (BAP x 8192) / (VAT/2 + 115)
And uses the function at 2FEE to find the actual Air Mass Multiplier (AMM)

```
3E7B:  DIVW R34, R30         : R35:34 = R35:34 / R31:30
3E7E:  LDW R32, #2FEE        : R33:32 = 2FEEh -> Start of Air Mass Transfer Table
```

```
3E82:  CALL 40C6            : Call lookup function
```

It then multiplies the AMM by the Air Volume Multiplier (0.3186)

```
3E85:  ML2W R38, $25EC   : R3B:38 = R39:38 * 5196h => AMM = AMM * 20886
3E8A:  LDW R3E, R3A      : R3F:3E = R3B:3A => AMT = AMM * 20886 / 65536
```

So what have we accomplished so far? Basically, AMT= $\sqrt{\frac{BAP}{VAT + 460}}$

The EEC code has no operation for square root, which is why a lookup table and extra calculations are needed.

Now we need the air volume. This part reads the VAM and uses a lookup table to convert the voltage to a flow number.

```
3E8D:  LDW R32, #2ED6    : R33:32 = 2ED6h VAM Transfer table
3E91:  LDW R34, RB8      : R35:34 = VAM
3E94:  CALL 40C6         : Call lookup function
```

Finally, we get to multiply the VAM volume flow by the Mass Air multiplier:

```
3E97:  ML2W R38, R3E     : R3B:38 = R3F:3E * R39:38 => MAF = AMT * VAM
3E9A:  CMPB R3B, #20     : if MAF < 2000h
3E9D:  JNC 3E93          :  then goto 3E93 (max flow has not occurred)
3E9F:  LDW R3A, #FFFF    :  else R3B:3A = FFFF
3EA3:  SHLDW R38, 03     : MAF = MAF * 8
3EA6:  LDW R_90, R3A     : R91:90 = MAF => R90 is top 2 bytes of MAF value
```

Through all this, there are 7 calculations (multiply, divide, shift) and two table lookups.

Here is the code I use, it reads the MAF voltage, then looks the voltage up in the MAF transfer function to get the corresponding mass air flow.

```
3E5C:  LDW R_32, #2ED6   : R33:32 = MAF transfer table
3E60:  LDW R_34, RB8     : R35:34 = MAF (voltage)
3E63:  CALL 40C6         : Call lookup function
3E66:  LDW R_90, R38     : R91:90 = MAF
3E69:  SJMP 3EA9         : goto 3EA9
3E6B - 3EA8: 00          : FILLER
```

No calculations and only one table lookup. I don't think it gets any simpler ☺

Determining the correct scalar:

This is the fun part. The VAM function was setup to convert volume flow into hex numbers, not mass flow.

Mark did this by using the formulas in his document, I use actual hex values, and run it through the same way the EEC does.

So, here goes:

We'll use the STP (standard temperature and pressure) values, where the density 0.002378 slugs/ft^3 (1.22556 kg/m^3) occurs at 59 F and 29.92 in. Hg.

59F is 1D80h
29.92 in. Hg is EF5Ch

The EEC only uses the MSW, so:
VAT = 1D
BAP = EF

Let's start crunchin' (all numbers in HEX, except comments)

```
BAP = EF          ; start
BAP = EF00        ; *256
BAP = 1DE0        ; /8
BAP = 1DE00000    ; *65536

VAT = 1D          ; start
VAT = 0E          ; /2
VAT = 81          ; +115
VAT = 8100        ; *256
```

X = 1DE00000 / 8100 => 3B49

3B49 in the 2FEE table comes out to:
(6666, A1E8) (3333, 727C)

```
Y = A1E8 - (A1E8 – 727C) * (6666 – 3B49) / (6666 + 3333)
AMM = 79FA
AMT = 26DF927C    ; *20886
AMT = 26DF        ; /65536
```

So at this point, we have our Mass Air multiplier, now we need the air volume
For example, we'll say the VAM is flowing 200 CFM, and skip the lookup function.

```
VAM = 6400          ; 6400 = 200CFM
MAF = 0F2F1C00      ; AMT * VAM
MAF = 7978E000      ; *8
MAF = 7978          ; Top two bytes
```

So, now we now that 200CFM at 59F and 29.92 in. Hg is 7978h, or 31096

Now we need to convert this to either lbs/min or kg/hr.

The air density at 59F and 29.92 in. Hg is .002378 slugs per cubic foot or 1.22556 kg per cubic meter

200 * 0.002378 = 0.4756 slugs/min
0.4756 * 32.174 = 15.302 lbs/min

Even though a slug is a mass and a lb is a force, we use lbs anyways…..

For kg/hr:
200 CFM x 1.69901079552 = 339.802 CMH (cubic meters per hour)
339.802 x 1.22556 = 416.448 kg/hr

So, if you want to use lbs/min:
31096 / 15.302 = 2032.153

If you want to use kg/hr:
31096 / 416.448 = 74.670

With a MAF multiplier of 2.0, use:
2032.153 / 1.9998779296875 = 1016.139
74.670 / 1.9998779296875 = 37.337

Comparison
So now the big question is, will these numbers match Mark's?

The BAP/VAT calculations are ignored, since Mark sets the Air Mass Transfer table to 0.25 (8000h). No matter what comes in, 8000h is coming out.

AMM = 8000
AMT = 28CB0000 ; *20886
AMT = 28CB ; /65536

Mark is using a scalar of 1606.5, so if we use the 15.302 lbs/min (200CFM @ STP) from above:
1606.5 x 15.302 = 24582.663
VAM = 6006h

MAF = 0F4D14C2 ; AMT x VAM
MAF = 7A68A610 ; *8
MAF = 7A68

Mark's 7A68 compared to the actual 7978 is a 0.77% difference.

Enough to worry about? Not really.

How to do it

You will need a Hex Editor, I use Hex Edit, from http://www.expertcomsoft.com/ the older versions are available for free, and works pretty well.

Go to location 1E5C, and replace the following hex:
B0 A5 37 11
36 08 03 36 01 34 B0 73 31 37 73 02 13 31 18 01
31 37 73 02 13 31 75 73 31 11 30 8C 30 34 A1 EE
2F 32 EF 41 02 6F 01 EC 25 38 A0 3A 3E A1 D6 2E
32 A0 B8 34 EF 2F 02 6C 3E 38 99 20 3B D3 04 A1
FF FF 3A 0D 03 38 A0 3A 90

With:
A1 D6 2E 32
A0 B8 34 EF 60 02 A0 38 90 20 3E 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00

If you want to use a 32 point curve (and I highly suggest you do)
Replace D6 with BA in the first line: (replacing step 8)
A1 BA 2E 32

Then follow the rest of the instructions in Mark's document for a 32 point curve.

While you're in the hex editor, go ahead and remove the overflow checking to allow flow values greater than 32 lbs/min (870 kg/hr), again, refer to Mark's document.

For the MAF transfer definition, follow Mark's instructions, but instead of the 1606.5 he uses, use one of the following:

For lbs/min and a 1.0 MAF multiplier:	2032.153
For lbs/min and a 2.0 MAF multiplier:	1016.139
For kg/hr, and a 1.0 MAF multiplier:	74.670
For kg/hr, and a 2.0 MAF multiplier:	37.337