

Trionic 7 Documentation

Dilemma, typeset in L^AT_EX by Jonathan Jogenfors

September 27, 2015

Todo list

Figure:	10
Who is this?	11
Add reference	11
link	15
link	16
Figure:	16
Figure:	16
Figure:	19
Figure:	19
Figure:	20
Figure:	21
Figure:	21
Figure:	22
Figure: DI Cassette	23
Figure: idlecontrol	23
Figure: Ignition is normally controlled by the main ignition matrix: IgnNormCal.Map	23
Figure: PedelMapCal.m_RequestMap	25
Figure: TorqueCal.M_NominalMap	25
Figure: footer	27
Figure: AirCtrlCal.m_MaxAirTab	29
Figure: Altering airmass p37	31
Figure: Torque limiters	33
Figure: TorqueCal	35
Figure:	36
Emphasize the limitations of tuning wizard	37
Figure: Tuning wizard images	37
Figure: DB9	41
Section should be updated with p-bus obd2 information	41
Figure: Desk connection to ecu	42
Finish I-bus and P-bus section	43
Internal link	45
Figure: bdm-adapter	49
We should only use SI units	52
Figure: Compressor map	52
imperial warning	54
must convert to metric	54

Chapter 1

Introduction

This document is intended for Saab fanatics and engineers who want to start understanding the Saab Trionic 7 motor management system. It will give as much information as possible about the technical part of the system. The only limitation will be the knowledge of the author. In short the content of this document will enable you to understand Trionic 7 better and give you hands-on information about altering the maps it uses. Prerequisites are minor electronics and computer knowledge and of course some understanding of how a turbo charged engine works. Throughout the document the T7Suite software will be referenced. This software will enable you to really “get into” the Trionic. The T7Suite software can be downloaded from the T7Suite website.

Contents

1	Introduction	5
2	Hardware	9
2.1	Integrated Circuit List	9
2.2	Block Schematic Diagram	9
2.3	DI Cassette	9
3	Flashing	11
3.1	Checksums	11
3.1.1	FB and F2 checksums	11
3.1.2	Misc checksum	11
3.1.3	Area 70000 checksum	12
3.2	Computing the Checksums	12
4	Firmware	13
5	Symbol table	15
5.1	Finding start of symbol table:	15
5.2	Finding start of address lookup table:	15
6	Maps	17
6.1	Fuel	17
6.1.1	DI Cassette	22
6.1.2	Idle control	23
6.2	Torque	23
6.2.1	Torque request	24
6.3	Second lambda sensor	25
6.3.1	Turning off second lambda sensor	25
6.3.2	Alternative solution to turning off second lambda	25
6.4	Calibration of OBD2 and LEV EVAP systems	26
6.4.1	Info on LEV (Low Emission Vehicle)	26
6.5	Footer information	26
7	Tuning Trionic 7	29
7.1	Tuning with T7Suite	29
7.1.1	AirCtrlCal.m_MaxAirTab	29
7.1.2	AirCtrlCal.m_MaxAirE85Ta	29
7.1.3	BoostCal.I_LimTab	29
7.1.4	BoostCal.P_LimTab	30
7.1.5	BoostCal.RegMap	30

7.1.6	BstKnkCal.MaxAirmass	30
7.1.7	BstKnkCal.MaxAirmassAu	30
7.1.8	FCutCal.m_AirInletLimit	30
7.1.9	IgnE85Cal.fi_AbsMap	30
7.1.10	IgnNormCal.Map	30
7.1.11	MapChkCal.CheckSum	30
7.1.12	MaxVehicCal.v_MaxSpeed	30
7.1.13	PedalMapCal.m_RequestMap	30
7.1.14	TorqueCal.M_ManGearLim	30
7.1.15	TorqueCal.m_AirTorqMap	31
7.1.16	TorqueCal.M_EngMaxTab	31
7.2	Tuning Boost calibration	31
7.3	Altering Airmass limiter	31
7.4	Altering fuelcut	32
7.5	Engine speed limiter	32
7.6	Vehicle speed limiter	32
7.7	Airmass request	32
7.8	Torque limiter	32
8	Automatic transmission specifics	35
9	Using the tuning wizard	37
10	OpenSID values	39
11	CAN bus interface	41
11.1	General information	41
11.2	OBD2 socket pinout	41
11.3	Saab I-bus communication	42
12	General tuning advice	45
13	Acknowledgements	47
A	BDM Technical Information	49
A.1	Home build 2 chips design schema	49
A.2	BDM Pinout	49
B	Understanding turbo compressor maps	51
B.1	Reading a compressor map	52
B.1.1	Choke area	53
B.1.2	Compressor maximum flow	53
B.1.3	Compressor maximum pressure	53
B.1.4	What the compressor map reads	53
B.1.5	Comparing compressor maps	54
B.2	Selecting a different turbocharger	54

Chapter 2

Hardware

The Trionic 7 is built around a Motorola MC68332 (CPU32) microcontroller. This is a 32-bit controller that handles the entire motor management including fuel injection, ignition timing and boost pressure control. The processor has a vast 4 MB (512 kB) flash memory for fetching program code and maps. This flash memory consisting of a AM29F400BT-90SI (AMD) holds the program memory. There is a coprocessor from Philips, a P83C592FHA/019. This is a 8-bit 8051-based microcontroller with a CAN (Controller Area Network) module. As the CAN physical line driver there is an Intel AN82527 (same family as used in Trionic 5). RAM memory is done by two 32 kbit SRAM chips (U62H256S1K). There is also a special component that would appear to be a barometric pressure sensor.

2.1 Integrated Circuit List

The table below lists almost all integrated circuits on the board. This is just to give you an idea on what to expect.

2.2 Block Schematic Diagram

2.3 DI Cassette

The DI cartridge has a trigger input for firing the four individual sparkplugs. These are triggered by signals from the ECU on pin 9, 10, 11 and 12 which are generated in the power driver IC CA3236 on the Trionic PCB (topside, 16 pin DIL housing). Internally these four pins are connected as shown in the table and the image below.

Partnumber	Function	Usage	# on board
TC55257DFI-85L	SRAM	(working memory)	1
16233970	Microcontroller	Main 32-bit CPU	1
PC83C592	Microcontroller with CAN contr.	8-bit coprocessor	1
AM29F400	Flash memory	4 Mbit	1
51862	DA converter		1
AN82527	CAN controller CAN line driver	1	
16238669 0H11	Pressure sensor?		1

Table 2.1



Figure 2.1

DI cartridge pin	ECU pinnumber	CA3236 pinnumber	Description
2	7	1 (OUT A)	Trigger cylinder 1
3	8	3 (OUT B)	Trigger cylinder 2
4	67	6 (OUT C)	Trigger cylinder 3
5	68	8 (OUT D)	Trigger cylinder 4

Table 2.2

Chapter 3

Flashing

The Trionic 7 ECU binary images uses several checksums to verify integrity. Most of them have been easy to figure out, but one of them is so complicated, that it seems to been done to deter map changing. There are still some unknowns, that would be nice to figure out. For example, I've discovered some binaries don't seem to have all four checksums. And of course there could be more checksums that have gone unnoticed. Two of the checksums are in the end of the binary and the other two are scattered in the code. The latter ones can be found by using pattern searching. Again the calculations are pretty simple, and even the harder checksum is easy to implement. Big thanks to solving these things goes to Tomi and General Failure.

3.1 Checksums

First of all, there are four different checksums. They have been given names by Tomi: FB checksum, F2 checksum, Misc checksum, and Area 70000 checksum. Who is this?

3.1.1 FB and F2 checksums

The first two checksums, FB and F2, can be found at the end of the binary. This end area has been called the file header (footer would be more logical). See also chapter Trionic 7 file header. The F2 checksum is not present in all binaries, so be aware of this. Finding the two other checksums is more of a challenge. Add reference

3.1.2 Misc checksum

The Misc checksum resides inline within the code. It is usually found somewhere between 0x02000 and 0x05000. The checksum address can be found by pattern searching the bin file using a set of hex values along with mask bits. If a mask bit is not set, the corresponding hex value does not have to match. Here are the hex values: 0x48, 0xE7, 0x00, 0x3C, 0x24, 0x7C, 0x00, 0xF0, 0x00, 0x00, 0x26, 0x7C, 0x00, 0x00, 0x00, 0x00, 0x28, 0x7C, 0x00, 0xF0, 0x00, 0x00, 0x2A, 0x7C and the mask is 1, 1, 0, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 1.

So, we are searching the binary for a string of bytes beginning with 0x48, 0xE7, 0x00, 0x3C... Then we mask out the bytes that change from binary to binary. When we've located this pattern, we know where to start. Now we start primitively disassembling the code. We search for byte patterns 0x48, 0x6D, 0x48, 0x78, 0x48, 0x79, 0x2A, 0x7C and 0xB0, 0xB9. The three first patterns reveal addresses and lengths of checksum areas. There are 15 checksums areas from which the Misc checksum is calculated. The 0x2A, 0x7C pattern gives a base address for the 0x48, 0x6D addresses.

Bear with me. These 0x2A, 0x7C addresses are summed with the base address to make the actual address. This way the address is only 2 bytes long. On the 0x48, 0x79 addresses it's 4 bytes long

without any base address. And the 0x48, 0x78 pattern gives 2 bytes which correspond with the length of the checksum area. Finally the 0xB0, 0xB9 pattern is followed by 4 bytes to the address of the Misc checksum.

3.1.3 Area 70000 checksum

This checksum refers to an area in the region of 0x70000. Like the Misc checksum, there is no clean way of finding out the length of the area along with the checksum address. Using pattern searching with this also has results. There are binaries that are incompatible with this approach, so this requires some fixing in the future. The pattern is 0x20, 0x3c, 0x00, 0x00, 0x11, 0x52, 0x2F, 0x00, 0x20, 0x3C, 0x00, 0x00, 0x09, 0xD0, 0x2F, 0x00, 0x20, 0x3C, 0x00, 0x00, 0x00, 0xCC, 0xD0, 0x9F and the mask is 1, 1, 0, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 1

After finding that pattern, the masked addresses are summed together. In the pattern, the original addresses are 0x00001152, 0x000009D0 and 0x000000CC. Summing these gives the Area 70000 length of 0x1BEE. At the same time this is the address where to find the Area 70000 checksum.

3.2 Computing the Checksums

The FB checksum shares the same calculation method as the Misc and Area 70000 checksums. It's simply a sum of the bytes from the checksum area. Four bytes are made into a 32 bit value and summed with the next 32-bit value. This goes on until there are fewer than 4 bytes left. The last 1, 2 or 3 bytes are then individually summed together with the checksum.

The Misc checksum is a sum of the individual checksums calculated from 15 areas. The checksum calculation used is the same as with the FB checksum.

Once you have found the length of Area 70000, you can calculate the checksum by using the function described in section 3.1.1. The start address is 0x70000. Notice that your binary might not have this area present.

Chapter 4

Firmware

Once you are done with dumping the flash contents and you want to do more than only alter variables and maps you can start analyzing the binary. This is a difficult task because there are a lot of different firmware versions, stock ones – maybe different per MY and tuned ones that differ for every manufacturer and stage. In every case the code can be disassembled using a 6833x disassembler like the one in IDA Pro. There are scripts available to automatically disassemble the code and make it more readable by replacing addresses by variable names that are extracted from the symbol table inside the binary.

Chapter 5

Symbol table

Each Trionic 7 firmware file contains a symbol table describing data structures in the program. The major problem is that from some point in time SAAB started to compress the symbol tables in the binary file. Probably just to save space in the flash memory but it has made tuning a little harder. We actually need these symbol names because they tell us what a certain memory location means. For unpacked binaries these symbols can be extracted together with their corresponding memory addresses (ROM and RAM).

```
000015d0h: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ; .....
000015e0h: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ; .....
000015f0h: 00 00 00 00 00 00 00 00 00 00 42 6C 6F 63 6B 54 ; .....BlockT
00001600h: 79 70 65 00 42 6C 6F 63 6B 2E 54 69 6D 65 72 00 ; type.Block.Timer.
00001610h: 42 6C 6F 63 6B 2E 54 69 6D 65 72 31 00 FF 42 6C ; Block.Timer1.ÿBl
00001620h: 6F 63 6B 2E 54 69 6D 65 72 32 00 FF 42 6C 6F 63 ; ock.Timer2.ÿBloc
00001630h: 6B 2E 41 44 5F 54 68 72 6F 74 74 6C 65 44 65 6D ; k.AD_ThrottleDem
00001640h: 61 6E 64 00 42 6C 6F 63 6B 2E 41 44 5F 54 68 72 ; and.Block.AD_Thr
00001650h: 6F 74 74 6C 65 53 75 6D 00 FF 42 6C 6F 63 6B 2E ; ottleSum.ÿBlock.
00001660h: 4E 65 77 00 42 6C 6F 63 6B 2E 4D 69 6E 00 42 6C ; New.Block.Min.Bl
00001670h: 6F 63 6B 2E 4D 61 78 00 42 6C 6F 63 6B 2E 6D 73 ; ock.Max.Block.ms
00001680h: 5F 43 6F 75 6E 74 65 72 00 FF 42 6C 6F 63 6B 2E ; _Counter.ÿBlock.
00001690h: 41 44 5F 54 6D 70 54 68 72 42 6C 6F 63 6B 00 FF ; AD_TmpThrBlock.ÿ
000016a0h: 42 6C 6F 63 6B 32 54 79 70 65 00 FF 42 6C 6F 63 ; Block2Type.ÿBloc
000016b0h: 6B 32 2E 46 43 4F 41 63 74 69 76 65 00 FF 42 6C ; k2.FCOActive.ÿBl
000016c0h: 6F 63 6B 32 2E 54 68 72 6F 74 74 6C 65 4F 4E 00 ; ock2.ThrottleON.
000016d0h: 42 6C 6F 63 6B 50 6F 74 69 32 54 79 70 65 00 FF ; BlockPoti2Type.ÿ
```

Figure 5.1

While examining the symbol table you can see that the separator is 0x00. In contrast to T5 where symbol and SRAM addresses reside in the same table, we now only find the symbol name. In another table in the binary we can find flash addresses and lengths in the same sequence as the symboltable.

5.1 Finding start of symbol table:

Search binary for string the first sequence of 15 zeros.

5.2 Finding start of address lookup table:

Search binary for 20 00 00 00 XX YY 00 F0 where XX YY is the index of the first symbol found in the symbollist.

To save you the time to lookup all addresses manually the T7Suite application will extract all symbol information in one run. Symbol name, flash address and length will be displayed all together.

This [image \(6\)](#) will give you an idea of what the symbol table should look like once it has been [link](#)

extracted. See appendix I for a complete list of known symbols.



Figure 5.2

When the user double clicks one of the symbols that has a flash address attached to it, T7Suite will display the corresponding symbol in a viewer. This viewer will display the data in table form as well as in graphical form.



Figure 5.3

Chapter 6

Maps

A lot of maps in Trionic 7 are not only made up of a piece of raw data. It also includes x-axis and y-axis information. T7Suite will automatically display all known axis information when a map is opened. In Trionic 7 most symbols have an English name (Trionic 5 has lots of Swedish names) that explains lots about its function. Also, the symbols are categorized by name, which makes browsing the symbols much easier. All torque calibration symbols start with “TorqueCal.”. T7Suite groups all symbols by their respective category by default.

6.1 Fuel

Fuel calculation in Trionic 7 is based on the Airmass entering the engine. In rough steps this seems to be the flow of the calculation:

Basic calculation of fuel quantity per combustion The current air mass/combustion is divided by 14.7 and sent to box 2. The unit is now in mg fuel/combustion

Compensation In case of a cold engine, shortly after starting, rapid load changes, knocking or high loads, the current value is multiplied by a compensation factor

Closed loop The closed loop value is used as a multiplier. The value is then sent to box 4

Correction for purge Multiply by the value for purge adaptation. The value is sent to box 5

Multiplicative adaptation (long term fuel trim) The multiplicative adaptation value is used as a multiplier and the new value is sent to box 6

Additive adaptation The additive adaptation value is added and the new value is sent to box 7

Starting fuel quantity If the engine has not yet started, starting fuel is selected. The value is sent to box 8

Fuel quantity per combustion to be injected The fuel quantity per combustion is the amount of petrol to be supplied to the engine. The value is sent to box 9

Injector opening duration Converts the value to the time during which the injector must be open and the new value is sent to box 10

Injection twice per combustion Injection takes place twice per combustion until the camshaft position has been found. Injection duration is divided by two. The value is sent to box 11

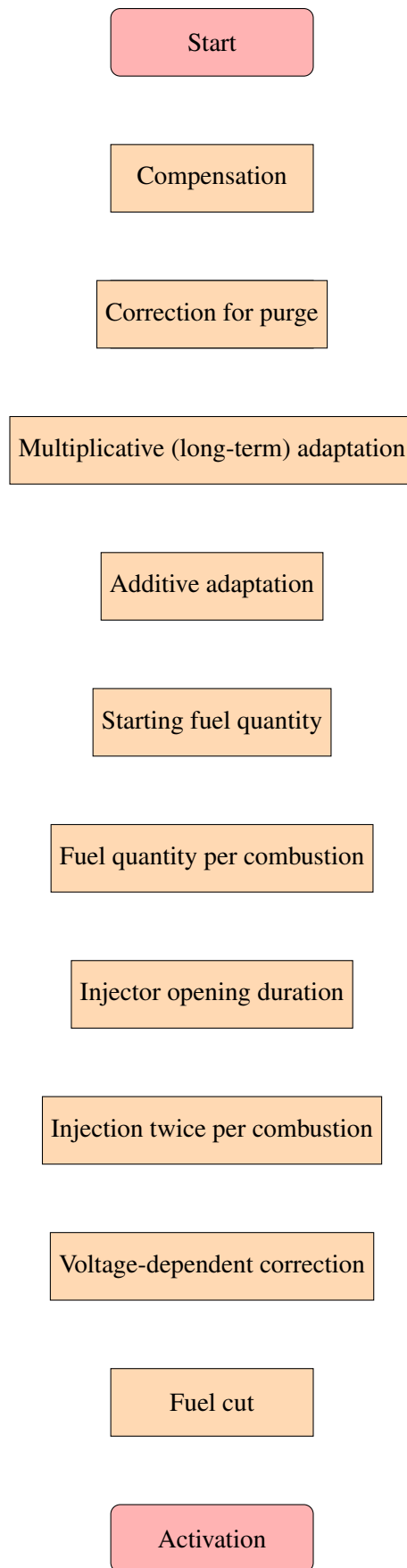


Figure 6.1: Flowchart for fuel calculation

Voltage dependant needle lift duration added (battery correction) Adds the injector time delay, which is voltage dependant. The value is sent to box 12

Fuel cut The value is sent to box 13 unless fuel cut is active

Activation of injector At a DETERMINED crank shaft angle, the microprocessor will control the transistor for the injector that is next in the firing order

The basic fuel quantity is calculated based on Airmass and Injector constant. This injector constant is called InjCorrCal.InjectorConstant. If the engine is not warmed up yet, an alternate fuel map is used called



Figure 6.2

BFuelCal.StartMap. If the engine has reached operating temperature the normal map "BfuelCal.Map" is used.



Figure 6.3

You will see the areas calibrated to be run in closed loop have a value of around 1.00. It can be .98-1.02 or so. Then you will notice the high load part of the maps ramp up to enrich the mixture. The trick is to set the closed loop part of the map first, the areas that are represented by values of 1.00.

You will need to switch closed loop off and drive around with a wideband in the tailpipe. What you want to achieve is an AFR of 14.7 for petrol while driving around under light loads where the value is 1.00. What Trionic 7 does is calculate the injection time to be say 5ms, if that is not correct it is multiplied by this map. Say you need to enter a value of 1.1 in the map to get correct AFR it will change injection time to 5.5ms ($5\text{ms} \times 1.1 = 5.5\text{ms}$)

The idea is to get closed loop area correct first. This will stop any negative adaption once the tune is finished and allowed to run in closed loop again. If the closed loop area of your fuel map is too rich it will negatively adapt over a long period of time. This will have the effect of leaning your AFR's across the board.

Example: you make a tune, closed loop AFR's are fine (because the O2 is making it fine through feedback) but unknown to you its rich and short term fuel trim is driving negatively 13% leaning off injection time by 13%.

You don't notice this and make some full power runs to check AFR its fine at say 12.5 AFR. After several weeks the multiplicative adaptation (Long term fuel trim) has absorbed some adaption and has earned a value of -13% this will now subtract 13% from whole fuel calculation including full power. All of a sudden your full power AFR has jumped up to 14.0 AFR, *engine failure happens very easily from here.*

Now back to fuel mapping. To set closed loop area of fuel map, monitor the AFR in this light load area and if its wrong after adjusting for large injectors, start by just adjusting the Injector constant up and down accordingly instead of altering the closed loop area of the BfuelCalMap. This will affect the whole map instead of one point. By doing it this way you can almost get AFR spot on in closed loop area just by a few goes at adjusting the injector constant.

It can be found in InjCorrCal.InjectorConst, the value represents the injectors flow in mg of fuel (not capacity or cc's as injectors are normally rated in). The injector constant is a calculation factor used by Trionic 7 to calculate injection time.

Once closed loop area is done the high load area can be mapped. If its too lean just increase the values in the relative column relating to what site of the map you are running in. Once your high load areas are done, activate closed loop again so you can see how it all runs. Monitor fuel adaptations and AFR etc.

One thing to note is how quickly it drops into open loop under full throttle. By going into open loop the o2 sensor is "masked" where the ECU listens to what its saying but ignores it, this allows afr's to go beyond 14.7 and injection correction is directly taken from the fuel map we just adjusted allowing much enrichment to cool charge etc.

To alter open loop enrichment you can change at what Airmass flow Trionic 7 switches to open loop in LambdaCal.MaxLoadNormTab. Also, open loop entry (so, leaving closed loop situation) has a delay attached to it. This way, short overruns of the maximum load will not immediately result in leaving closed loop. Stock bins often have this set to 2000 milliseconds which seems quite long. If you want to ECU to leave closed loop faster after overrunning the load limit, just decrease the time in LambdaCal.TimeOpenLoop.



Figure 6.4: Battery correction values for injector latency

1. Idling speed ignition timing With idle speed control active, the timing is adjusted to stabilize idle engine speed. The value is sent to box 3
2. Normal ignition timing When idle speed control is inactive, the ignition timing is read from a load and engine speed depending matrix. The value from the matrix is optimized for lowest fuel consumption (best engine torque) and sent to box 3



Figure 6.5: Water temperature correction



Figure 6.6: Fuel injection correction map for knock conditions

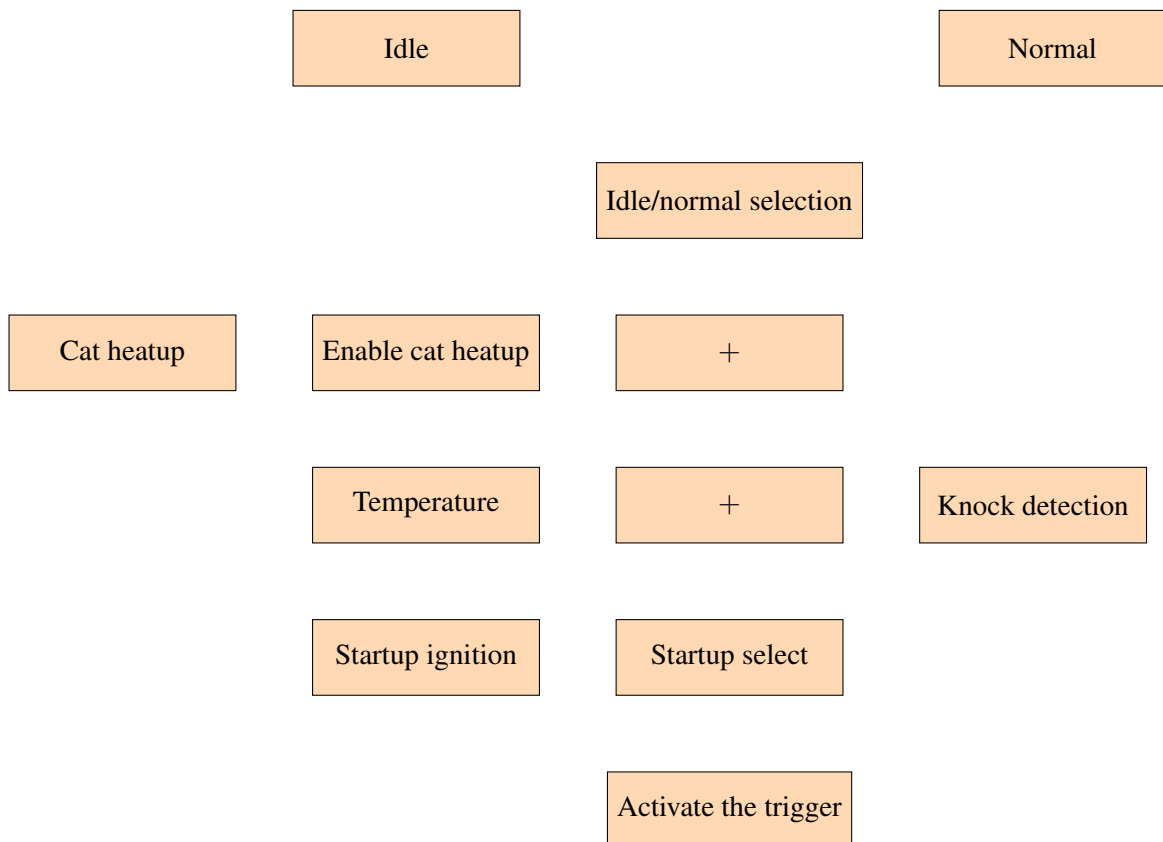


Figure 6.7: Flowchart for ignition calculation

3. Selection of ignition timing One of the ignition timing calculation is selected depending on which function is active. The value is sent to box 6
4. Catalytic converter heating timing In order to heat up the catalytic converter as fast as possible after start, the ignition will be retarded. This is a compensation matrix that is added to the value in box 3. The matrix is dependent on load and engine speed
5. Engagement of catalytic converter heating timing The function is active when coolant temperature is above -10 degrees Celsius and below +64 degrees Celsius
6. Total The value from box 5 is added to the value of box 3
7. Compensation The ignition timing is corrected depending on engine coolant temperature and intake air temperature. The value is sent to box 6.
8. Knock control If knocking occurs, a timing retardation will be calculated. The value is sent to box 6
9. Total The compensation angle and knock retardation are totalled to give the current ignition timing. The value is sent to box 7
10. Selection of ignition timing Starting ignition timing is selected when the engine has not been started. The value is sent to box 9
11. Starting ignition timing Starting ignition timing is selected when the engine has not yet been started. The value is sent to box 9
12. Activate relevant trigger At the calculated crankshaft angle, the microprocessor controls the transistor for the trigger that is next in firing order



Figure 6.8: ignition chart

6.1.1 DI Cassette

The ignition cassette is mounted on the valve cover on top of the spark plugs. The ignition cassette houses four ignition coils/transformers whose secondary coil is directly connected to the spark plugs. The ignition cassette is electrically supplied with battery voltage from the main relay (B+) and is grounded in an earth point. When the main relay is activated the battery voltage is transformed to 400 V DC which is stored in a capacitor. The 400 V voltage is connected to one of the poles of the primary coil in the four spark coils. Connected to the ignition cassette there are four triggering lines (from the Trionic ECU, pin 9 (cyl. 1), pin 10 (cyl. 2), pin 11 (cyl. 3) and pin 12 (cyl. 4)). When the ECU is grounding pin

9, the primary coil for the first cylinder is grounded (via the ignition cassettes B+ intake) and 400 V is transformed up to a maximum of 40 kV in the secondary coil for cyl. 1. The same procedure is used for controlling the ignition on the rest of the cylinders.

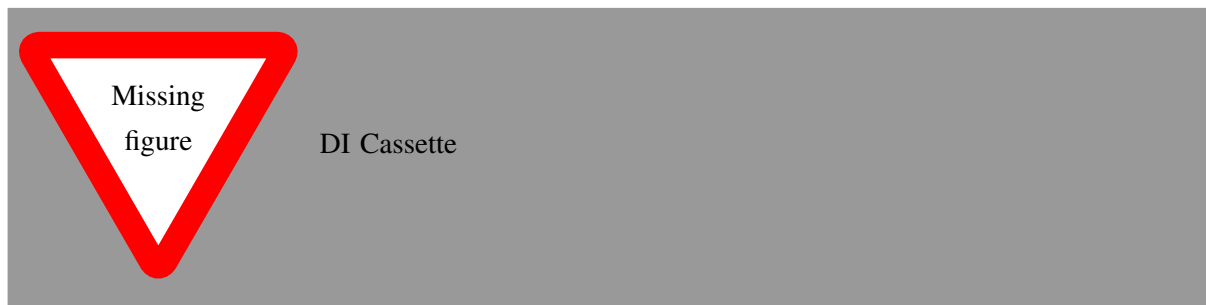


Figure 6.9: DI Cassette

6.1.2 Idle control



Figure 6.10: idlecontrol

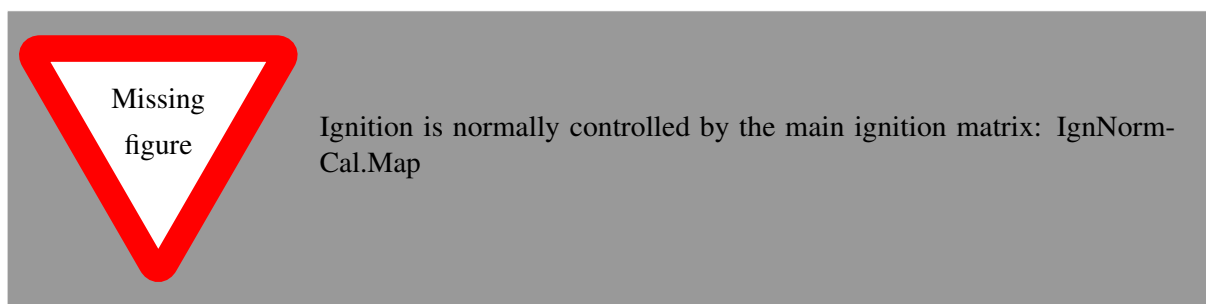


Figure 6.11: Ignition is normally controlled by the main ignition matrix: IgnNormCal.Map

6.2 Torque

Trionic 7 is a torque/Airmass request system instead of a boost request system like Trionic 5 is. The basic procedure for the Airmass controller is like in the table below.

1. Driver request The control module reads pedal potentiometer 1 and converts the voltage to Airmass per combustion (mg/c). The value is sent to box 3
2. Cruise control request When cruise control is active, the air mass per combustion required to maintain the set speed is calculated. The value is sent to box 3
3. Select highest value The control module selects the highest of the two values (box 1 or box 2). The value is sent to box 5
4. Engine torque limitation The maximum permissible air mass per combustion varies depending on the engine type. During operation, the maximum permissible mg/c must also be limited to protect the engine, gearbox, brakes and turbo
5. Select lowest value The control module selects the lowest value and sends it to box 8
6. Compensation request When the AC compressor is on, and when the heated rear window or radiator fan is on, the mg/c required to compensate for the increased load is calculated. The value is sent to box 8
7. Other air request The control module calculates the mg/c required for idle speed control. The value is sent to box 8
8. Totalling values The control module totals all the values. The total is sent to box 9
9. Total requested mg/c
10. Total Airmass request
11. Throttle control The requested mg/c is converted to requested voltage for throttle position sensor 1. The charge air pressure and intake air temp are used to correct this conversion. The throttle motor rotates the throttle until the current voltage for throttle position sensor 1 corresponds with the requested voltage
12. Current mg/c The requested mg/c is also compared with the current mg/c (MAF reading). If needed the requested voltage for throttle position sensor 1 is finely adjusted
13. Turbo control If mg/c is too high for throttle alone the turbo control will take over. The excess is converted to a PWM which controls the charge air control valve. The absolute pressure sensor is used to correct the conversion
14. Current mg/c The requested mg/c is compared to current mg/c and the charge air control valve PWM is finely adjusted if required

6.2.1 Torque request

So, if the driver (or cruise control for that matter) pressed the accelerator pedal he actually requests a certain Airmass from the system. This value is fetched from the PedelMapCal.m_RequestMap shown below.

The table holds Airmass values for each position of the accelerator pedal and each rpm site. Trionic now looks up the estimated engine output (torque) based on Airmass and rpm. This is done through map "TorqueCal.M_NominalMap" as shown next.

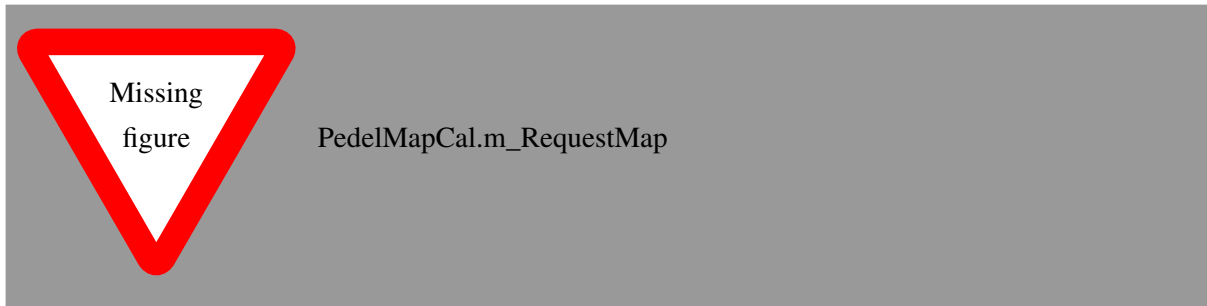


Figure 6.12: PedelMapCal.m_RequestMap

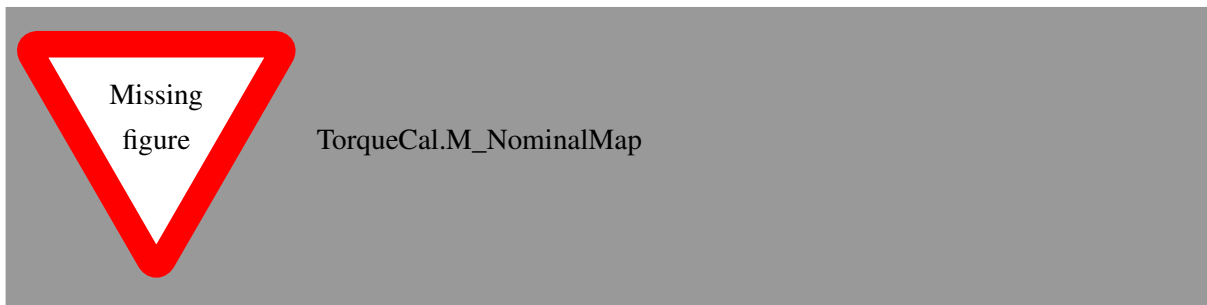


Figure 6.13: TorqueCal.M_NominalMap

6.3 Second lambda sensor

In the years Trionic 7 was shipped on cars, several things changed in these cars setups. One of the major changes was the introduction of the second lambda (oxygen, O₂) sensor that is placed after the catalyst to ensure the catalyst is working properly. If you want to run software from a double lambda sensor car in a single lambda car, you have to make some changes in the settings. This information is courtesy of L4staero.

6.3.1 Turning off second lambda sensor

You can use this procedure in cars having only one lambda sensor and in cars having two lambda sensors, but with a missing catalyst.

6.3.2 Alternative solution to turning off second lambda

Change low limit on O₂heaterPostCal.I_LowLim to 0 mA to disable sensor heater error, and change CatDiagCal.LoadHi and LoadLo to values never seen normally, like 30 and 20.

Map	Value	Description
LambdaCal.ST_AdapEnable	0	Second lambda sensor disabled
LambdaCal.ST_AdapEnable	1	Second lambda sensor enabled

Table 6.1

Map	Value	Description
O2HeatPostCal.I_LowLim	0	
CatDiagCal.LoadLo	20	Second lambda sensor disabled
CatDiagCal.LoadHi	30	
O2HeatPostCal.I_LowLim	230	
CatDiagCal.LoadLo	140	Second lambda sensor enabled
CatDiagCal.LoadHi	425	

Table 6.2

6.4 Calibration of OBD2 and LEV EVAP systems

If we want to run a file that was developed for OBD2 or a LEV car in an earlier car we run into problems because the early car is missing a second catalyst, a tank pressure sensor and a purge canister behind the fuel tank. If you have an early B205E/L engine you simply couldn't run a later B205R software version in it because it would through CEL's for the missing hardware. We need to make changes to the file before we can run in on an earlier car (e.g. switch of the control of the new hardware).

OBDCal.OBD2Enabled= This is self explanatory, if car is OBD2 put value at 1 if it's not OBD2 put value at 0.

On this point in later bins(compressed) there is EOBDEnable which is always on in EC2000 EU files and LOBDEnable which is always on in EC2000 RW files. File type is shown in firmware information under engine type.

OBDCal.EnableOBD2Limit= As above but its a 4 byte value. If done in Hex value for a OBD2 car is 00000001 and for non-OBD2 car is 00000000. As shown in T7suite is 2 values. OBD2 cars top value is 1 and bottom value is 0. In non OBD2 car both values are 0.

OBDCal.evapEquipmentExist= If car is equipped with a canister at rear of tank and a tank pressure sensor value will be 1. If neither exist value should be set to 0.

6.4.1 Info on LEV (Low Emission Vehicle)

For example take a 2001 9-3 Aero (or SE as called in USA) equipped with a B205R, Saab's decision to take all "R" engines and clean them so to speak by developing new emission systems for them leaves them with some differences to their low level engine relatives. The term LEV(Low emission vehicle) in this sense refers to Saab's decision to add a second catalytic converter and a tank pressure sensor and a large purge canister behind fuel tank, as well as adding a 2nd oxy to monitor condition of first cat.

6.5 Footer information

If we look at the footer in the binary (last page in hex viewer) we see a set of reversed strings. Each of these strings contains an identifier. These identifiers have a hardcoded meaning.

Identifier	Length	Description
0x91	0x09	Ecuid.vehicleidnr
0x94	0x07	Ecuid.ecuhardwversnr
0x95	0x0C	Ecuid.ecusoftwnr
0x97	0x1E	Ecuid.ecusoftwversnr
0x9A	0x04	Ecuid.softwaredate
0x9C	0x04	variable name table crc (not really sure)
0x9B	0x04	Symboltable (packed table with symbol names)
0xF2	0x04	F2 checksum
0xFB	0x04	Romchecksum.piareachecksum
0xFC	0x04	Romchecksum.BottomOffFlash
0xFD	0x04	RomChecksumType
0xFE	0x04	Romchecksum.TopOffFlash
0xFA	0x05	Lastmodifiedby
0x92	0x0F	Ecuid.partnralfacode (IMMO)
0x93	0x07	Ecuid.ecuhardwnr
0xF8	0x02	?
0xF7	0x02	?
0xF6	0x02	?
0xF5	0x02	?
0x90	0x11	Ecuid.scaletable (VIN)
0x99	0x06	Ecuid.testerserialnr
0x98	0x0D	Ecuid.enginetype
0xF9	0x01	Romchecksum.Error

Table 6.3



Figure 6.14: footer

Chapter 7

Tuning Trionic 7

7.1 Tuning with T7Suite

To get the ECU to produce more engine output, several parameters (maps) have to be altered. This chapter will give you a general idea on what to change – and why – for getting to an approximate stage II equivalent. The example is a 9-3 B205R.

7.1.1 AirCtrlCal.m_MaxAirTab

Airmass value from controller where area map has reached max-area and there is no point to increase the I-part. Resolution is 1 mg/c



Figure 7.1: AirCtrlCal.m_MaxAirTab

7.1.2 AirCtrlCal.m_MaxAirE85Ta

(if running on E85) Same as above for E85

7.1.3 BoostCal.I_LimTab

Load limit tab. to enable the I Part of boost regulator. If the load request from Airmass master is above this value plus the hysteresis is the I Part enabled and the throttle closed loop is disabled. If the load request from Airmass master is below this value is the I Part disabled and the throttle is allowed to run in closed loop.

7.1.4 BoostCal.P_LimTab

Load limit tab. to enable the P Part of boost regulator. If the load request from Airmass master is above this value plus the hysteresis is the P Part enabled. If the load request from Airmass master is below this value is the P Part disabled.

7.1.5 BoostCal.RegMap

Main constant matrix. Resolution is 0.1 %.

7.1.6 BstKnkCal.MaxAirmass

(divide by 3,1 for approx torque, ignition, airtmp etc affect this!) Map for max allowed Airmass for manual gearbox, m_nHigh. Resolution is 1 mg/c.

7.1.7 BstKnkCal.MaxAirmassAu

Map for max allowed Airmass for automatic gearbox, m_nHigh. Resolution is 1 mg/c.

7.1.8 FCutCal.m_AirInletLimit

If the "MAF.m_AirInletFuel" is higher than this limit during m_AirInletTime will the fuelcut be activated (pressure guard).

7.1.9 IgnE85Cal.fi_AbsMap

(if you want to change the ignition) Ignition map for E85 fuel. Resolution is 0.1 degrees.

7.1.10 IgnNormCal.Map

(if you want to change the ignition) Normal ignition map. Resolution is 0.1 degrees.

7.1.11 MapChkCal.CheckSum

(automatically updated in between every map change with T7suite!)

7.1.12 MaxVehicCal.v_MaxSpeed

Speed limiter.

7.1.13 PedalMapCal.m_RequestMap

Requested Airmass from the driver as a function of rpm and accelerator pedal position. Resolution is 1 mg/c.

7.1.14 TorqueCal.M_ManGearLim

Maximum engine torque limit for each gear in the manual gearbox. Resolution is 1 Nm.

7.1.15 TorqueCal.m_AirTorqMap

(This is where all torque limiters take their data from and therefore needs to be "fooled" if you are running 400nm+ or an automatic!) Data-matrix for nominal Airmass. Engine speed and torque are used as support points. The value in the matrix + friction Airmass (idle Airmass) will create the pointed torque at the pointed engine speed. Resolution is 1 mg/c. axis to the above map: TorqueCal.m_AirXSP

7.1.16 TorqueCal.M_EngMaxTab

Data-table for maximum engine out put torque for manual cars. Resolution is 1 Nm.

TorqueCal.M_EngMaxAutTab Data-table for maximum engine output torque for automatic cars. Resolution is 1 Nm.

TorqueCal.M_5GearLimTab Data-table for maximum engine output torque for manual cars on fifth gear. Resolution is 1 Nm.

TorqueCal.M_EngMaxE85Tab (if running on E85) Data-table for maximum engine output torque when running on E85. Resolution is 1 Nm.

TorqueCal.m_PedYSP Air mass support points for (Calc) X_AccPedalMap. Resolution is 1 mg/com-bustion.

7.2 Tuning Boost calibration

This map holds percentages (0.1% accurate) of how much air should be passed to the return hose of the boost control value. The higher the value, to more air is bled off and the less the wastegate will open (and thus, the more air the turbo will be spooling). As you can see, the more Airmass is requested (x – axis) the more the wastegate is held shut and thus, the more Airmass the turbo will be providing. If we want more Airmass from the turbo, we need to keep the wastegate shut longer and thus we have to enter higher numbers on the right side of the table.

7.3 Altering Airmass limiter

To be able to flow more air though the engine that is allowed in the stock configuration we will have to modify the Airmass limiter tables as well. Note that there are two different ones, one for manual gearbox and one for automatic gearbox. This example will only show the manual gearbox table (BstKnkCal.MaxAirmass) but for automatic cars BstKnkCal.MaxAirMassAu needs to be changes.

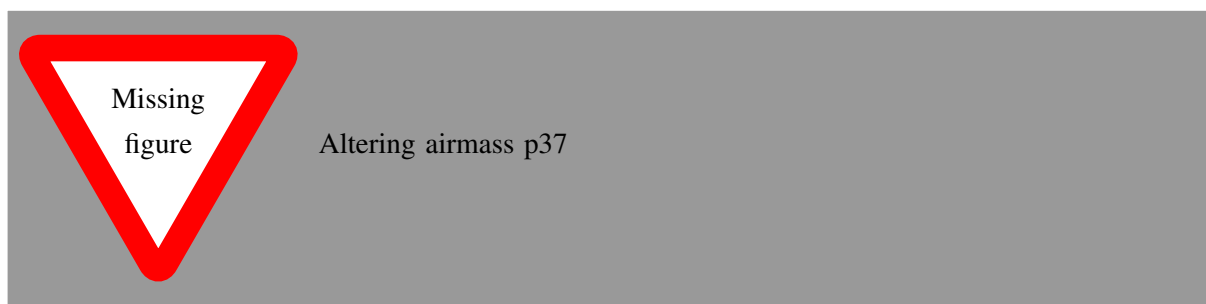


Figure 7.2: Altering airmass p37

As you can see, the maximum amount of Airmass allowed is approximately 970 mg/c. We need to change the table so that it will allow more Airmass. In this case we just up the table with 25% with the

math functions in T7Suite. NOTE: Please do not simply turn off this limiter by setting it way higher than the actually intended level because it is an important limiter to provide engine safety.

7.4 Altering fuelcut

Then there's the fuelcut function to worry about. We need to increase the limit of what the fuel cut function will accept to prevent it from shutting off fuel too early. NOTE: Please do not simply turn off this limiter by setting it way higher as the actually intended level because it is an important limiter to provide engine safety.

7.5 Engine speed limiter

To prevent the system to reduce Airmass above engine speeds that are still acceptable we need to change MaxSpdCal.n_EngLimAir as well. Y axis values are engine temperature (coolant). Please note that 200 rpm above this limit, the fuel cut mechanism will become active!

7.6 Vehicle speed limiter

An option is to increase the vehicle speed limiter as well. In this stock binary the vehicle speed is limited to 240 km/h. We can change it to – for example 280 km/h.

7.7 Airmass request

To get more from the engine than in the stock configuration we need to actually request more Airmass for a certain pedal position and rpm site. This can be done through PedalMapCal.m_RequestMap. Because we want more power at wide open throttle (from the drivers perspective) we need to increase the Airmass request at pedal positions in the high percentage range (top of the table).

As you can see we increased the top two rows so that a maximum of 1350 mg/c will be requested. In addition we need to alter the y axis support point for the pedal map that lets Trionic lookup a pedal position for a given Airmass. This map is called TorqueCal.m_PedYSP. This axis map should support the maximum Airmass we're requesting in the m_Requestmap, so in our case we need to modify the map to match the 1350 mg/c we are requesting as a maximum.

The map that uses this axis is called TorqueCal.x_AccPedalMap. It is shown below with the altered axis values for clarification.

7.8 Torque limiter

To prevent the system to reduce Airmass above a certain engine output, the torque limiter needs to be increased according to expected engine output.

TorqueCal.m_AirTorqMap (This is where all torque limiters take their data from and therefore needs to be "fooled" if you are running 400nm+ or an automatic!) Data-matrix for nominal Airmass. Engine speed and torque are used as support points. The value in the matrix + friction Airmass (idle Airmass) will create the pointed torque at the pointed engine speed. Resolution is 1 mg/c.

Finally, we're all done!

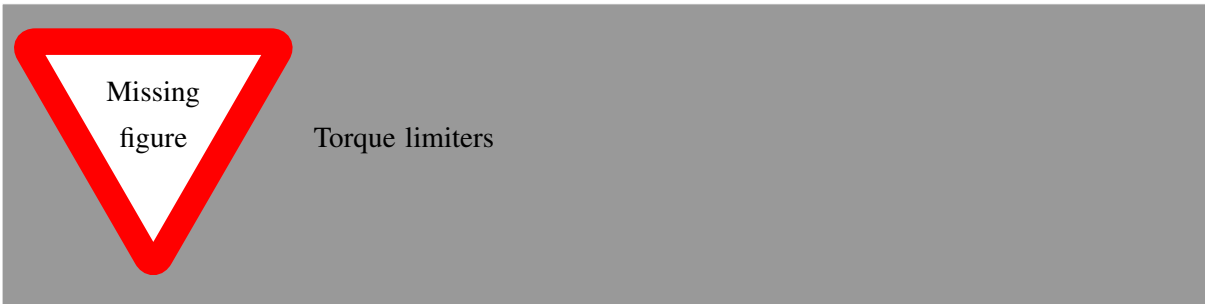


Figure 7.3: Torque limiters

Chapter 8

Automatic transmission specifics

In automatic Trionic 7 cars the TCM (Traction Control Module) sends a torque limit over can to the ECU (Trionic). This means – theoretically - you cannot achieve more torque than the torque limit the TCM dictates. The only known way around this at present time is to make Trionic THINK it's not making that much torque, so we have to fool the ECU into thinking it is still below the torque limit set by the TCM.

There are different TCM limits depending on year, engine type, gearbox etc. A MY01-AERO AUT has a 330NM limiter while a 5 speed automatic gearbox has a 350Nm limit. To fool the ECU into thinking it is making less torque is to rescale the x-axis for TorqueCal.mAirTorqMap which is TorqueCal.M_EngXSP. The top value in this list must be no more than the TCM limit.

In this case the top three rows have been altered to keep the calculated torque below 330Nm.



Figure 8.1: TorqueCal

This means that when requesting 330Nm you will actually get 400, 320 will get you 350 and so on. The torque limiters in TorqueCal.M_EngMaxAutTab must be scaled with this in mind... In this case 400Nm between 2780 and 3920rpm. Values in between you need to recalculate, at 4300rpm the user wanted 390Nm, (400=330, 350=320) means that 322=360, 324=370, 326=380, 328=390nm

If you want to use the same bin in manual cars all manual limiters must be calculated and set correctly!

NOTE: In Bio power bins TorqueCal.M_EngMaxE85Tab !

400	->	330Nm
350	->	320Nm
320	->	310Nm

Table 8.1



Figure 8.2

Chapter 9

Using the tuning wizard

T7Suite incorporates a tuning wizard. This wizard allows you to automatically alter the maps in the binary file to get it to a stage I equivalent file. The wizard can be activated by selecting “Tuning” > “Easy tune to stage I” from the menu. A dialog will appear in which you can confirm that you want to tune the file to stage I. Once you’ve selected this the process will start. After a few seconds a report will appear showing all actions taken on your file.

Emphasize the
iterations of tuning
wizard

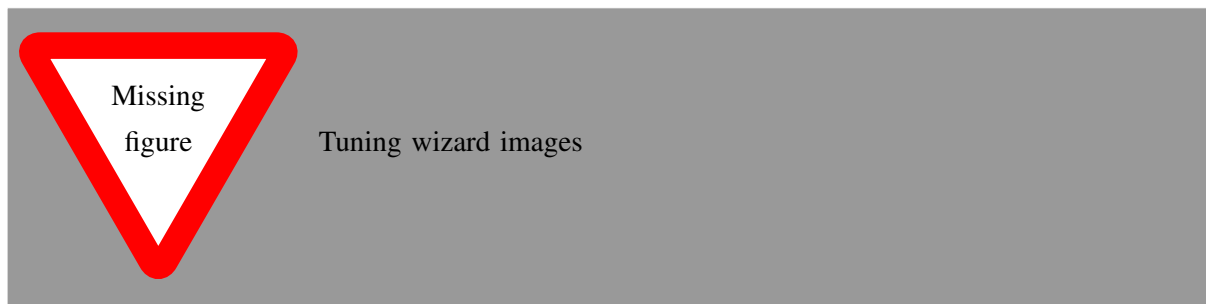


Figure 9.1: Tuning wizard images

Chapter 10

OpenSID values

T7Suite incorporates a function to allow visualization of information on the SID (System Information Display). This way you can view real-time information without utilizing the Canbus interface. You can select the variables you want the SID to display using the SID information selection option in T7Suite.

Also, the software should be opened to be able to view the selected data on the SID. This is done in the firmware information screen.

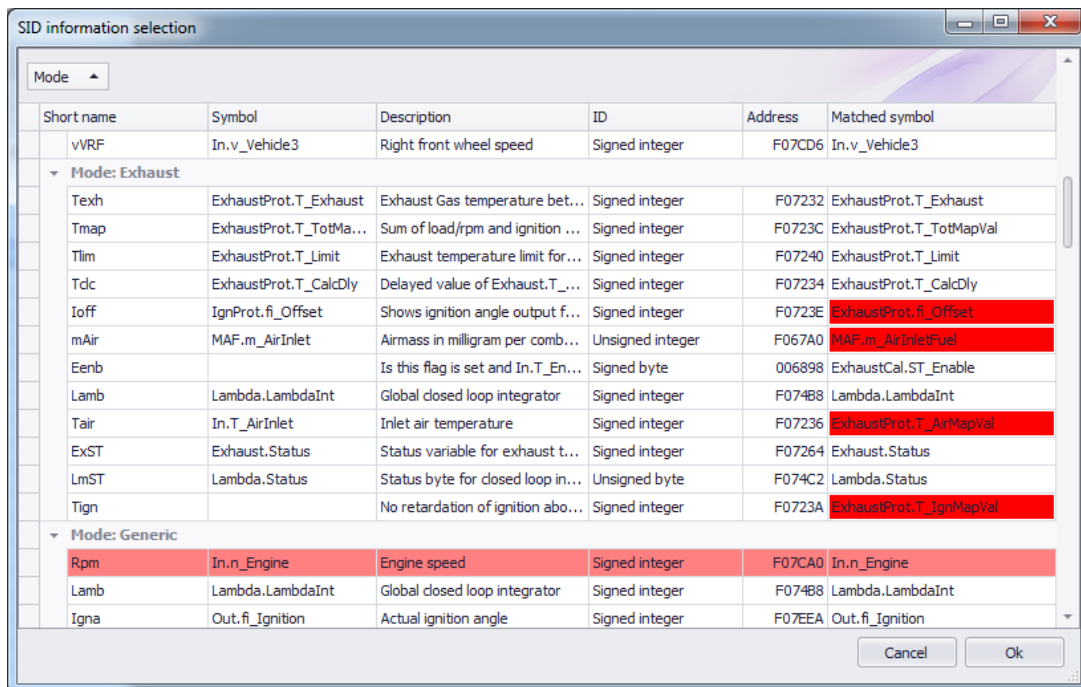


Figure 10.1: SID Information

Some tips on how to use the SID information option:

- ECMStat.ST_ActiveAirDem shows the current Airmass limiter
- ECMStat.P_Engine shows calculated engine power (hp)
- ECMStat.AirFuelRatio shows calculated AFR
- ECMStat.p_Diff shows boost pressure (manifold – ambient) in 0.1 kPa units

- BstKnkProt.MapPointer shows the offset in 0.1 degrees for BstKnk.MaxAirmass (so, the ignition offset for knock)
- ExhaustCal.ST_Enable allows you to enable and disable the EGT algorithm. These algorithms are based on the stock engine and won't be properly calibrated for a stage 3+ setup.
- KnkDetAdap.KnkCntCyl first 2 bytes show cylinder 1 knock count, next 2 bytes shows cylinder 2 knock count etc.

Chapter 11

CAN bus interface

The most common way to interface with the Trionic 7 unit is via the CAN bus.

11.1 General information

The most frequently used interface for this is the Lawicel CANUSB interface*. This interface can convert CAN signals onto you USB port and vice versa. The interface has a USB port on one side – that connects to you computer – and an male DB9 connector on the other side. This side connects to the CAN bus of the Trionic.

The Lawicel interface has the following pin out on the DB9 connector.



Figure 11.1: DB9

11.2 OBD2 socket pinout

On some models, the OBDII port enables you to connect to the I bus directly. On most models, you need to wire into the P-bus (preferably, because data transmission rates are tenfold of that on the Ibus) or into the I-bus directly. The P-bus can be found at the pins of the ECU (as described on the previous page), the

Section should be updated with obd2 information

*www.canusb.com

CAN controller	Intel AN825257
Communication speed	615 kbit s ⁻¹

Table 11.1: CAN specifications for Trionic 7

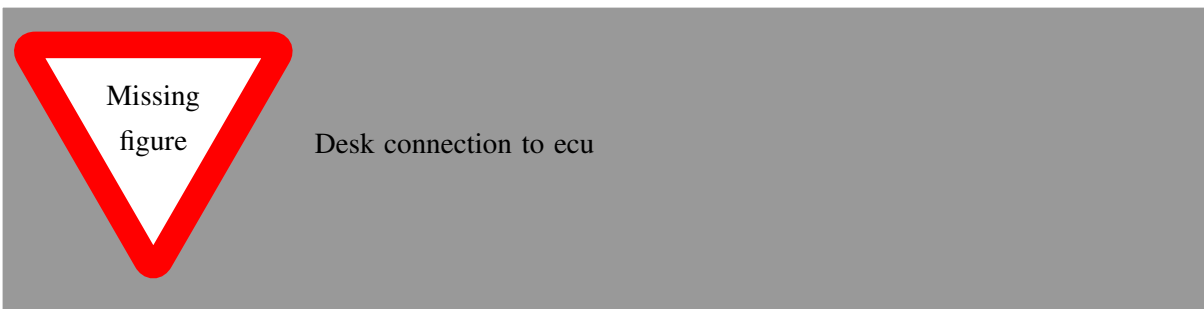


Figure 11.2: Desk connection to ecu

Pin number	Description
1	
2	J1850 Bus+
3	
4	Chassis ground
5	Signal ground
6	CAN High (J-2284) [†]
7	ISO 9141-2 K-line
8	
9	
10	J1850 Bus-
11	Airbag Controller (?)
12	ABS Controller (?)
13	
14	CAN Low (J-2284) [‡]
15	ISO 9141-2 L-line
16	Battery Power

Table 11.2

I-bus can be found in a lot of places like the CD changer connector in the trunk (other spots are shown in the table below).

11.3 Saab I-bus communication

Courtesy of Tomili and General Failure

The I-Bus is an internal bus (Instrumentation Bus) that connects together instruments such as the radio, ACC and the SID (Information Display). The I-bus is the non-critical bus which means that vehicle critical information is not sent over it. That is done through the P (powertrain) bus. The I-bus enables us to communicate with several devices in the car including the TWICE, DICE etc. Both the I and the P bus are CAN bus based communication buses which enables us to use a normal CAN adapter to interface with them.

The I bus follows the ISO 11898-2 standard which is the high speed variant, although it only implements a maximum communication speed of 47,619 Kbit/s. Messages on a CAN bus are sent within

[†]Only on some models

[‡]Only on some models

CAN frames that include an identifier number, number of data bytes, the actual data (called the payload) and checksum (to verify if the data was transferred correctly). There are two CAN frame formats: the basic frame (referred to as CAN2.0A) and the extended frame (referred to as CAN2.0B). The basic frame has a 11-bit identifier field, when the extended frame has a 29-bit identifier which makes it possible to extend the number of message types that can be sent over the bus. The I bus uses two signal (just like any other CAN bus connection) which are called I+ and I-. These refer to CAN High and CAN Low signals in general CAN terminology. Details on I bus communication:

Frame type: CAN 2.0A (11-bit identifiers) Bus speed: 47,619 Kbit/s Timing register settings: BTR0 0xCB, BTR1 0x9A

As an example the engine speed is located as a 16-bit integer value on message ID 460h (hexadecimal) in the second and third bytes (I define first byte as the most significant byte). Speed is in the same message in fourth and fifth bytes. The speed value is multiplied by ten, so you have to divide the 16-bit integer by 10 to get the real speed value. Here's an example ID 460h message: 00 03 9C 00 2A 00 00 00 Engine rpm is 039Ch (hexadecimal format) = 924 (decimal format) = 942 RPM Speed is 002Ah = 42 = 4,2 km/h

Finish I-bus a
bus section

Chapter 12

General tuning advice

This chapter will describe some frequently made mistakes in handling the Trionic.

Ignition advance When altering the ignition tables keep in mind that more than 35 degree advance from TDC is not good.

Ignition retard When altering the ignition tables keep in mind that more than 5 degreeen retarding from TDC is not good.

Ignition advance at WOT Try to keep the ignition advance at approximately 10 degrees BTDC

Recommended AFR Try to keep the AFR between 10.8 and 12.5 at WOT.

Recommended EGT Try to keep the exhaust gas temperature below 950 degrees C.

Determining the maximum boost request for a given turbo Check that the boost request level fits somehow to compressor map: <http://www.squirreelpf.com/turbocalc/index.php> In addition you can read appendix IV.

Internal link

Recommended maximum intake air temperature Up to 60 °C is good enough. If temperatures rise above 60 °C consider replacing your stock intercooler with an aluminium, cross-flow type. These are available from Speedparts, Abbott, ETS and others.

Chapter 13

Acknowledgements

The author would like to thank everyone on ecuproject for their help on getting all this information together. Special thanks go out to General Failure, J.K. Nilsson, Hook, Hma, Vigge, Mackan, Sandy Rus, JKB, L4staero and Steve Hayes.

The sections with technical information on checksums and Saab CAN bus were originally written by Tomi and General Failure.

Appendix A

BDM Technical Information

BDM stands for Background Debug Mode. This refers to the mode the Motorola microcontroller is forced into when activating the BDM interface. This mode enables us to hold the processor in the program execution and read and write data from and to the memory inside the microcontroller and the memory connected to it. In this way we can download and program the flash contents which gives us access to the binaries we like so much! The BDM software you need can be downloaded from <http://www.xendus.se/bdm/bd32-122.zip>.

A.1 Home build 2 chips design schema

An alternative to buying a BDM interface can be building one yourself. This chapter will hand you all information needed to buy the components needed and the schema to build the interface. The image below shows the schema for the 2 chip design. There is also a 5 chip design and a GAL based design but these are more difficult to build at home.

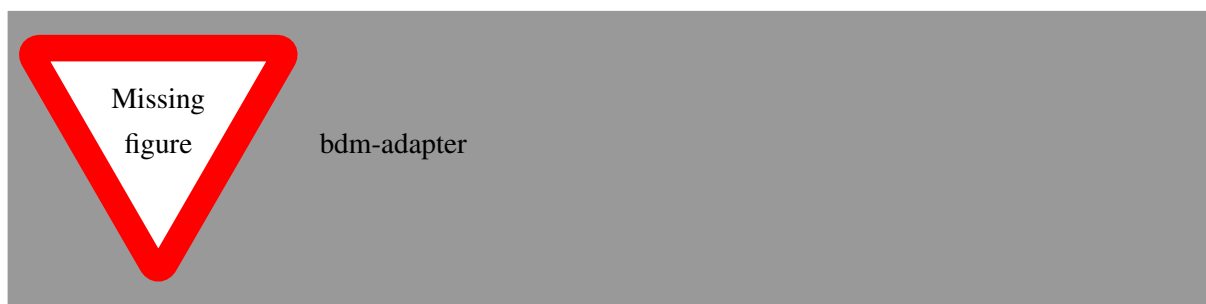


Figure A.1: bdm-adapter

Table A.1 lists the components you need to build the BDM interface. Of course a soldering iron, PCB etc. are things that you also need.

A.2 BDM Pinout

Component	Amount	Description
74HC74	1	Dual JK Flip-Flop with Set and Reset
74HC132	1	Quad 2-input NAND Schmitt Trigger
Capacitor	0.1 uF	1
Capacitor	0.001 uF	1
Resistor	10 kohm	1
LPT cable + connector	1 meter	Smart is to get PCB type with normal LPT cable.
10 wire flat cable	20 cm	
10 pin female header for flat cable	1	

Table A.1: DIY BDM interface part list

Pin	Name	Description
1	DS	Data strobe from target MCU. Not used in current interface circuitry
2	BERR	Bus error input to target. Allows development system to force bus error when target MCU accesses
3	VSS	Ground reference from target
4	BKPT/DSCLK	Breakpoint input to target in normal mode; development serial clock in BDM. Must be held low
5	VSS	Ground reference from target
6	FREEZE	Freeze signal from target. High level indicates that target is in BDM
7	RESET	Reset signal to/from target. Must be held low to force hardware reset
8	IFETCH/DSI	Used to track instruction pipe in normal mode. Serial data input to target MCU in BDM
9	VCC	+5V supply from target. BDM interface circuit draws power from this supply and also monitors
10	IPIPE/DSO	Tracks instruction pipe in normal mode. Serial data output from target MCU in BDM

Table A.2

Appendix B

Understanding turbo compressor maps

Each turbo has its own characteristics. These are determined by the size of the turbine housing, the size of the compressor wheel, the size of the turbine blades and many more parameters. The most important identification of a turbocharger is by its compressor map. This is a graphical representation of its efficiency. In Saab Trionic 7 cars there are two commonly used turbo chargers; the Garrett GT17 for all models except for B205R and B235R. These latter engines are instead equipped with the Mitsubishi TD04-HL-15T (6cm²).

For an introduction to turbocharger terminology and concepts, please see [1]. For information on basic flow calculation and how to choose between turbochargers, see [**TurboSelection**].

- Compressor and turbine wheels. The turbine wheel is the vaned wheel that is in the exhaust gases from the engine. It is propelled by the exhaust gases themselves. The turbine wheel is connected to the compressor wheel by an axle. So, the compressor wheel will spin together with the turbine wheel. The compressor wheel also is vaned and these vanes compress the air and force it into the intercooler.
- Wheel “trim”. Trim is an area ratio used to describe both turbine and compressor wheels. Trim is calculated using the inducer and exducer diameters. As trim is increased, the wheel can support more air/gas flow.
- Compressor and turbine housing A/R. A/R describes a geometric property of all compressor and turbine housings. Increasing compressor A/R optimizes the performance for low boost applications. Changing turbine A/R has many effects. By going to a larger turbine A/R, the turbo comes up on boost at a higher engine speed, the flow capacity of the turbine is increased and less flow is wastegated, there is less engine backpressure, and engine volumetric efficiency is increased resulting in more overall power.
- Clipping. When an angle is machined on the turbine wheel exducer (outlet side), the wheel is said to be ‘clipped’. Clipping causes a minor increase in the wheel’s flow capability, however, it dramatically lowers the turbo efficiency. This reduction causes the turbo to come up on boost at a later engine speed (increased turbo lag). High performance applications should never use a clipped turbine wheel. All Garrett GT turbos use modern unclipped wheels.
- CFM = Cubic feet per minute.
- Lbs/minute = pounds (weight) per minute.
- M3/s = cubic meters per second.
- Corrected Airflow. Represents the corrected mass flow rate of air, taking into account air density (ambient temperature and pressure)

Definition 1 The corrected airflow C_{corr} is defined as

$$C_{corr} = C_{air} \frac{13.95}{P} \sqrt{\frac{T_{air} + 460}{545}} \quad (B.1)$$

where T_{air} is the air temperature in Fahrenheit, P the barometric pressure in psi, and C_{air} the engine air consumption in lb/min.

Example 1 With $T_{air} = 60F$, $P = 14.7$ psi and $C_{air} = 50$ lb/min we get

$$C_{corr} = 50 \frac{13.95}{14.7} \sqrt{\frac{60 + 460}{545}} = 46.3 \text{ lb/min} \quad (B.2)$$

- Pressure ratio. Ratio of absolute outlet pressure divided by absolute inlet pressure.

Definition 2 The pressure ratio $R_{pressure}$ is defined as

$$R_{pressure} = \frac{P_{boost} + P_{IC} + P_0}{P_0 - P_{AF}} \quad (B.3)$$

where P_{boost} is the intake manifold pressure (boost) in psi, P_{IC} is the intercooler pressure drop in psi, P_{AF} the air filter pressure drop in psi and P_0 is the air pressure at sea level in psi.

Example 2 With $P_{boost} = 12$ psi, $P_{IC} = 2$ psi, $P_{AF} = 0.5$ psi and $P_0 = 14.7$ psi we get

$$R_{pressure} = \frac{12 + 2 + 14.7}{14.7 - 0.5} = 2.02 \quad (B.4)$$

B.1 Reading a compressor map

This section contains a short description of reading compressor maps. For a more detailed analysis, see Isaac-Lowry [2]. A 2-dimensional pressure map looks like this.

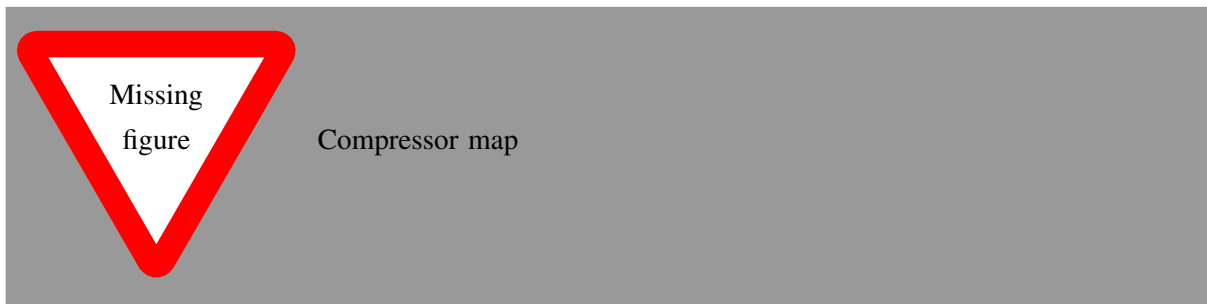


Figure B.1: Compressor map

The curved lines indicate the rotation speed (rpm) of the compressor wheel. In the sample map above these values are 45050, 69750, 84200 up to 125650 rpm. This is how fast a turbine wheel spins!! The elliptical circle means the compressor's efficiency area. It's marked by the percent sign. The horizontal axis is the amount of air before turbo, (1 m³/s = 2118.88 cfm, 10 lb/min = 144.718 cfm).

The vertical axis is the pressure ratio, the ratio of air pressure leaving to the turbo to air pressure entering the turbo. Pressure Ratio=The pressure at compressor exducer vs. the pressure at compressor

inducer. In another word, the ratio of the pressure of the air after compression vs. the pressure before compression. As you can see, the pressure ratio depends on the ambient pressure. For example, at sea level, a turbo boosts 14.7psi. Ambient pressure is 14.7psi. That's 2 pressure ratio (PR) on the compressor map. Take that turbo to a higher elevation, the ambient pressure is less than 14.7psi. If the turbo still boosts 14.7psi, the pressure ratio would be higher. Now on the compressor map, you will see by moving up along a vertical line (to pump out the same cfm) and turbo efficiency has decreased as the elevation increases (PR increases). Simply put, turbos lose performance and become less efficient as elevation gets higher.

B.1.1 Choke area

The area to the right of the outer most elliptical circle is the least efficient area, the choke area. It means when the compressor reaches certain rpm, the air moved by the compressor wheel in the diffuser area of the compressor housing is moving at or past the speed of sound. When the air speed reach sonic speed, the amount of air flow increase is very small as compressor wheel rpm increases. In plain words, the compressor has reached its limit. You can try to pump more psi, have the wheel spin faster, but very little more air is pumped out the turbo compressor. You can see now, the compressor housing will need to properly match the compressor wheel. If you simply stuff a big wheel inside a small compressor housing, the diffuse area will be very small. This causes the air inside the housing to move at higher speed. That's why some of the so-called T28s which use a bigger compressor wheel inside the stock compressor housing does not produce good hp.

B.1.2 Compressor maximum flow

The max flow of a compressor is shown on the compressor map. On the map, look for the intersection of maximum compressor wheel speed (rpm) and the least compressor efficiency curve. Find that intersection. The horizontal coordinate is the max flow. The area to the right of maximum flow is the 'choke area'.

The vertical coordinate is the pressure ratio at which the compressor reaches that maximum flow. From this boost level, as the boost increases, very little air flow is increased. For example, if a compressor reaches its maximum flow at 2 PR or 1 atm pressure or 14.7psi, higher boost does not pump more air into the motor. But higher boost may be needed to increase the manifold pressure for the motor to flow more air. A 5 liter motor with this turbo needs 15psi of manifold pressure to flow a certain CFM. A 3 liter motor with the same turbo will need much higher manifold pressure to flow the same amount of air although that turbo's compressor does not flow more air past 14.7psi.

B.1.3 Compressor maximum pressure

On the map, find the top-most point on the graph. The vertical coordinate is the max pressure ratio. For example, 2.8 pressure ratio at sea level is 1.8 times the atmospheric pressure, $1.8 \times 14.7 \text{ psi} = 26.46 \text{ psi}$. Compressor max pressure is limited by compressor wheel speed. It's physically impossible to boost higher than this maximum pressure for one particular turbo. Plus the pressure drop in the intercooler system, the actual maximum boost reading from a boost gauge that's plugged into the intake manifolds maybe a few psi lower than this maximum pressure.

B.1.4 What the compressor map reads

Most manufactures rate their turbos at 1 bar (15 psi). That's 2 pressure ratio. On the map, draw a horizontal line from 2PR. When the line intersects the right-most elliptical circle, the corresponding number on the x-axis is the maximum cfm the turbo can flow at 1 bar. Use the TD04-15G's map for example, where the 2 PR line hits the right-most efficiency curve, it reads 428cfm as its flow rate at 15psi.

RPM	2.0L	2.3L
1000	35.3	40.6
2000	70.6	81.2
3000	105.9	121.8
4000	141.3	162.4
5000	176.6	203.1
6000	211.9	243.7
7000	247.2	284.3

Table B.1: Engine volumetric flow (H) in cfm as given by equation (B.5) for different rpm.

Table B.2

B.1.5 Comparing compressor maps

Well, compressor maps are really 3-dimensional maps. Any compressor map looks a hill/peak in 3 dimensions. Our compressor maps look like if you look at the hill directly from above vertically. The elliptical lines of elevations are the efficiency curves. Since in theory, we can always boost more and decrease turbo efficiency to get more cfm, let's set the same Pressure Ratio and compare turbos at the same efficiency curves.

As a rule of thumb, a large turbo will be better at making a lot of pressure but will spool slower than a small turbo. A small turbo will build boost fast but is less capable to make big boost pressure.

B.2 Selecting a different turbocharger

In order to put in a new turbocharger we first need some theory [2].

Definition 3 The engine volumetric flow (H) in cfm is defined as

$$H = \frac{D_{ci}}{1728} \times \frac{n}{2} \quad (\text{B.5})$$

where D_{ci} is the engine displacement in cubic inches and n is the number of crankshaft revolutions per minute.

We can then find the airflow in lb/min by computing [2].

$$N = \frac{29PH}{10.73T} \quad (\text{B.6})$$

where P is the absolute pressure in psi and T is the absolute ambient temperature in Rankin.

Tables B.1 and B.2The following tables apply to our Saab 2.0 and 2.3 liter engines. Since the amount of air to be flowed by the turbo is largest when RPM is at its top we will take the worst case scenario and get EVF @ 7000 RPM. We have to make an assumption on the ambient temperature which we will set at 20C. This is 68 Fahrenheit which is $(460 + 68) = 528$ Rankin. Now we can calculate the airflow of the engine in lb/min for any given boost level. If we want to draw a line into the compressor map for our engines needs we need to calculate the needed airflow for several boost levels.

Index

Area 7000 checksum, 11, 12

Boost, 52

CAN, 41

Engine Volumetric Flow, 54

F2 checksum, 11

FB checksum, 11

Firmware, 13

IDA Pro, 13

Misc checksum, 11

Symbol table, 13

Bibliography

- [1] Garrett. *Terminology*. URL: <http://www.turbobygarrett.com/turbobygarrett/terminology> (visited on 09/27/2015).
- [2] J. Isaac-Lowry. *Turbo Selection: A Guide to Understanding Flow Maps*. July 16, 2004. URL: http://www.automotivearticles.com/Turbo_Selection.shtml (visited on 09/27/2015).