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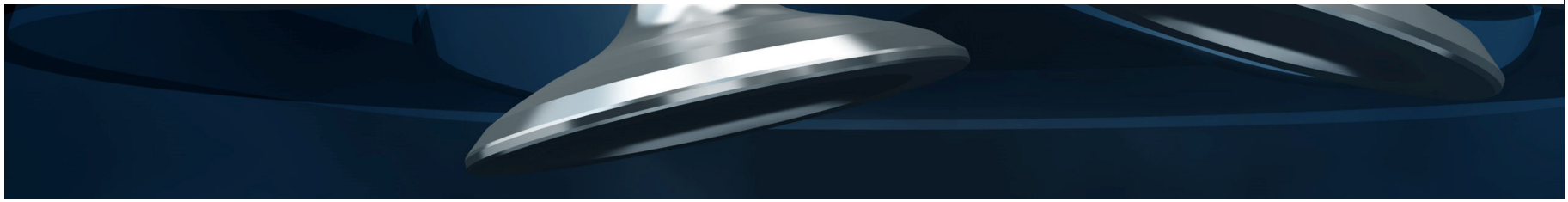
ANL – BSFC map prediction Engines 22-26

Status

Lars Böttcher, Panagiotis Grigoriadis, Berlin, 30th April 2019



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- Methodology
- Engine 22b (Atkinson n.a.)
- Engine 23b (VVL Miller VTG EGR)
- Engine 24 (VVT Miller eCharg. EGR)
- Engine 26a (VCR EGR)

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- **Methodology**

- Engine 22b (Atkinson n.a.)
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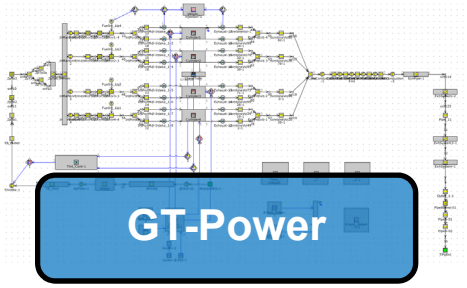
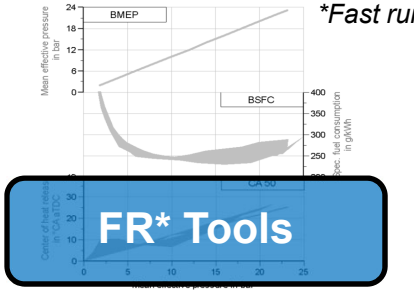
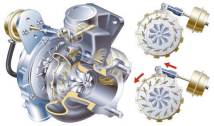
- Engine 24 (VVT Miller eCharg. EGR)
- Engine 26a (VCR EGR)

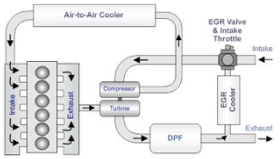
Methodology

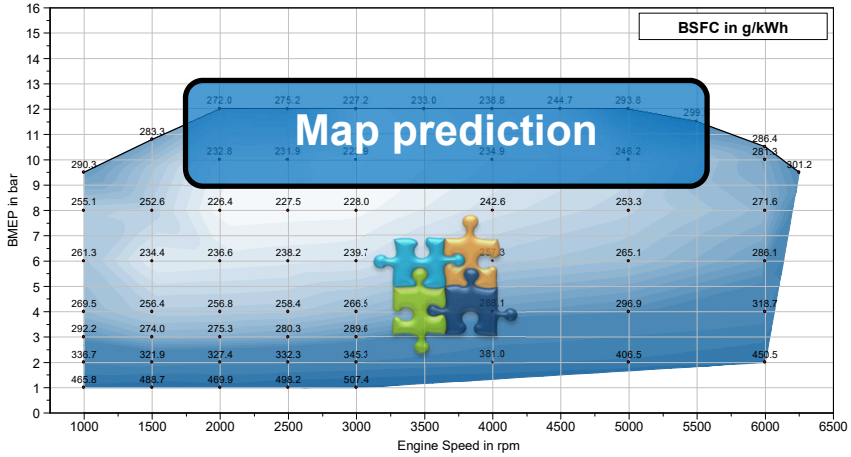




*Fast running







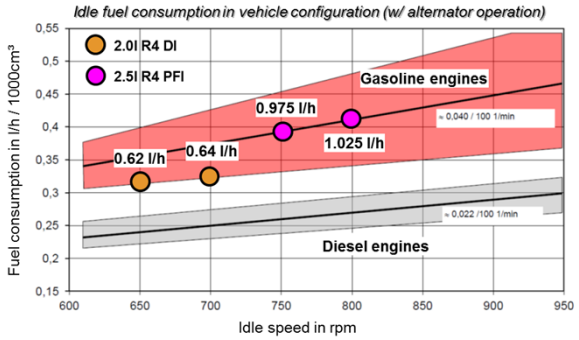
General information – Friction Level

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eCharger	4	12	DI	Yes	Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0	TC	4	10.5	DI	Yes	Yes	No
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No

Example FMEP at 2000rpm/6bar

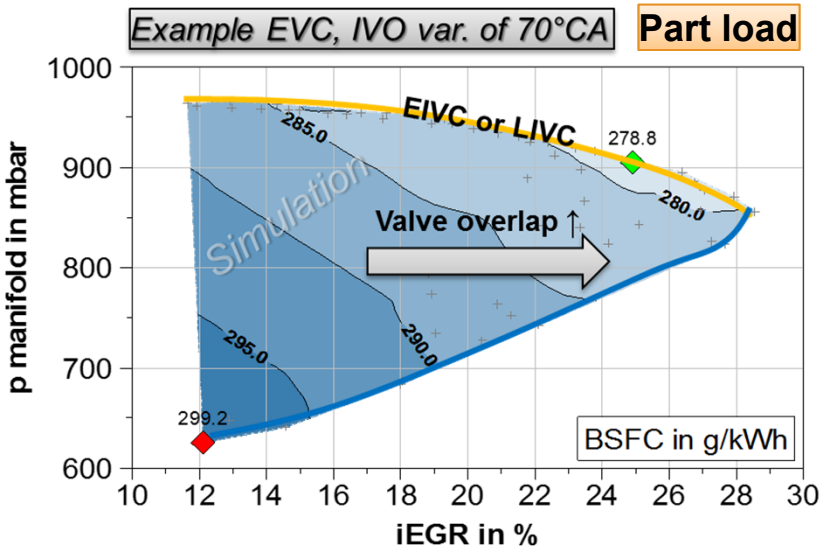
Level 1 Low friction	Level 2 Medium friction	Level 3 High friction
22b	23b,24,25a,26a	
<0.5 bar	0.5-0.7 bar	> 0.7 bar

On NA engines the impact of DI compared to PFI is quite small but to be fair it should be at least considered at idle speed.



Slightly higher values estimated for PFI engine

General information – VVT part load



Depiction shows possible operating range of one engine with one pair of valve lift curves

Aim is to combine low pumping losses with high internal EGR rates with one pair of valve lift curves

Left of optimum iEGR too low, right of optimum PMEP too high

Border of pressure difference that is necessary to provide a certain amount of iEGR to the engine

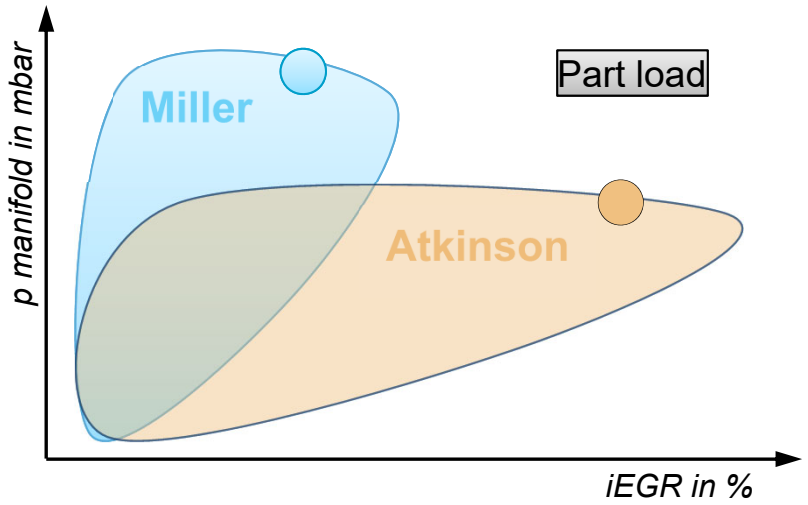
Border of intake pressure that is necessary to maintain the load with a certain amount of iEGR

EIVC = **E**arly **I**ntake **V**alve **C**losing

LIVC = **L**ate **I**ntake **V**alve **C**losing

General information – Miller / Atkinson

- Best Miller at quite low iEGR but highly dethrottled (low PMEP)
- Best Atkinson at high iEGR but lower manifold pressure



Miller operation range is shifted to lower iEGR rates but higher manifold pressure

This shifting is caused by much earlier IVC which results in higher manifold pressure but reduces the potential of iEGR at max. possible overlap

COV behavior coming from low charge motion (Miller) and high iEGR rates (Atkinson) estimated by empirical data

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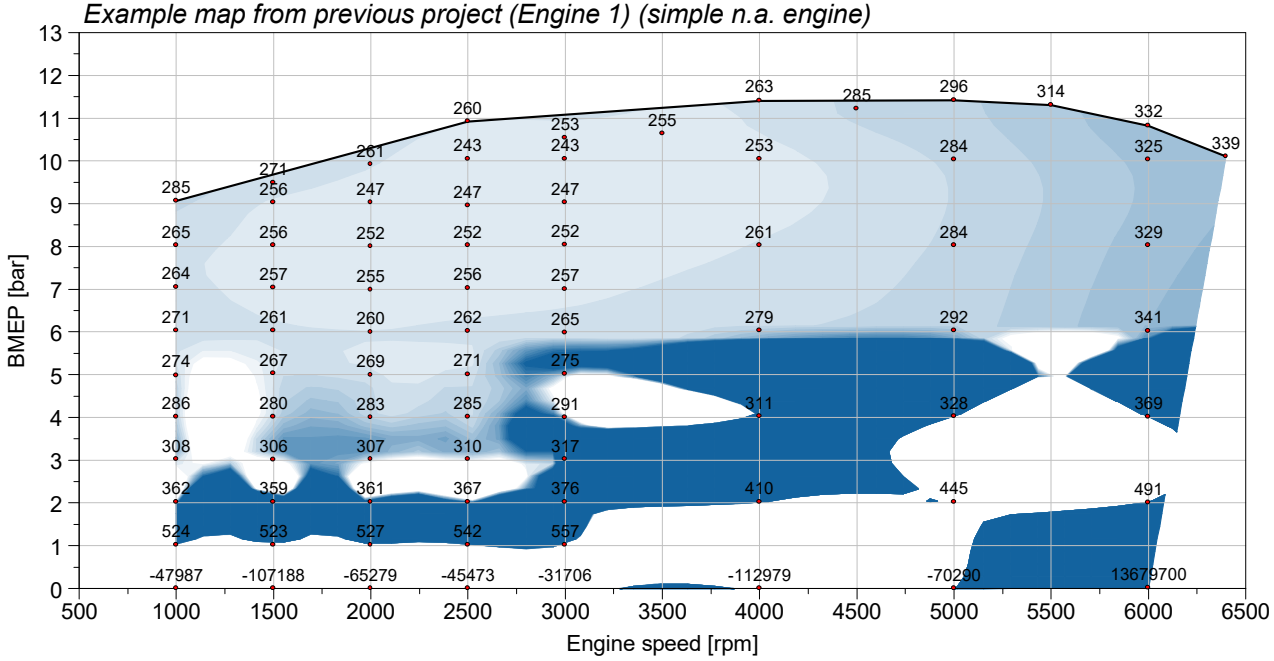
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eCharger	4	12	DI	Yes	Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0	TC	4	10.5	DI	Yes	Yes	No
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No

Example map from previous project (Engine 1) (simple n.a. engine)



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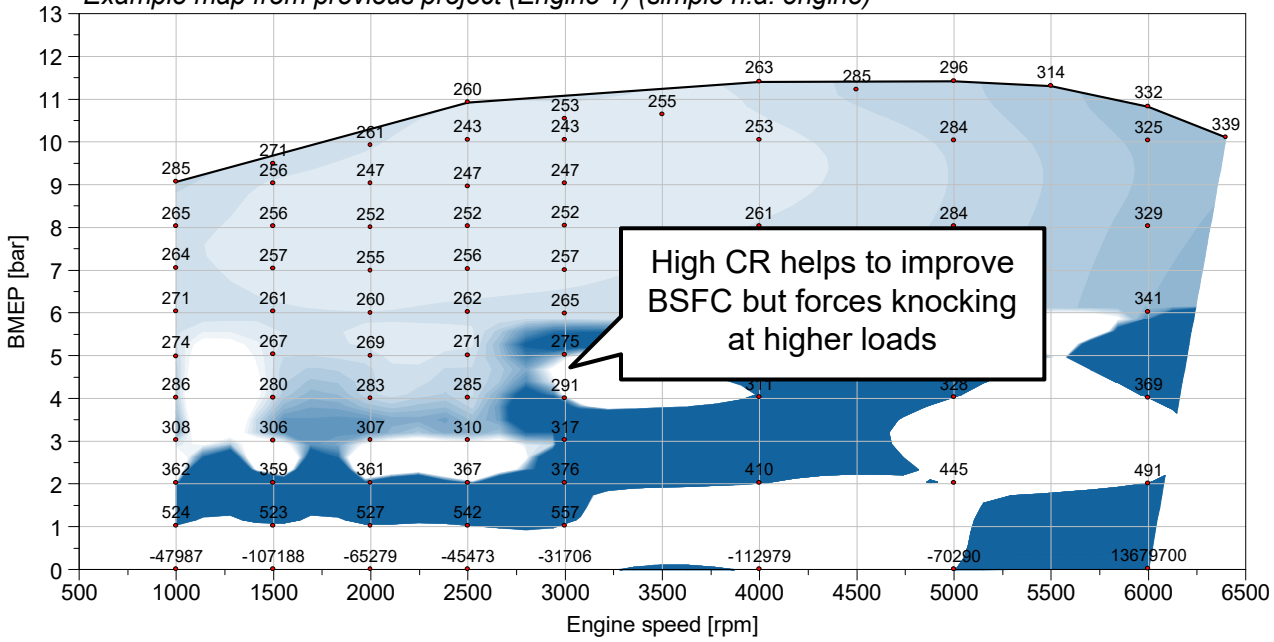
Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eCharger	4	12	DI		Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0	TC						No
VCR c. EGR	26a	2.0	TC						No

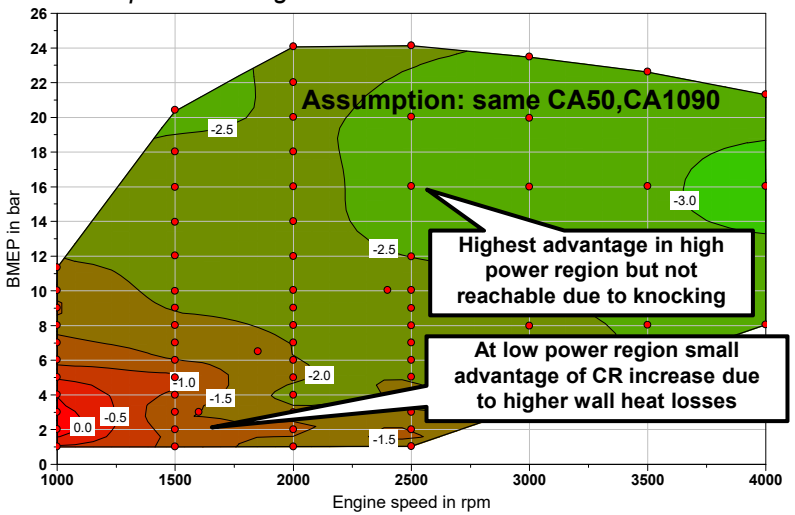
VVT intake & exhaust side

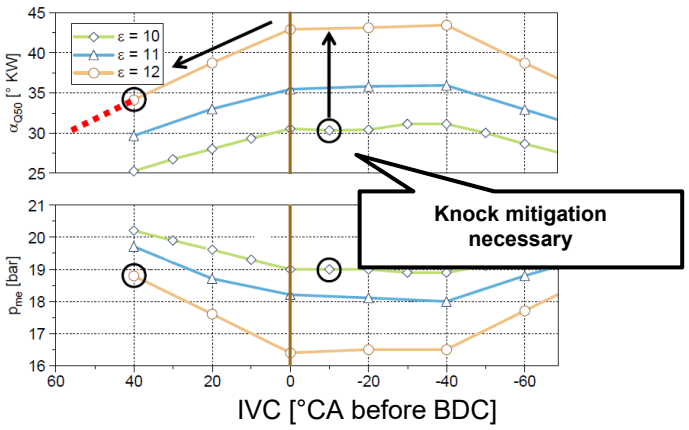
Example map from previous project (Engine 1) (simple n.a. engine)

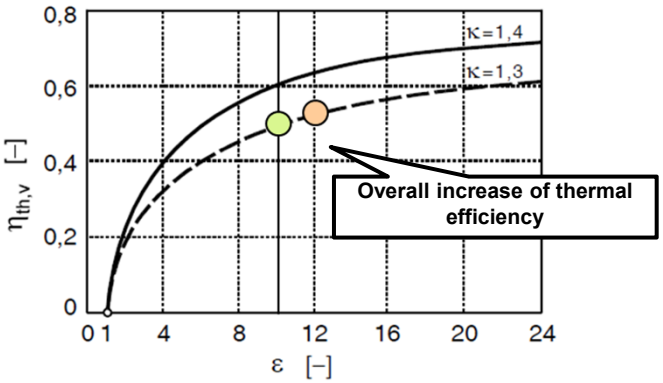


Effects of higher CR

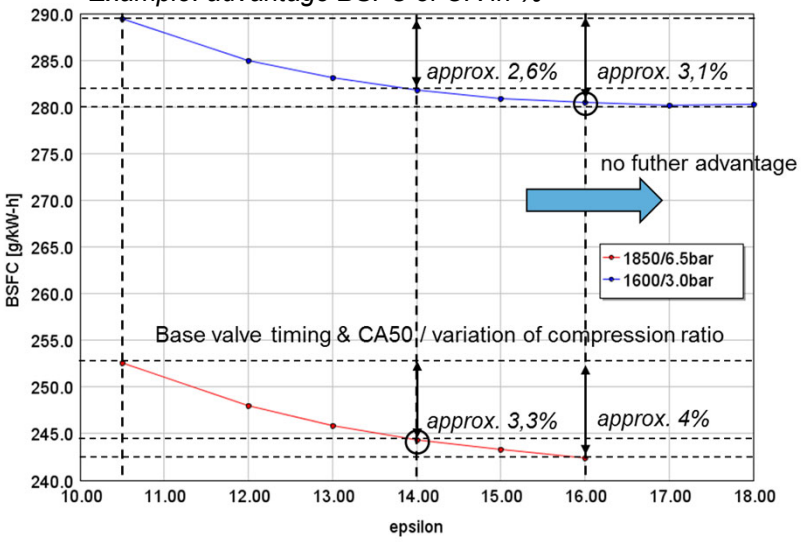
Example: advantage BSFC of CR12 to CR10.5 in %





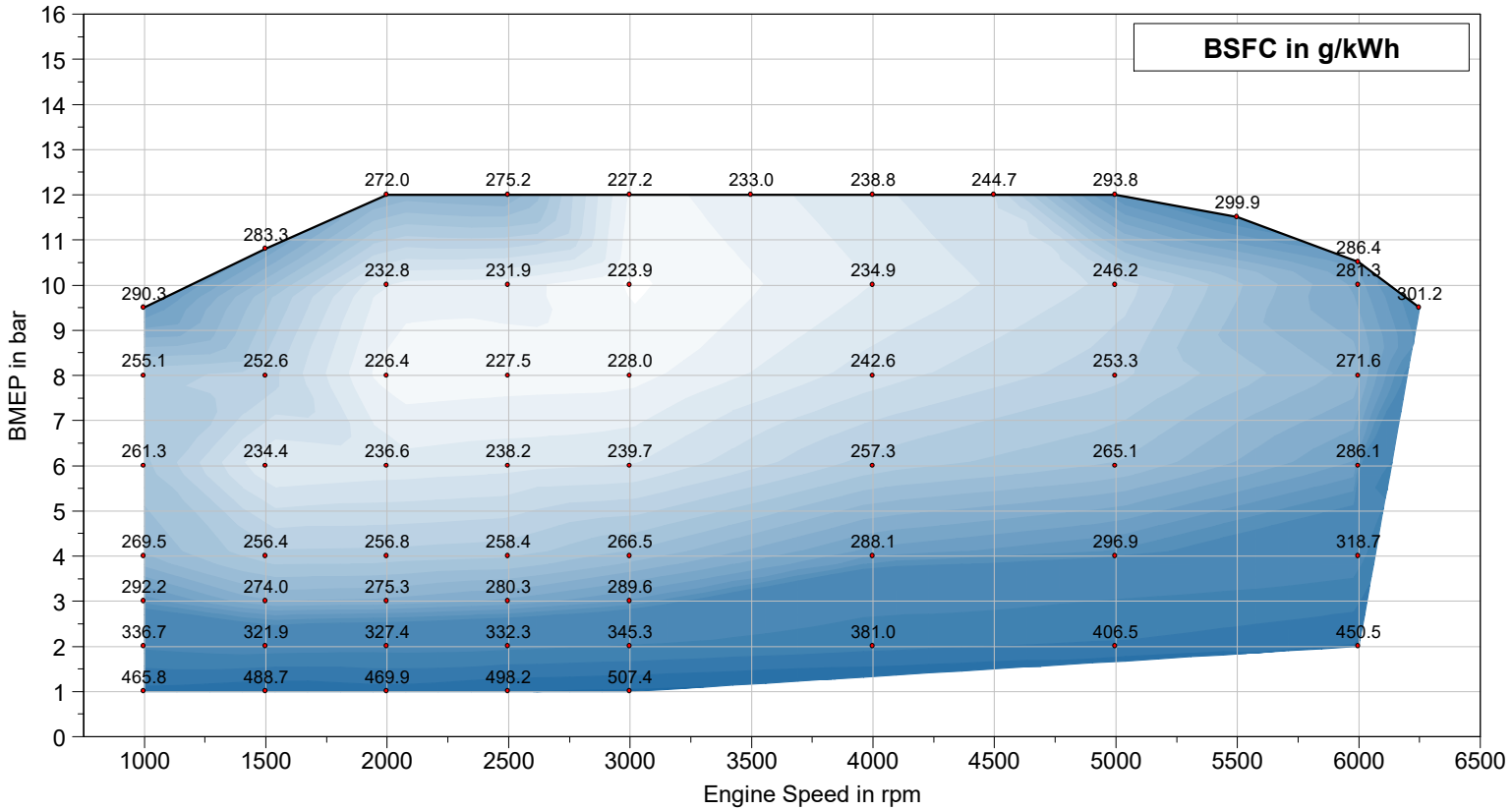


Example: advantage BSFC of CR in %



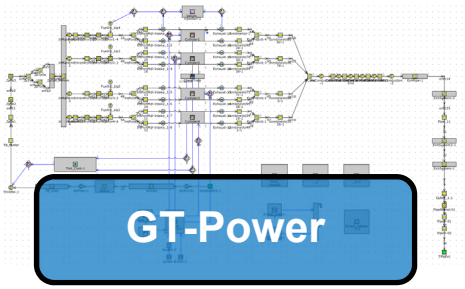
Map prediction – Engine 22b

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No

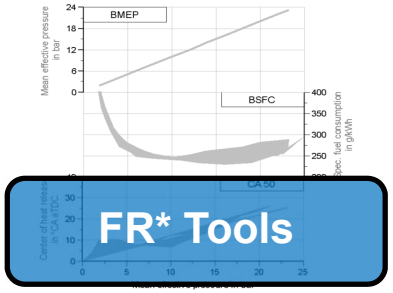


Methodology – Engine 22b

- Data with slightly smaller displacement available
- COV <= 3% (Cycle of variation)
- Spark Knock $KIS_{KH,max}$ = 2% (description next slide)



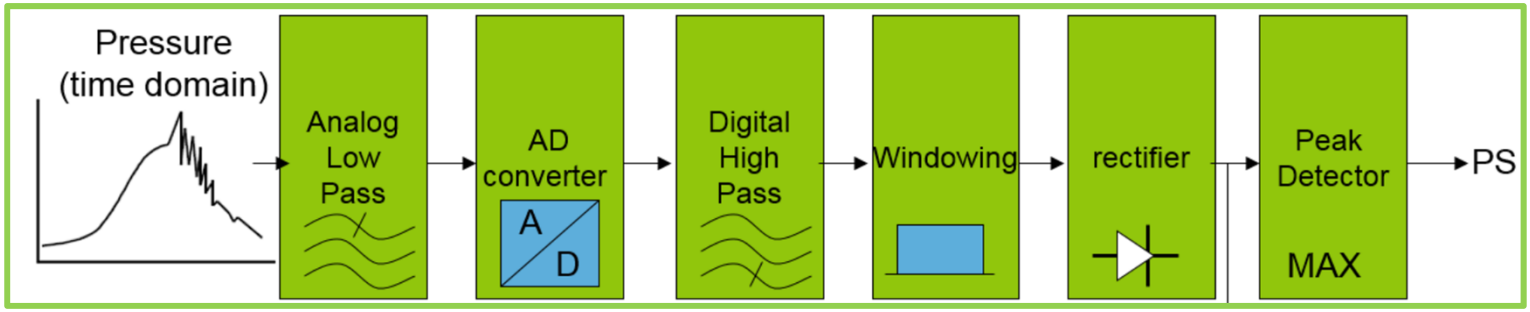
- GT-Power used to update model to compensate for effect of adapted displacement



- Validation with benchmark data

Methodology – Engine 22b

Spark knock limit determination



Empirical estimation

$$PS[bar] < \frac{engine\ speed}{1000}[bar]$$

Test bench input

cycles = 100

PS_{rate} *= 2%*

2% of 100 → PS_{cycles} *= 2*

Example 2000rpm

PS < 2 bar

cycles = 100 PS_{rate} *= 2%*

2% of 100 →

Knocking occurs:
if PS>= 2bar in 2/100 cylces

PS_{rate} *=2/100=* $KIS_{KH,max}$

Map prediction – Engine 22b

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
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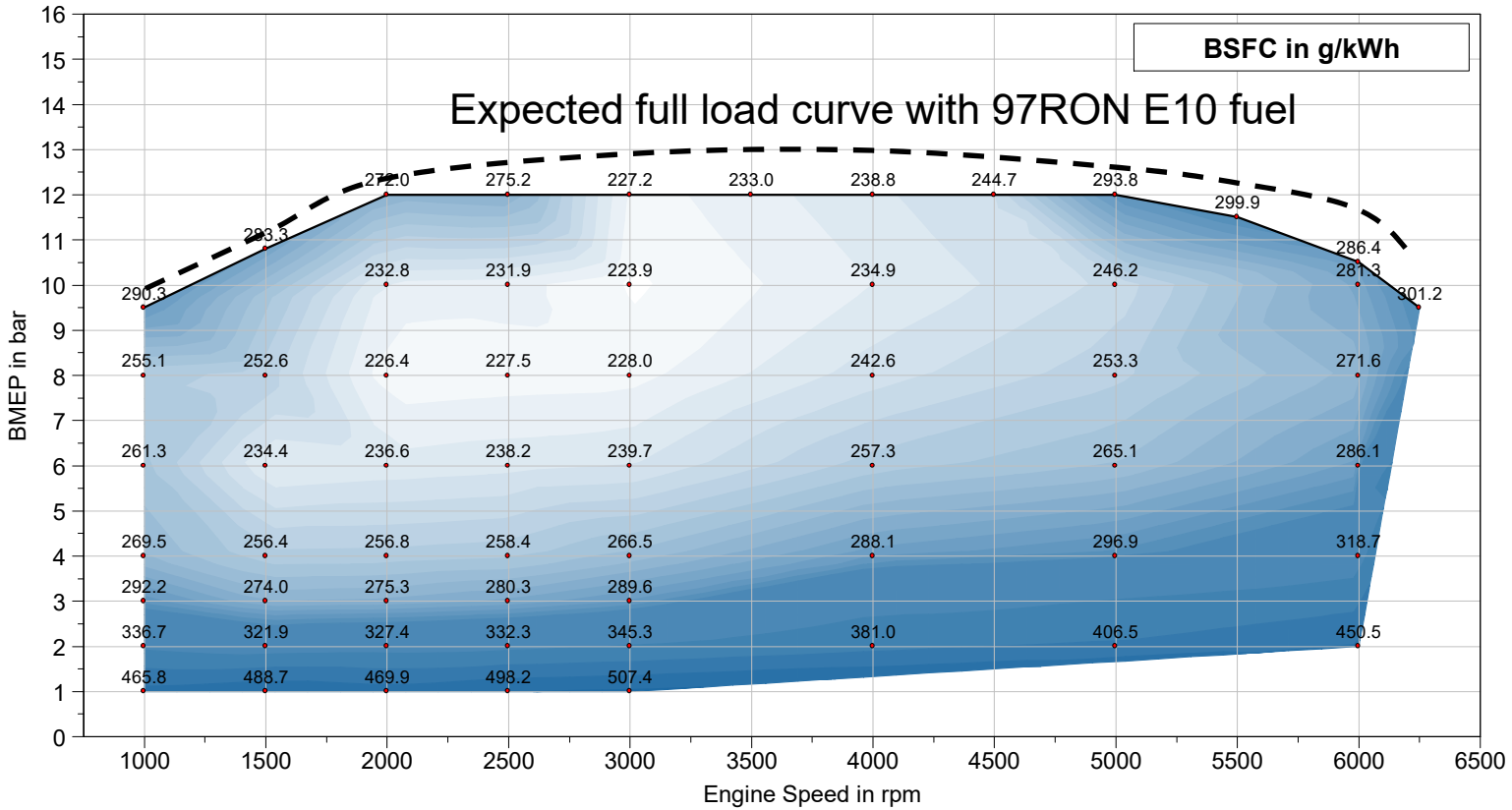
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No



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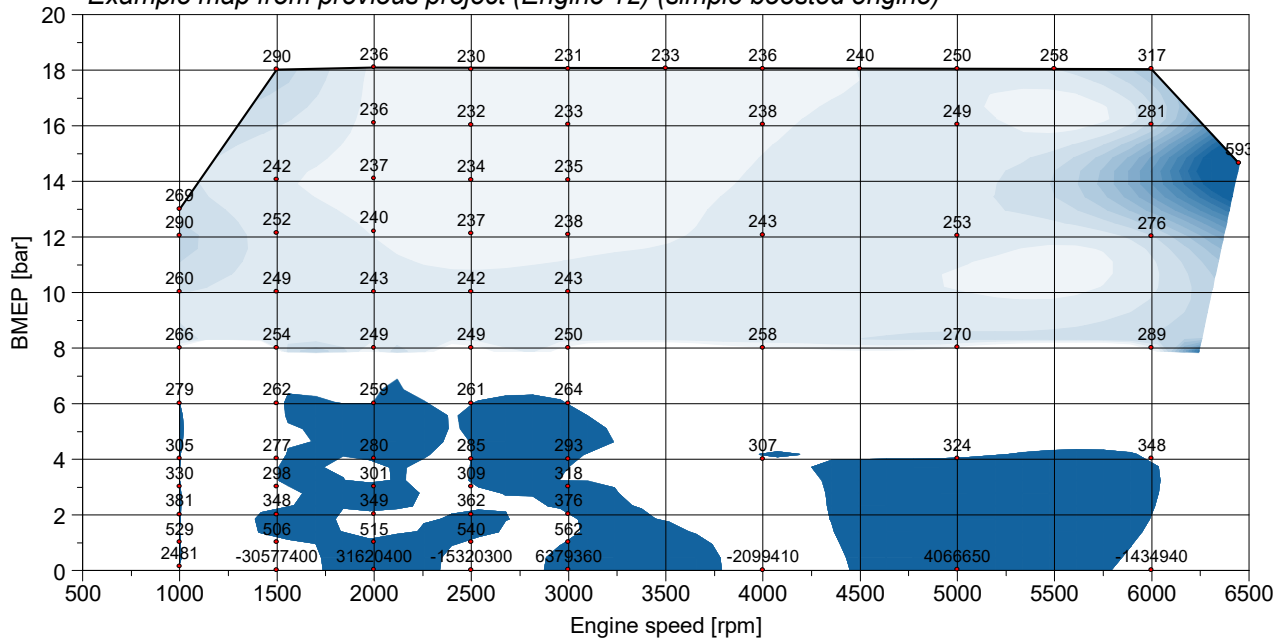
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eCharger	4	12	DI	Yes	Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0	TC	4	10.5	DI	Yes	Yes	No
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No

Example map from previous project (Engine 12) (simple boosted engine)



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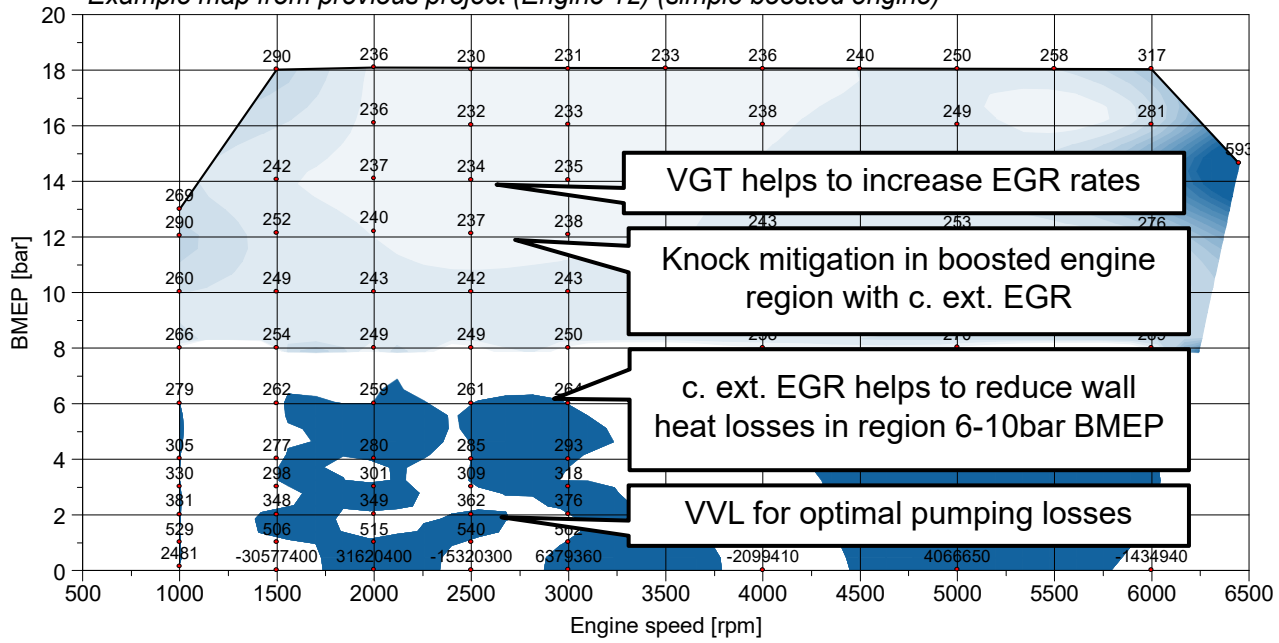
Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eC				Yes	Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0							
VCR c. EGR	26a	2.0	TC	4	9/12	DI			

Low pressure EGR

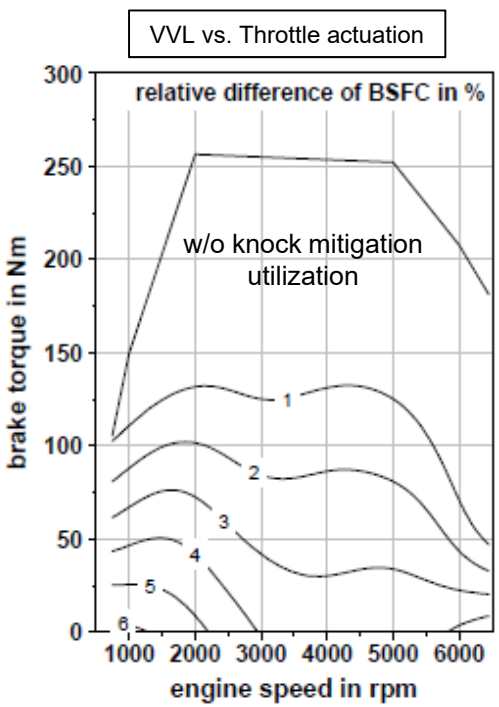
2 step VVL

VVT intake & exhaust side

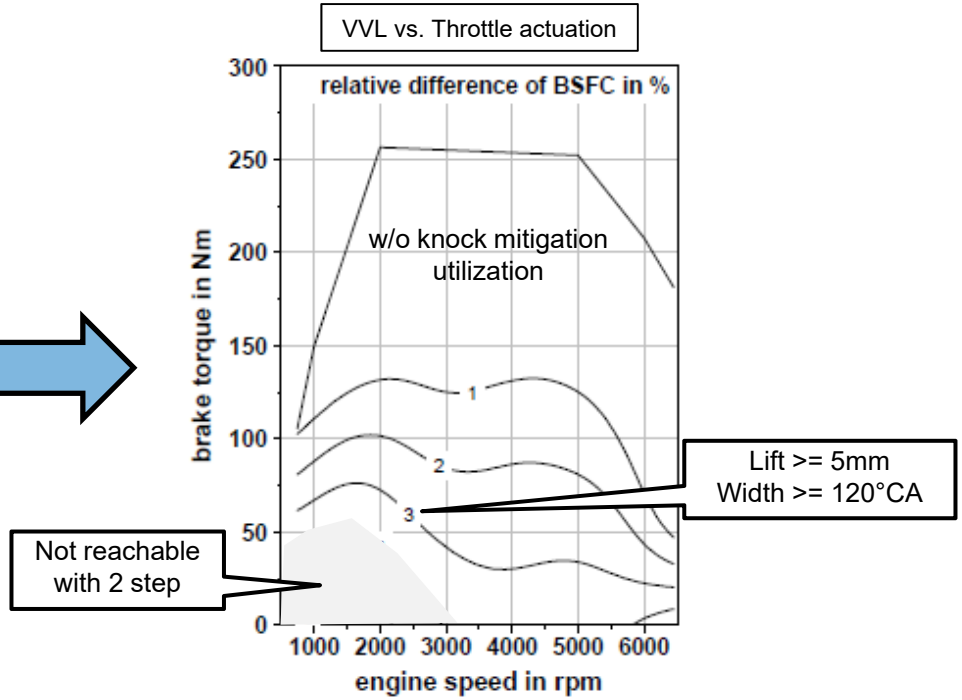
Example map from previous project (Engine 12) (simple boosted engine)



VVL vs. VVT – Test bench data

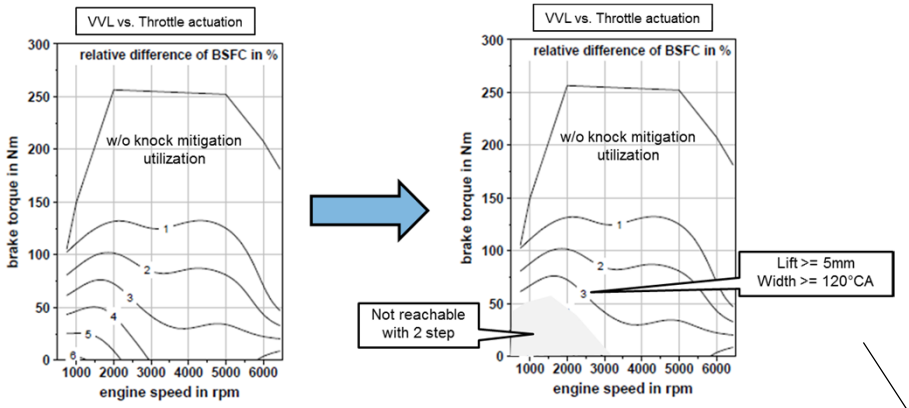


Potential of full variable valve lift compared to VVT



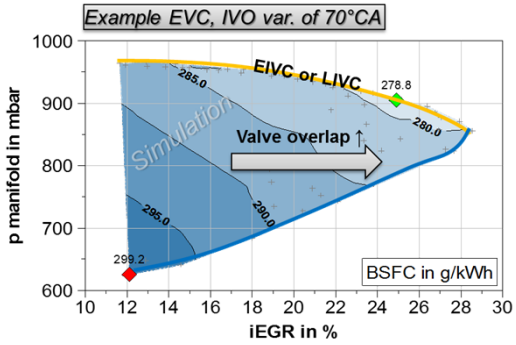
Potential of 2 step variable valve lift compared to VVT

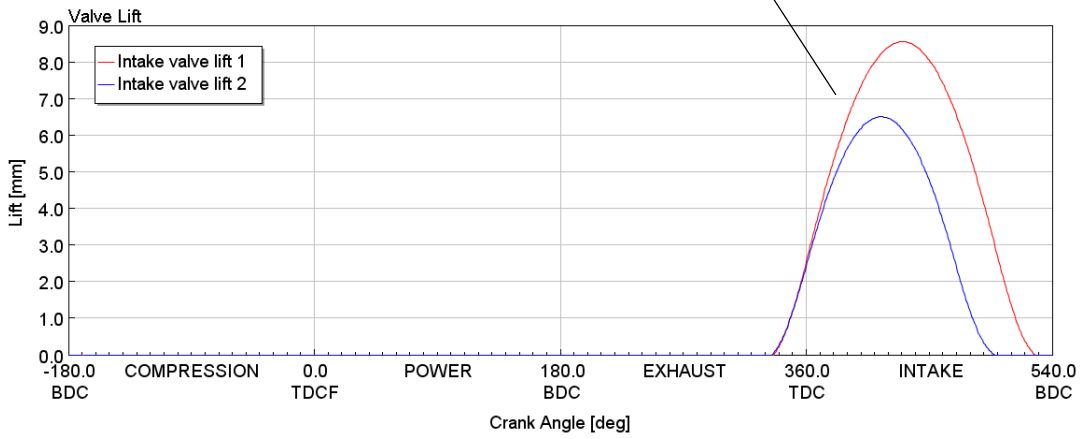
VVL 2-step estimation



Potential of full variable valve lift compared to VVT

Potential of 2 step variable valve lift compared to VVT





Potential of c. ext. EGR

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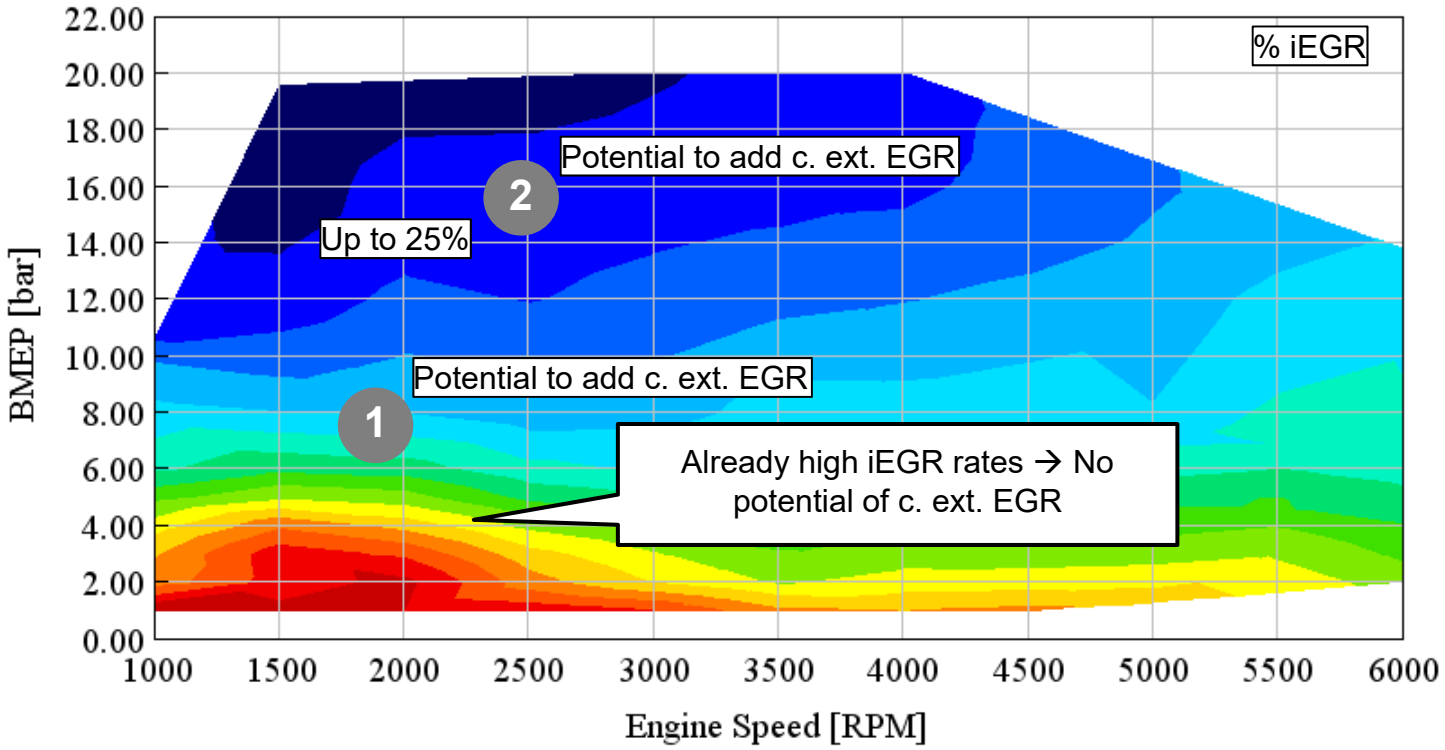
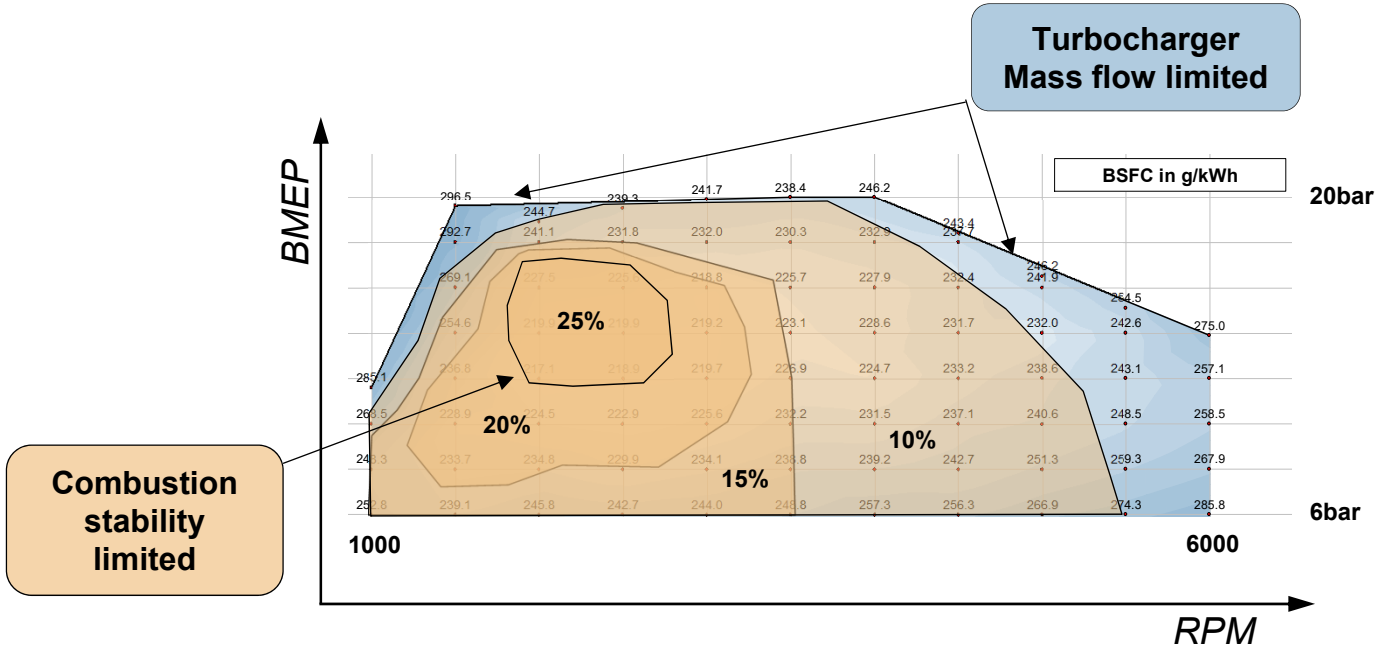
1 + wall heat losses
+ isentropic exponent in expansion phase
- burn duration

2 + wall heat losses
+ isentropic exponent in expansion phase
+ anchor angle (knock mitigation)
- burn duration

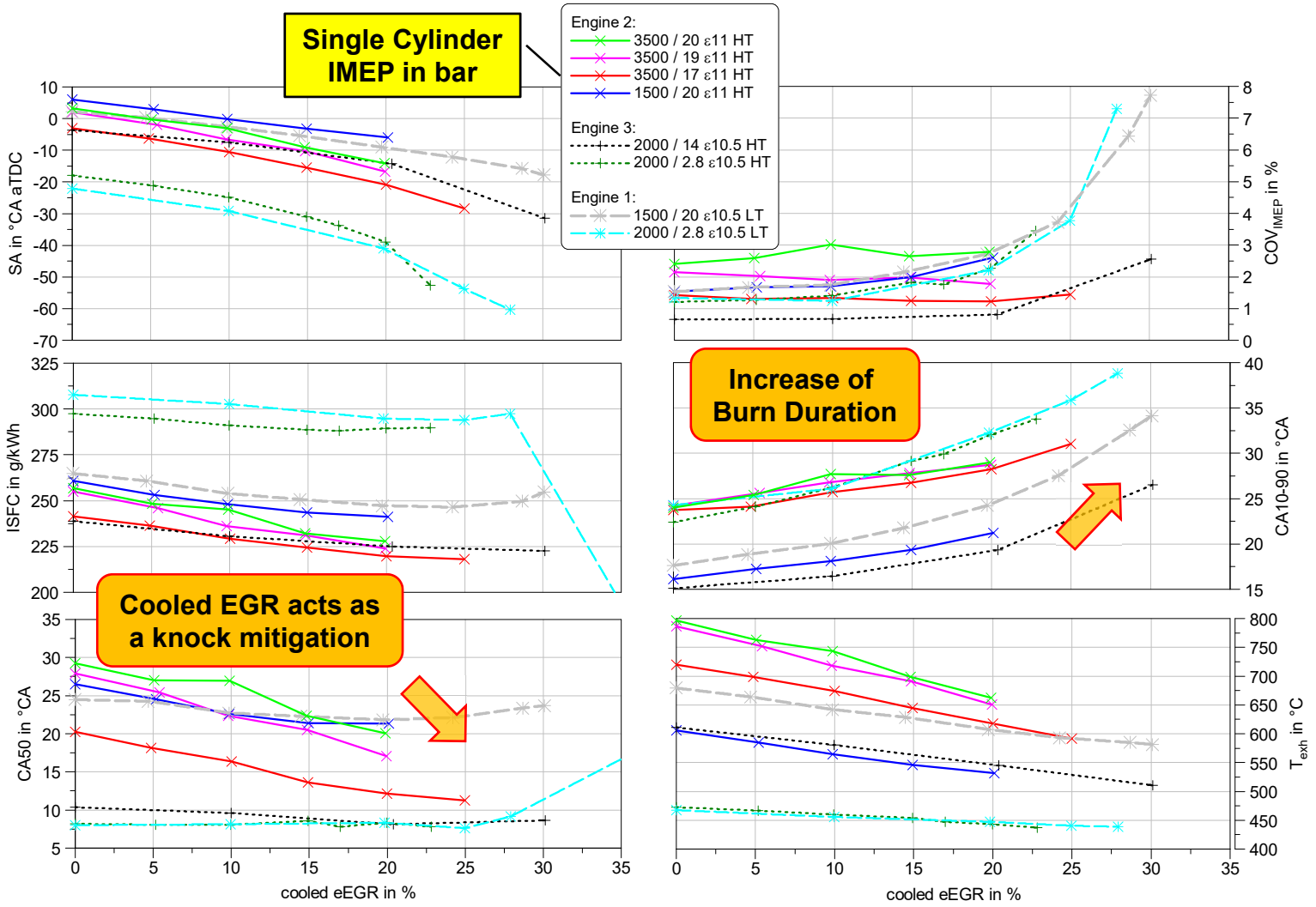


Potential of Cooled external EGR

- Typical border for percentage of cooled external EGR is shown in figure below
- Max target of 25% cEGR is constrained by:
  - COV of IMEP limits <2.5%
  - Misfire / borderline combustion stability
  - Boost limitations due to increased mass flow



Potential of c. ext. EGR – Test bench ex.



Map prediction – Engine 23b

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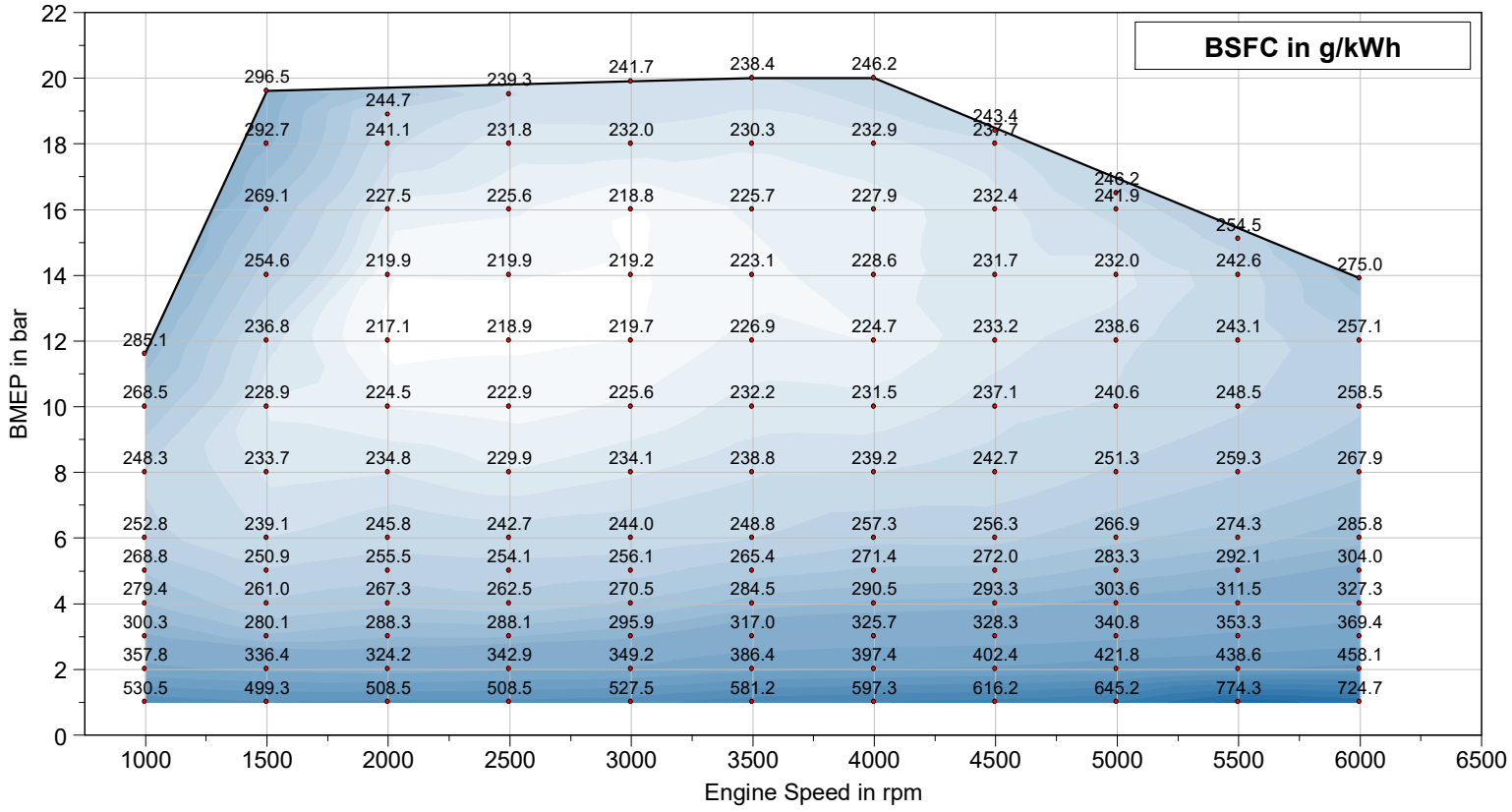
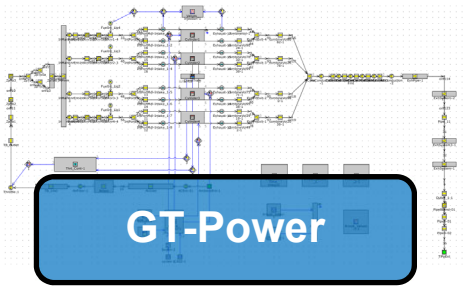
-	-	L	-	-	-	-	-	-	-
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes

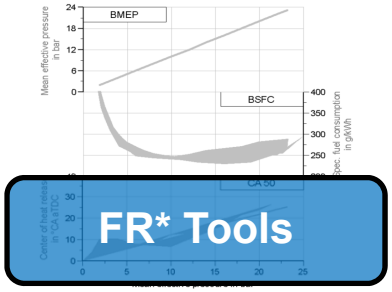


Methodology – Engine 23b

- Data of engine available but w/o cooled EGR
- COV <= 3% (Cycle of variation)
- Spark Knock $KIS_{KH,max}$ = 2% (description slide 11)
- Data of different engines with EGR available



- Effect of c. ext. EGR on BSFC on specific engine (Based on test bench data)



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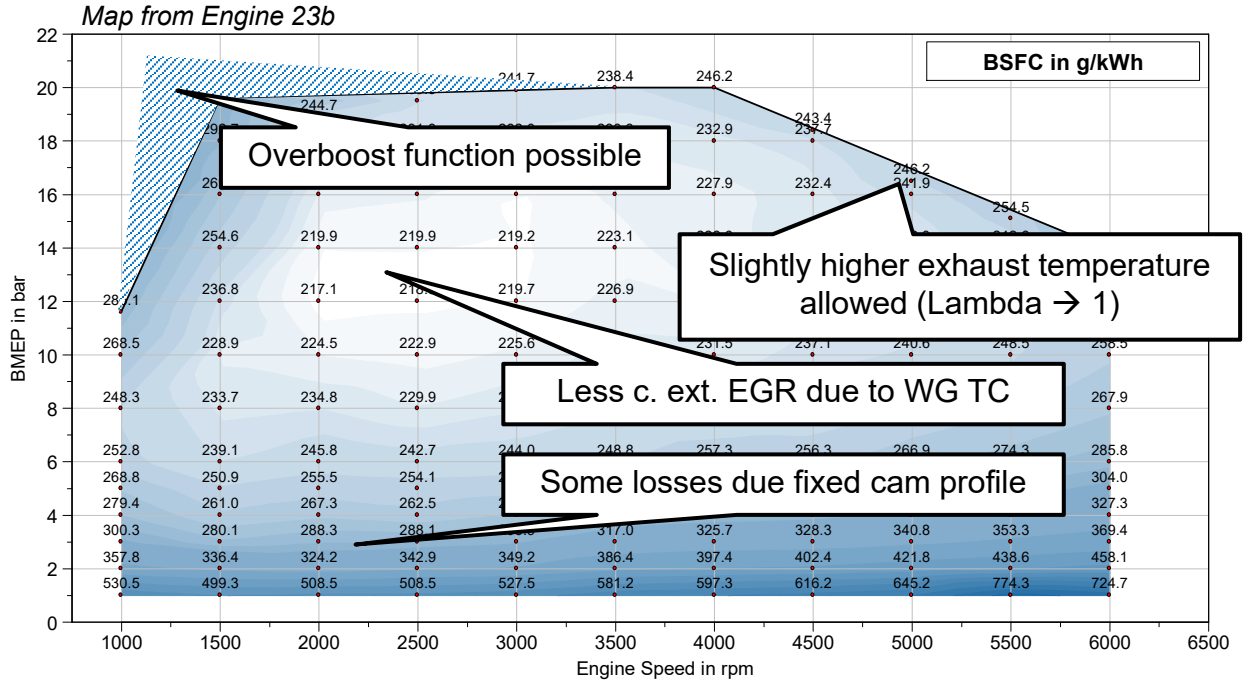
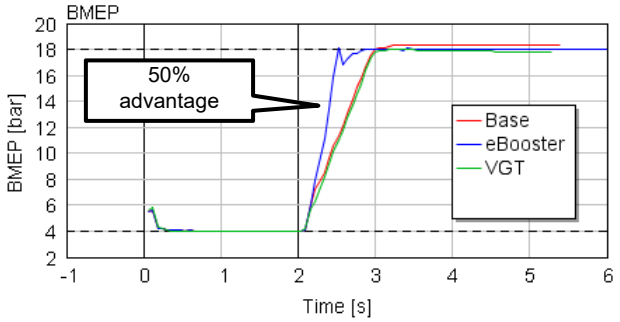
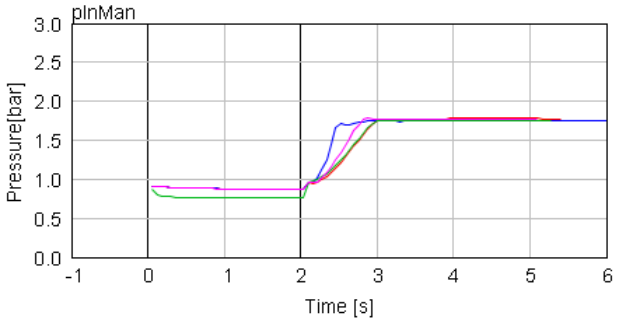
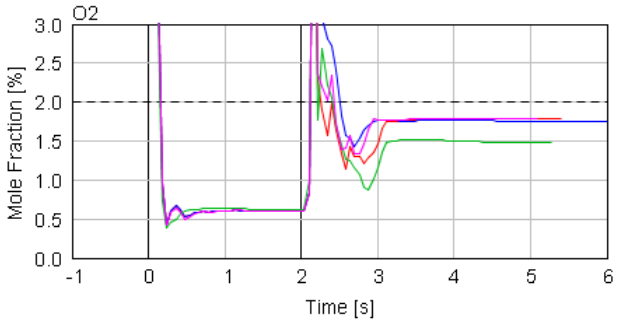
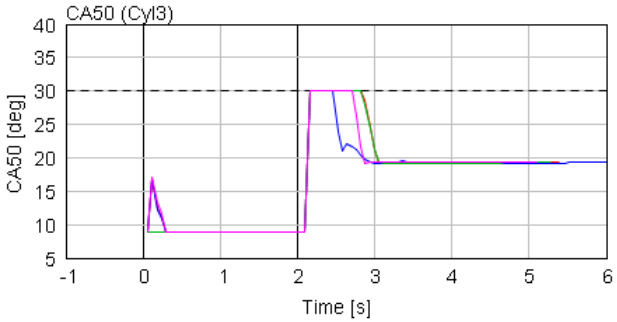


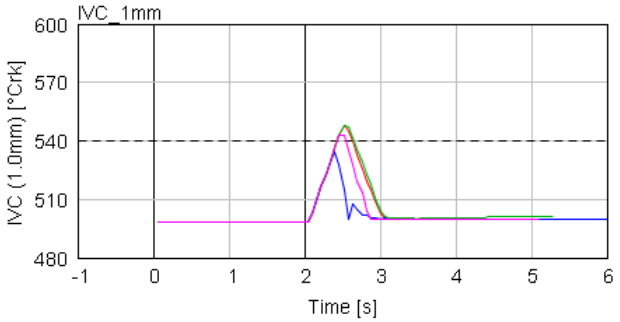
Transient response eBooster

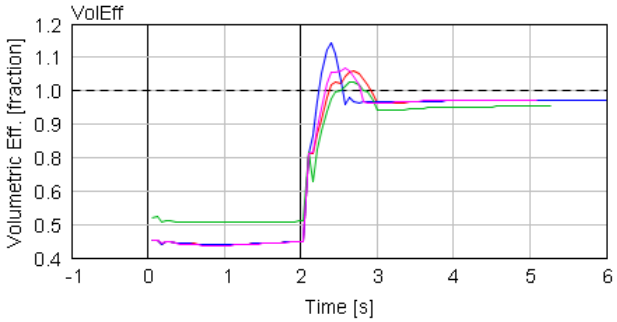












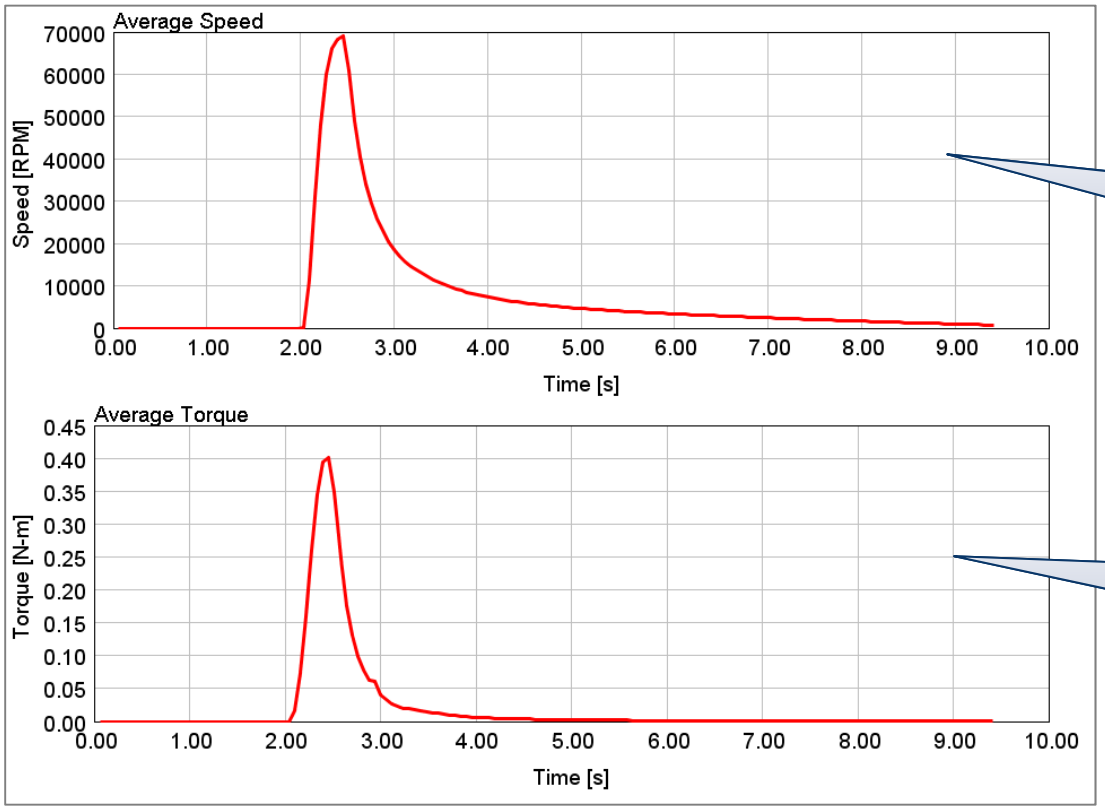
Transient response eBooster

automotive engineering iav

Values eCharger

Max. Power: 3.0kW Max. Torque: 0.53Nm

Voltage: 12V Current: 350A



Average speed compressor wheel

Average torque compressor wheel

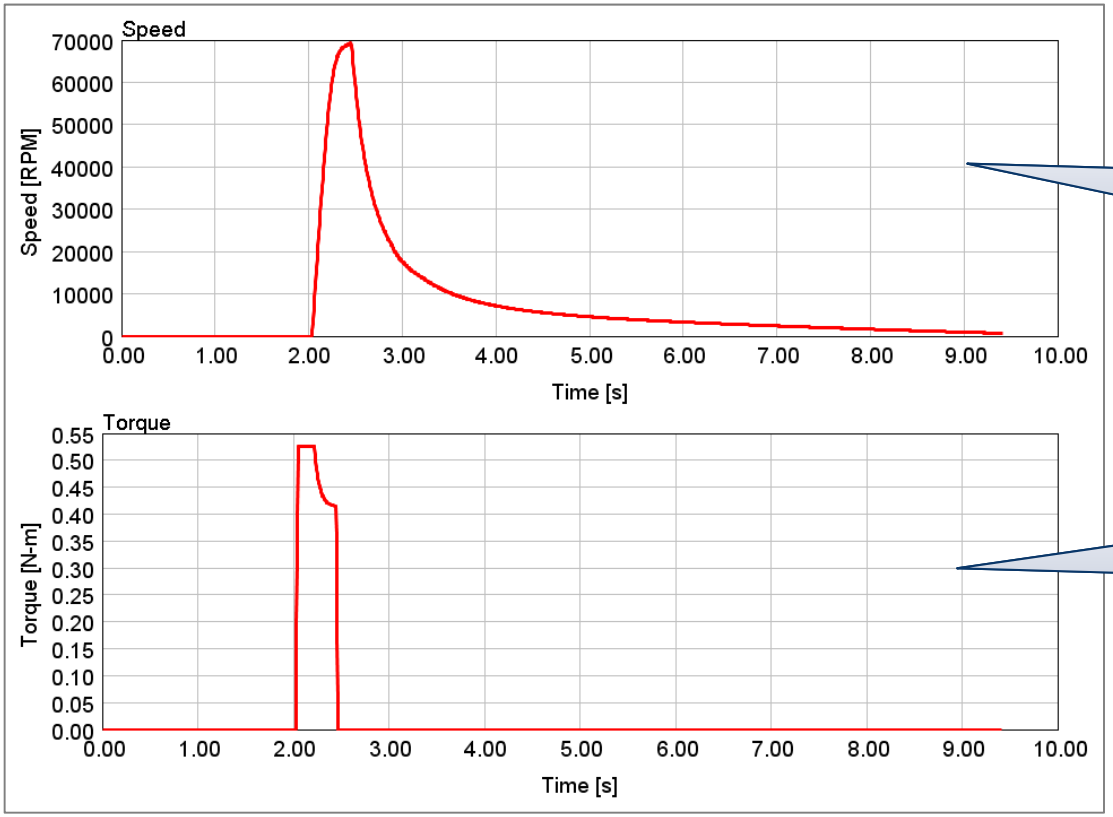
Transient response eBooster

automotive engineering iav

Values eCharger

Max. Power: 3.0kW Max. Torque: 0.53Nm

Voltage: 12V Current: 350A



Speed of echarger shaft

Torque echarger motor

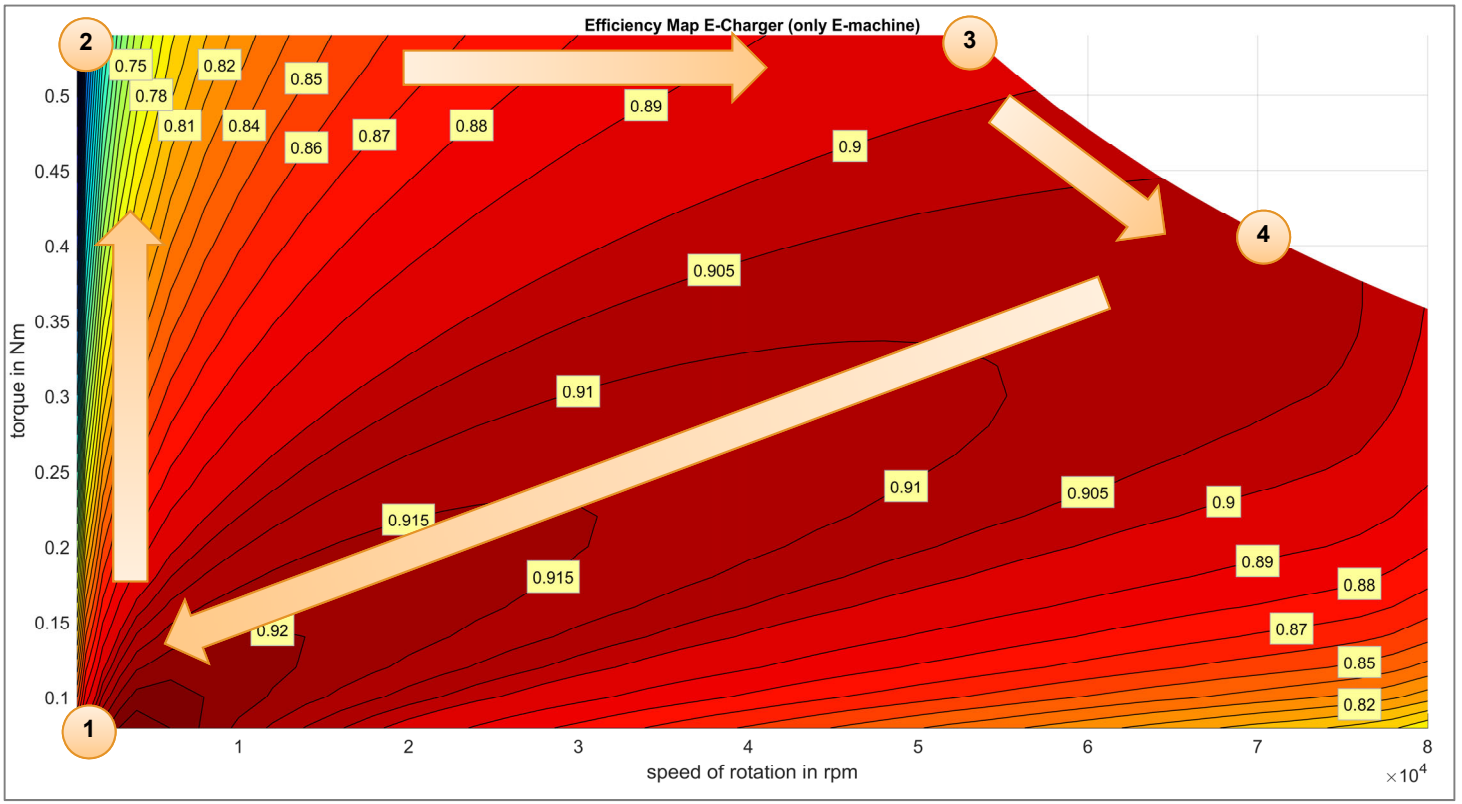
Transient response eBooster

automotive engineering iav

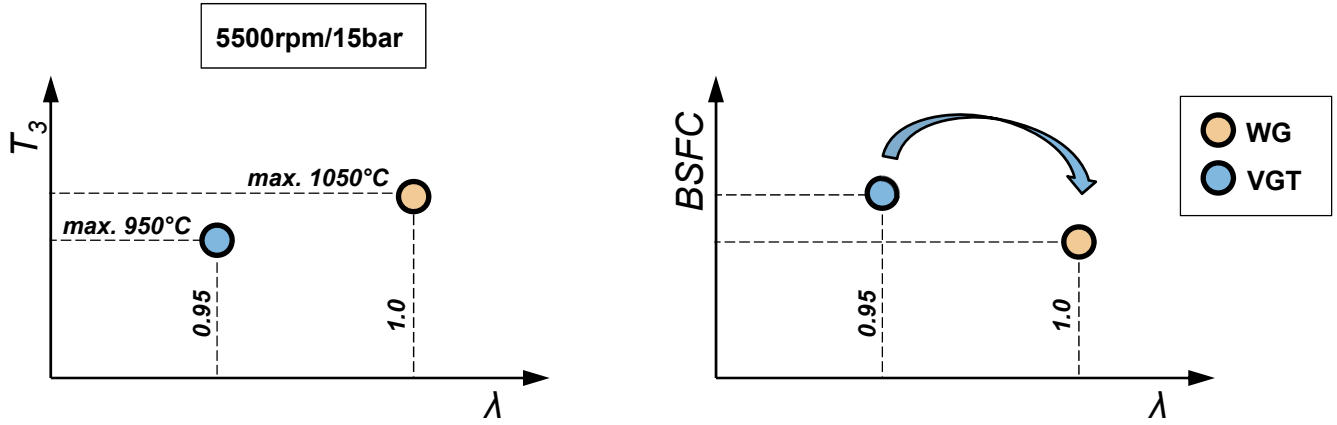
Values eCharger

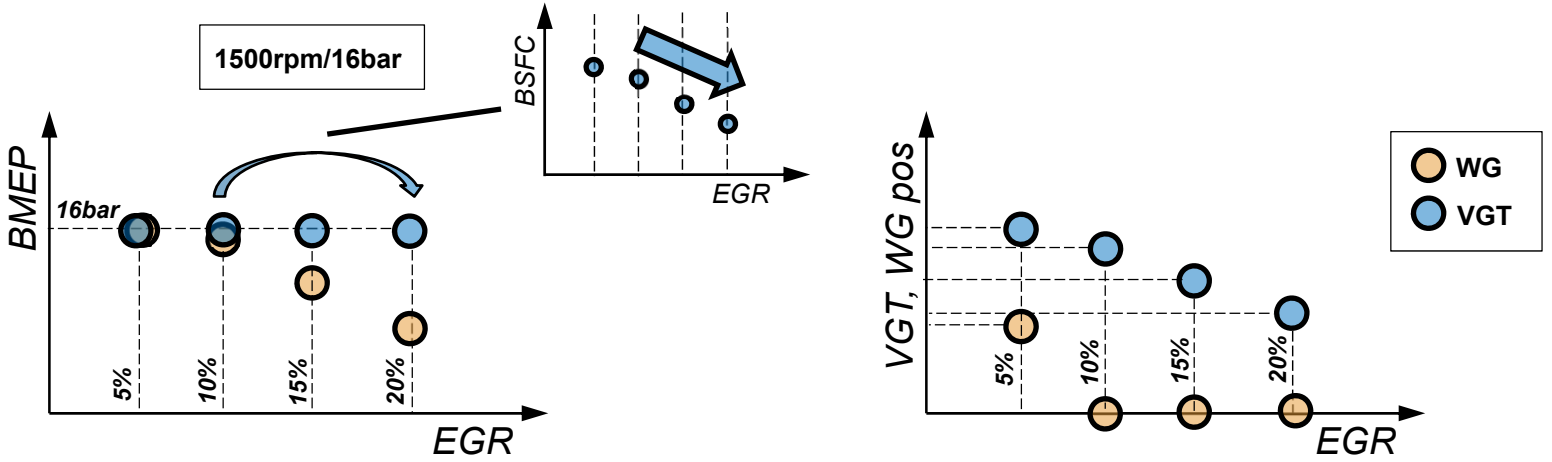
Max. Power: 3.0kW Max. Torque: 0.53Nm

Voltage: 12V Current: 350A



Comparison VGT and WG





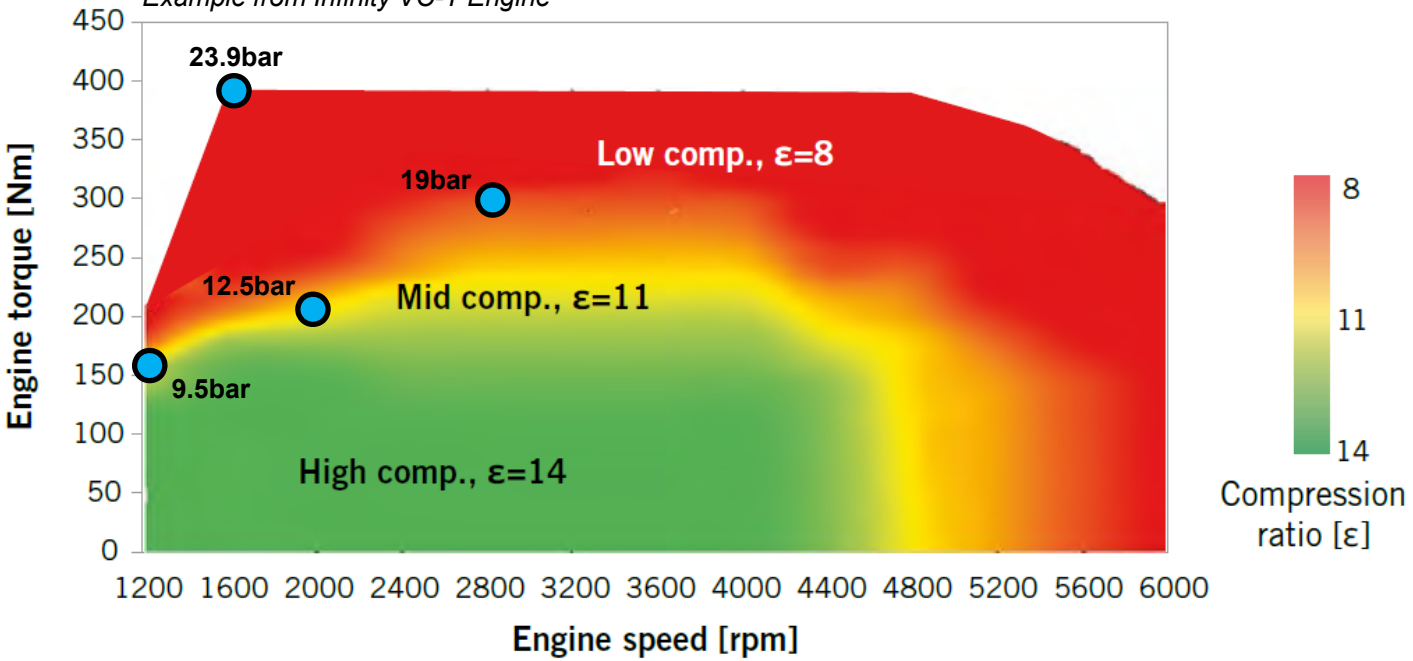
Content

- Methodology
- Engine 22b (Atkinson n.a.)
- Engine 23b (VVL Miller VTG EGR)
- Engine 24 (VVT Miller eCharg. EGR)
- Engine 26a (VCR EGR)

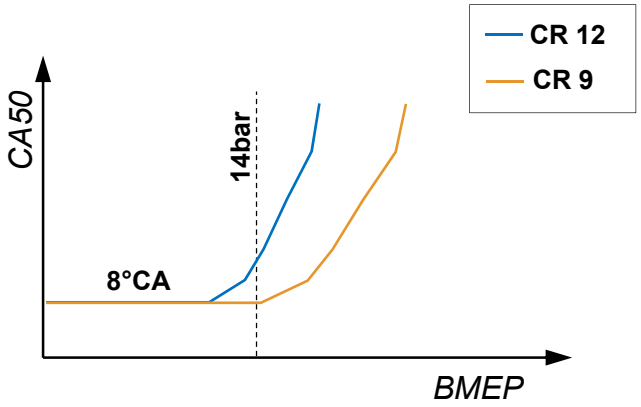
Overview

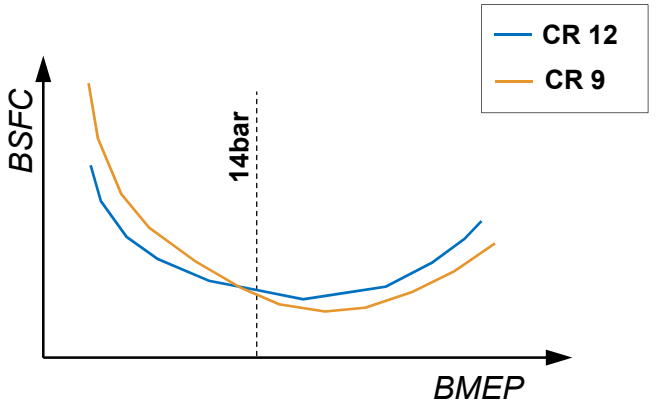
Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
Atkinson NA	22b	2.5	-	4	14	PFI	No	Yes	No
VVL Miller VTG c. EGR	23b	2.0	TC	4	12	DI	Yes	Yes	Yes
VVT Miller eCharger c. EGR	24	2.0	TC + eCharger	4	12	DI	Yes	Yes	No
Var. Cyl. Deact. c. EGR	25a	2.0	TC	4	10.5	DI	Yes	Yes	No
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No

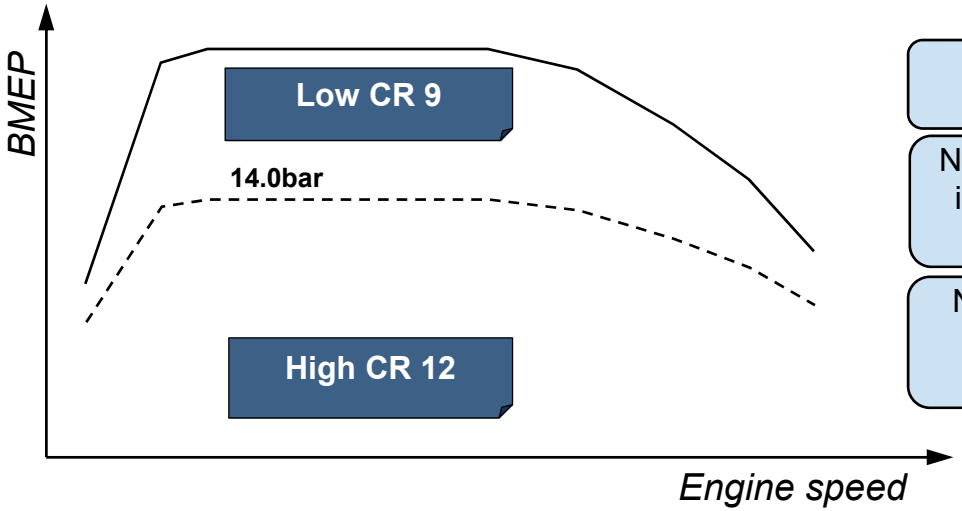
Example from Infinity VC-T Engine



VCR 2-step characteristic map







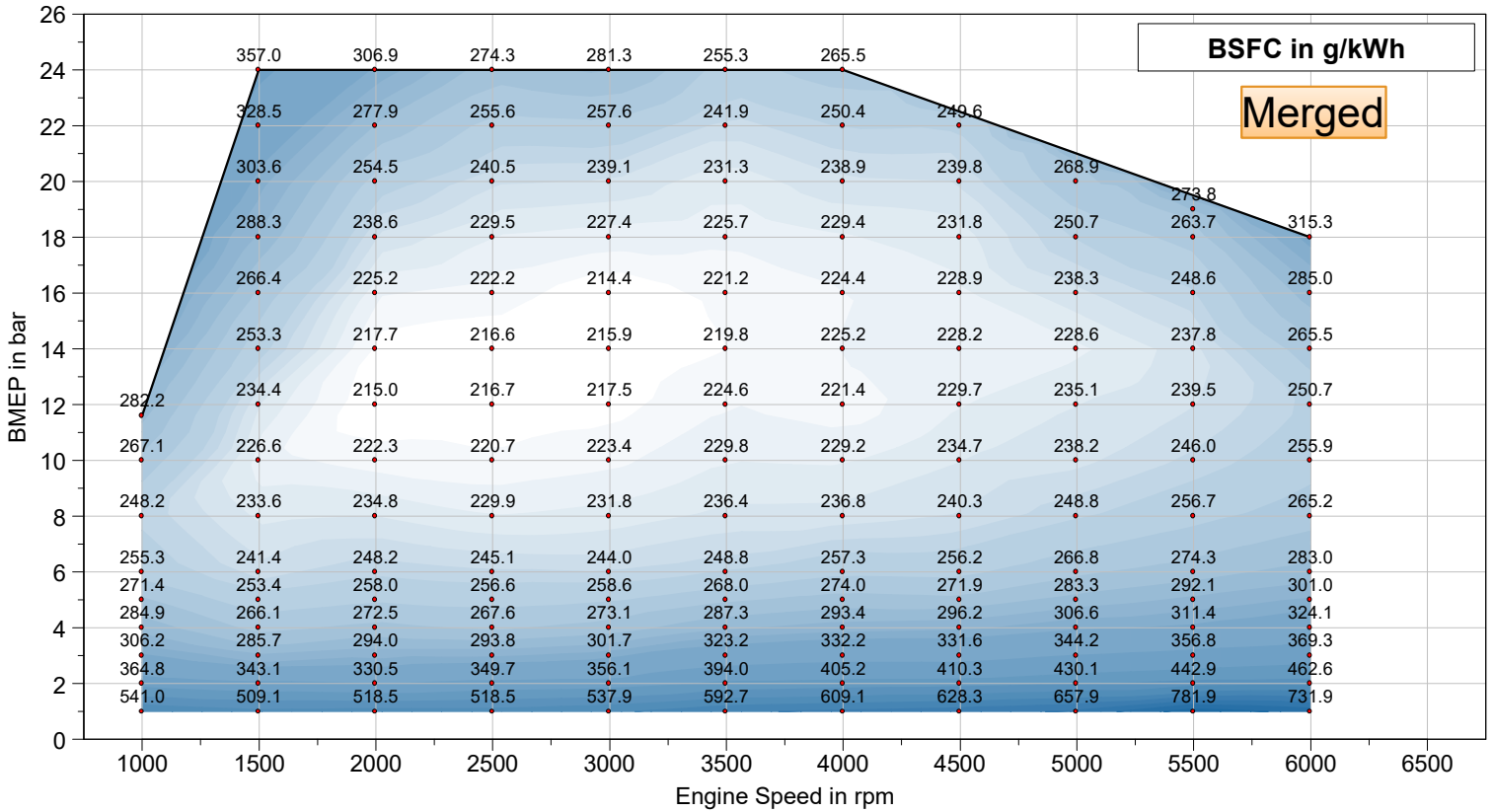
Very efficient with a adapted cooling concept

No low cooling concept needed as in fixed low CR to reduce losses at part load

No high cooling concept needed as in fixed high CR to reduce knocking at mid and high load

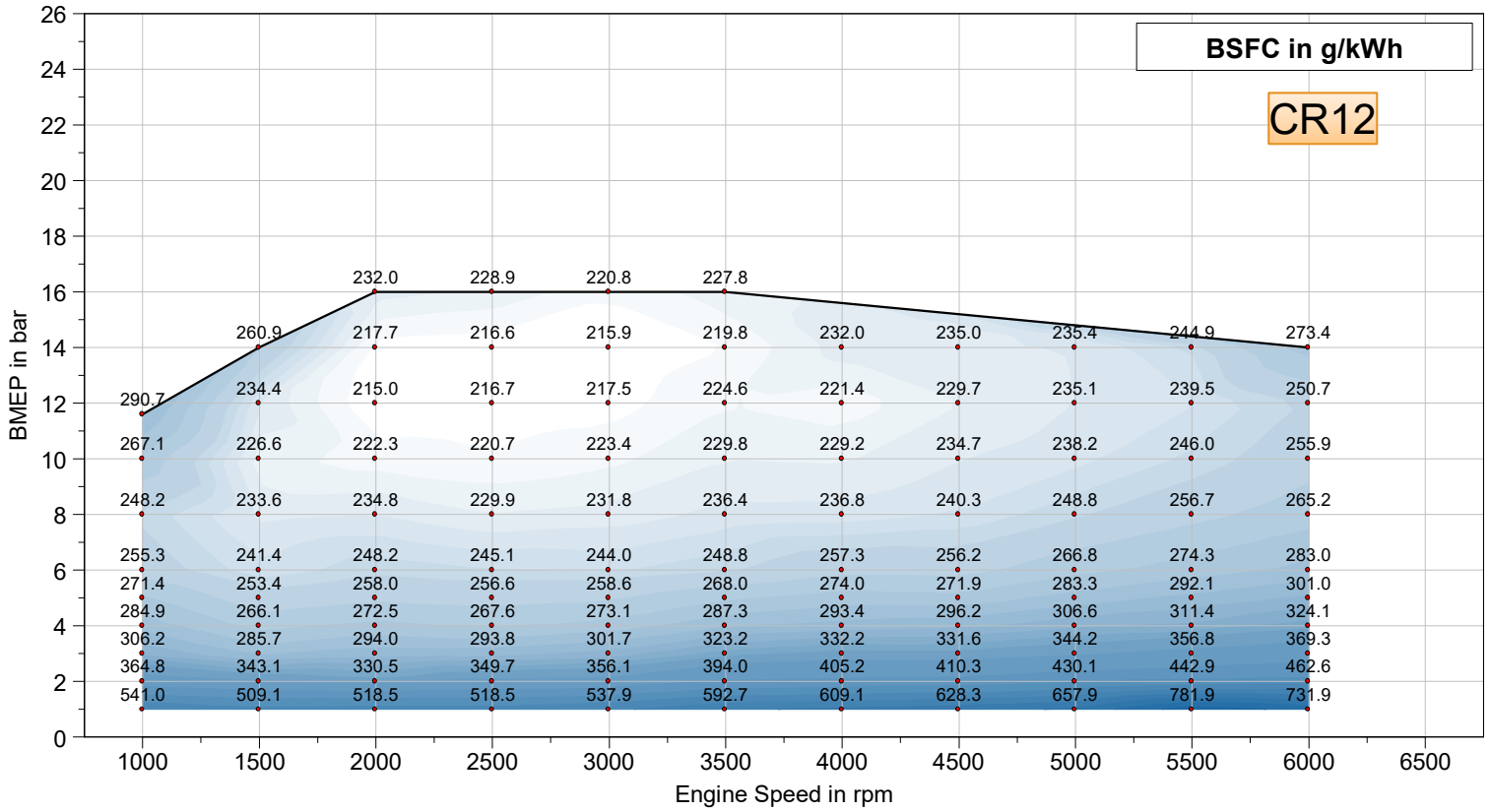
Map prediction – Engine 26a

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No



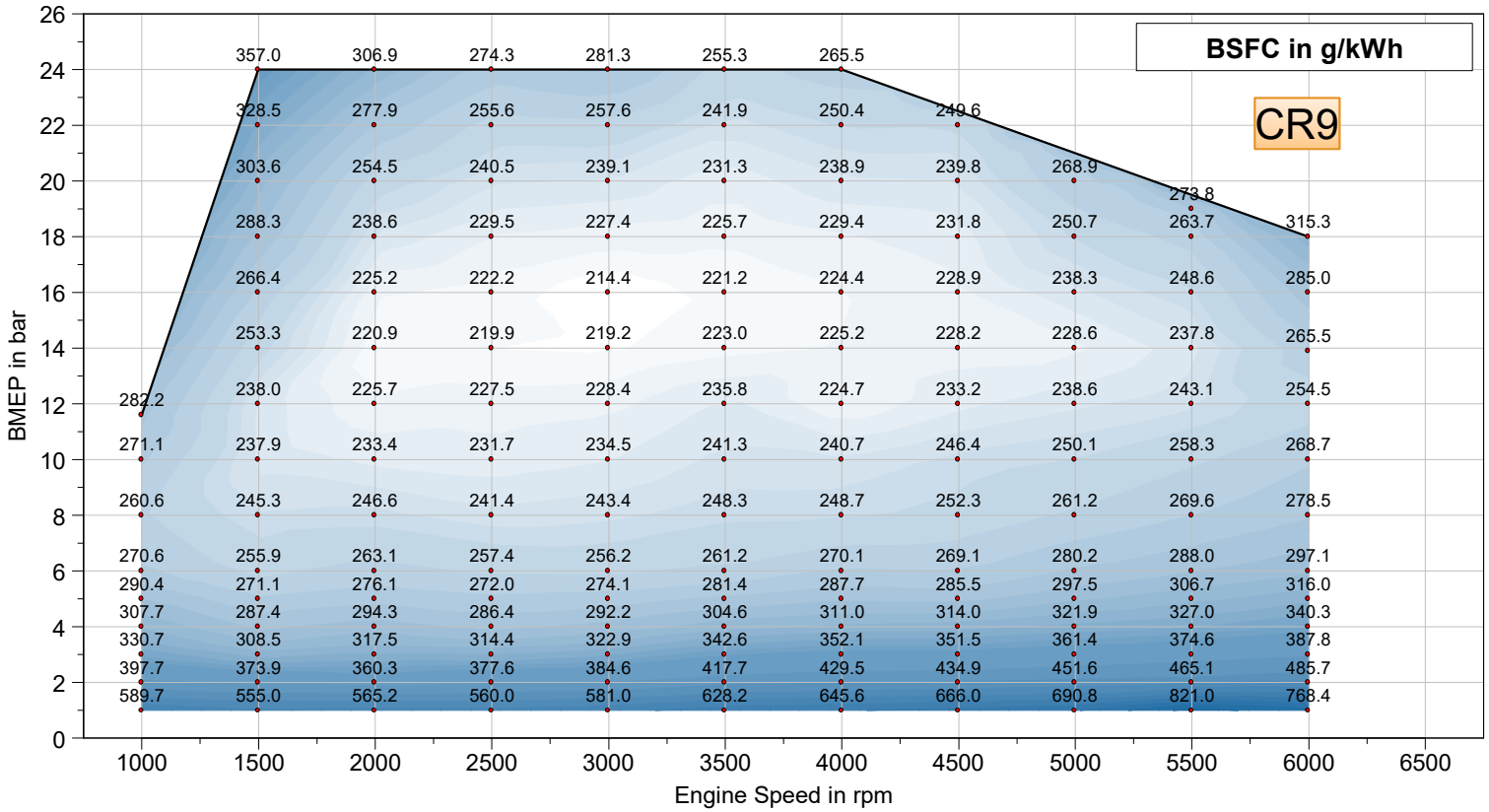
Map prediction – Engine 26a

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No



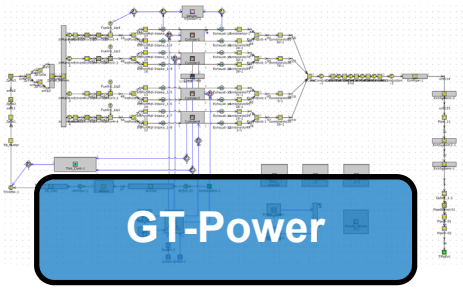
Map prediction – Engine 26a

Description	Engine label	Displacement	Boosting Device	Nr. cyl	CR	Injection	C. EGR	VVT	VVL
-	-	L	-	-	-	-	-	-	-
VCR c. EGR	26a	2.0	TC	4	9/12	DI	Yes	Yes	No

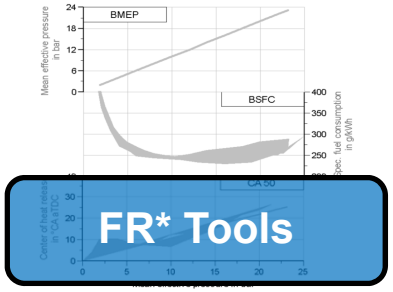


Methodology – Engine 26a

- Data of similar engine with CR12 and CR9 available
- COV <= 3% (Cycle of variation)
- Spark Knock $KIS_{KH,max}$ = 2% (description slide 11)
- Data of different engines with EGR available



- Effect of c. ext. EGR on BSFC for specific engine (Based on test bench data)



- Validation with benchmark data

Thank You

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