ULTRA BOOST FOR ECONOMY: ACHIEVING 60% DOWNSIZING AND 35% IMPROVEMENT IN FUEL CONSUMPTION

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Project Partners and Responsibilities

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Block and Head, Specifications

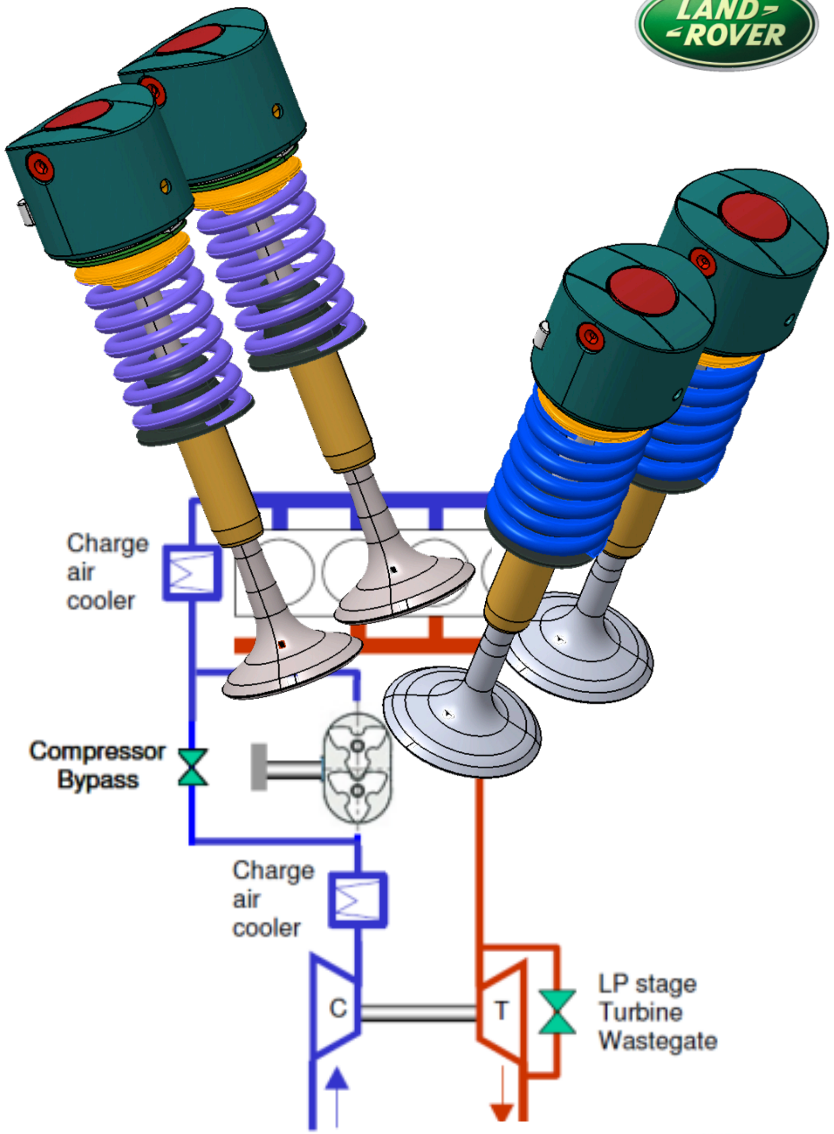
Combustion and Charging Systems

UB100 Preliminary Results

- *Including DI/PFI split, cooled EGR*

UB200 Concept

Conclusions



The Ultraboost Project

The 'Ultraboost' project aims to create a highly-boosted, heavily-downsized engine to provide the torque curve and power output of the naturally-aspirated Jaguar Land Rover AJ133 5.0 litre V8 engine

It is funded by the UK Technology Strategy Board as part of its Low-Carbon Vehicles Programme

Dyno-based multi-cylinder engine operation forms the core of the project, with modelling used to demonstrate a 35% improvement in fuel economy

The driveability of the original V8 engine is to be maintained

In order to meet these targets, an advanced charging system will be necessary

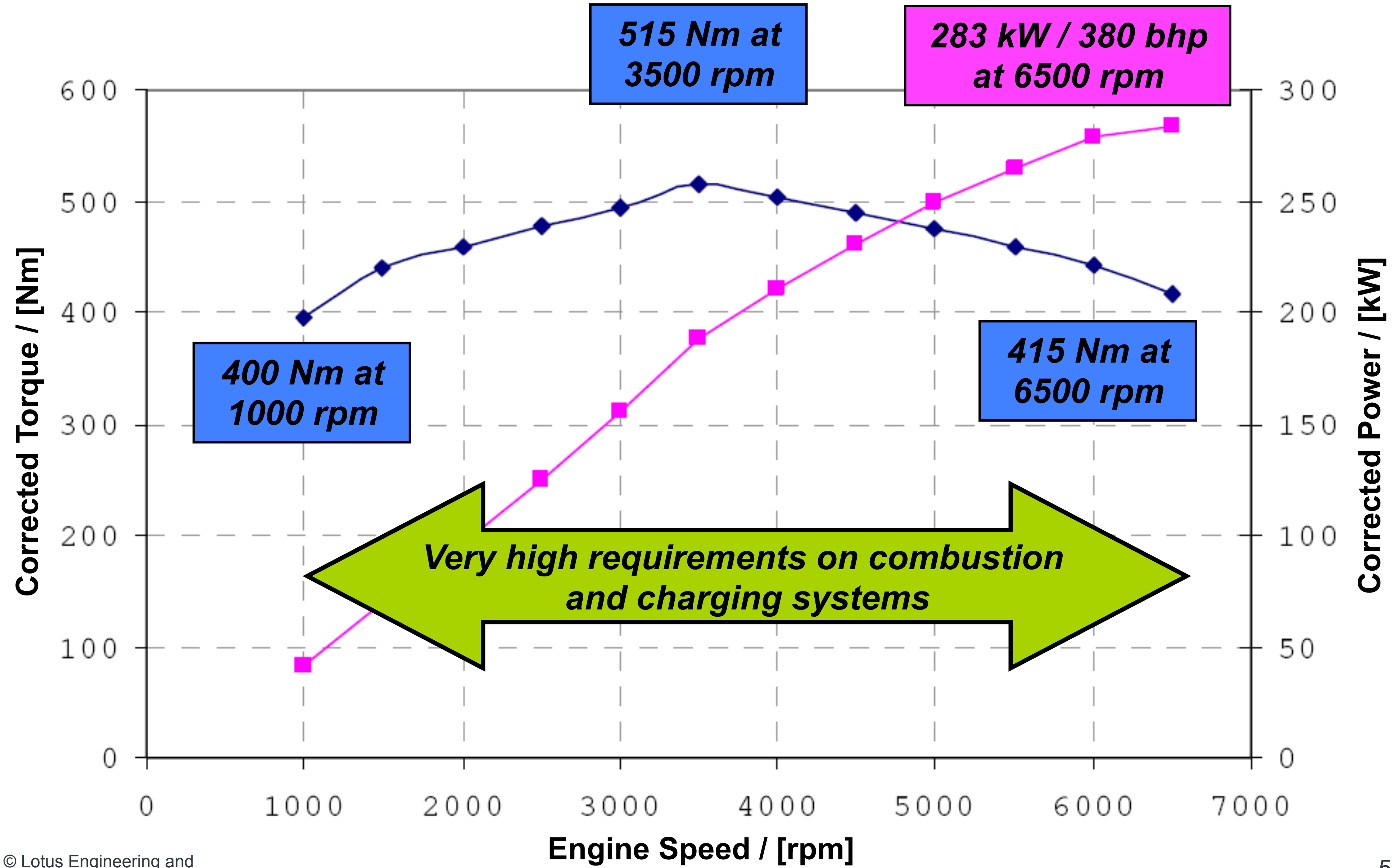
Operation on 95 RON pump gasoline is required

Operation at up to very high BMEPs will be necessary throughout the speed range

Project Partners and Responsibilities

Partner	Role
LAND ROVER	**Project Leader and Technical Direction** Engine design, prototype parts supply, procurement, engine build
GE PRECISION ENGINEERING	Engine design and component manufacture
LOTUS	Control and calibration, 1D simulation, high BMEP and knock experience
CD-adapco	Port flow analysis and in-cylinder flow modelling
	Fuel and lubricant supply, knock experience
UNIVERSITY OF BATH	Engine testing
UNIVERSITY OF LEEDS	Combustion modelling development through LUSIE
Imperial College London	Boosting system development

Project Target: Power Curve for JLR AJ133 NA V8



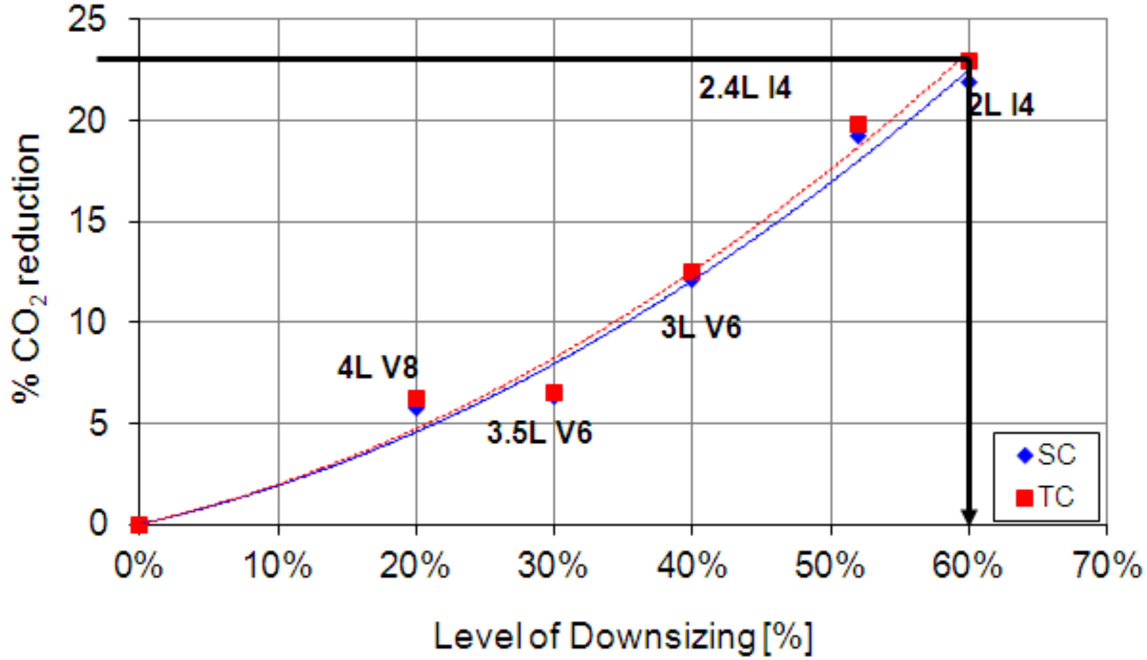
Project Target: CO2, Fuel Economy and Emissions

Metric		Units	AJ133 5.0 l V8 NA (BASELINE)	Ultraboost (TARGET)
Fuel Economy Vehicle	NEDC CO_2	g/km	296	192
	NEDC FE - Combined	mpg	22.6	34.8
	Metro-Highway	mpg	21.6	Report Status
	Real World – Cruise at 130 km/h	mpg	23.2	Report Status
Fuel Type	Test Fuel	-	Pump 95 RON ULG – EN228	
Engine Performance	Peak Power	kW	283	283
	Peak Torque	Nm	515	515
	Time to Torque	s	Report Status	Better than JLR 3.0 l twin turbo V6 diesel
	Maximum Engine Speed	rpm	6500	6500
	Peak BMEP	bar	12.6	Up to 35
	Mean Peak Cylinder Pressure	bar	85	~ 130-135
Emissions Vehicle	Euro	Target	EU5	EU6 > 7
	US	Target	CARB LEV3 – ULEV70 SFTP2 – ULEV70 EPA Tier 2 Bin 5	CARB LEV3 – ULEV30 SFTP2 – ULEV30 EPA Tier 2 Bin 5

Level of Downsizing

Previous work by JLR had shown that 23% of the total target of 35% can be reached by 60% capacity downsizing

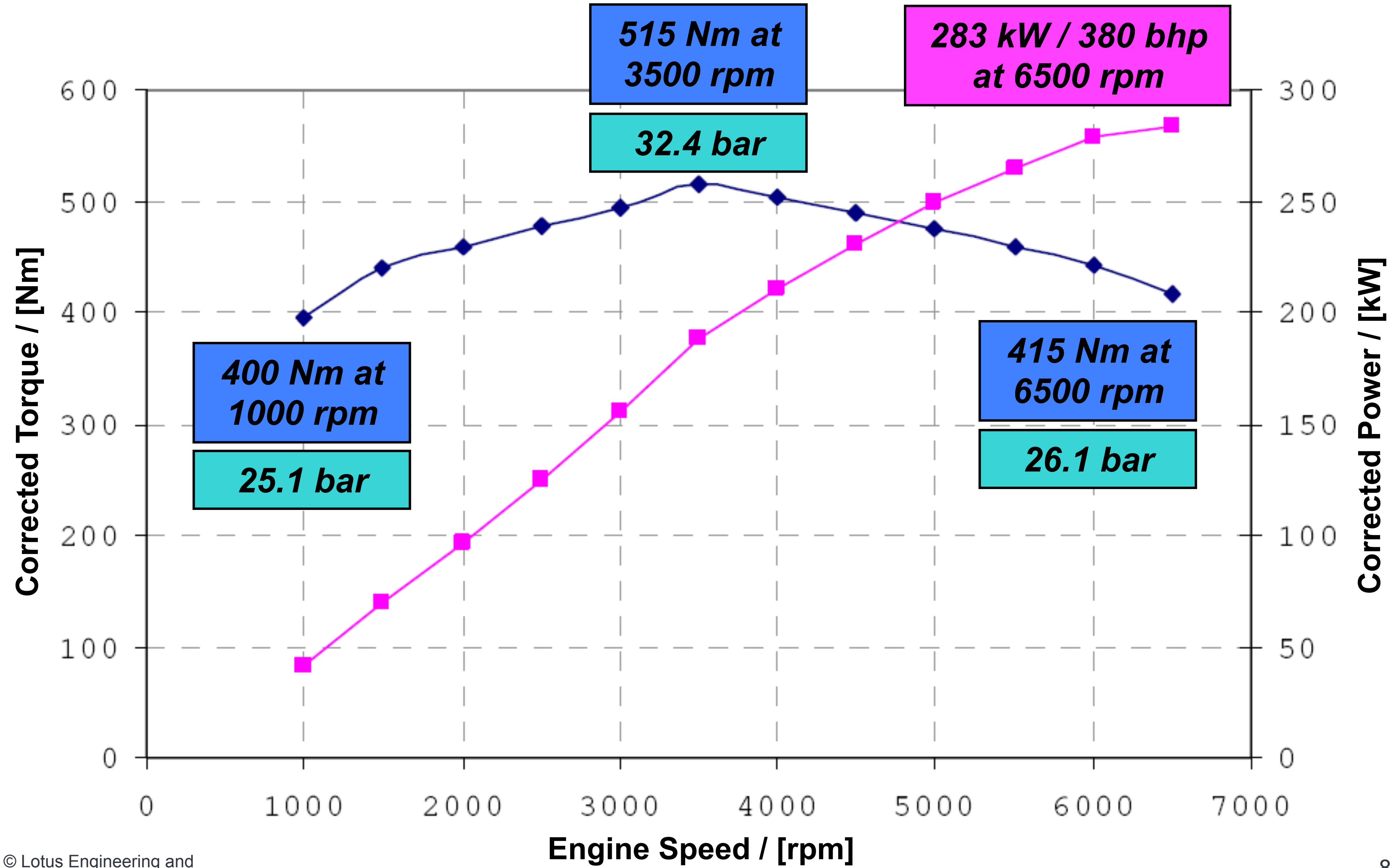
- *Remainder can be made up by friction reduction, stop-start and vehicle measures*



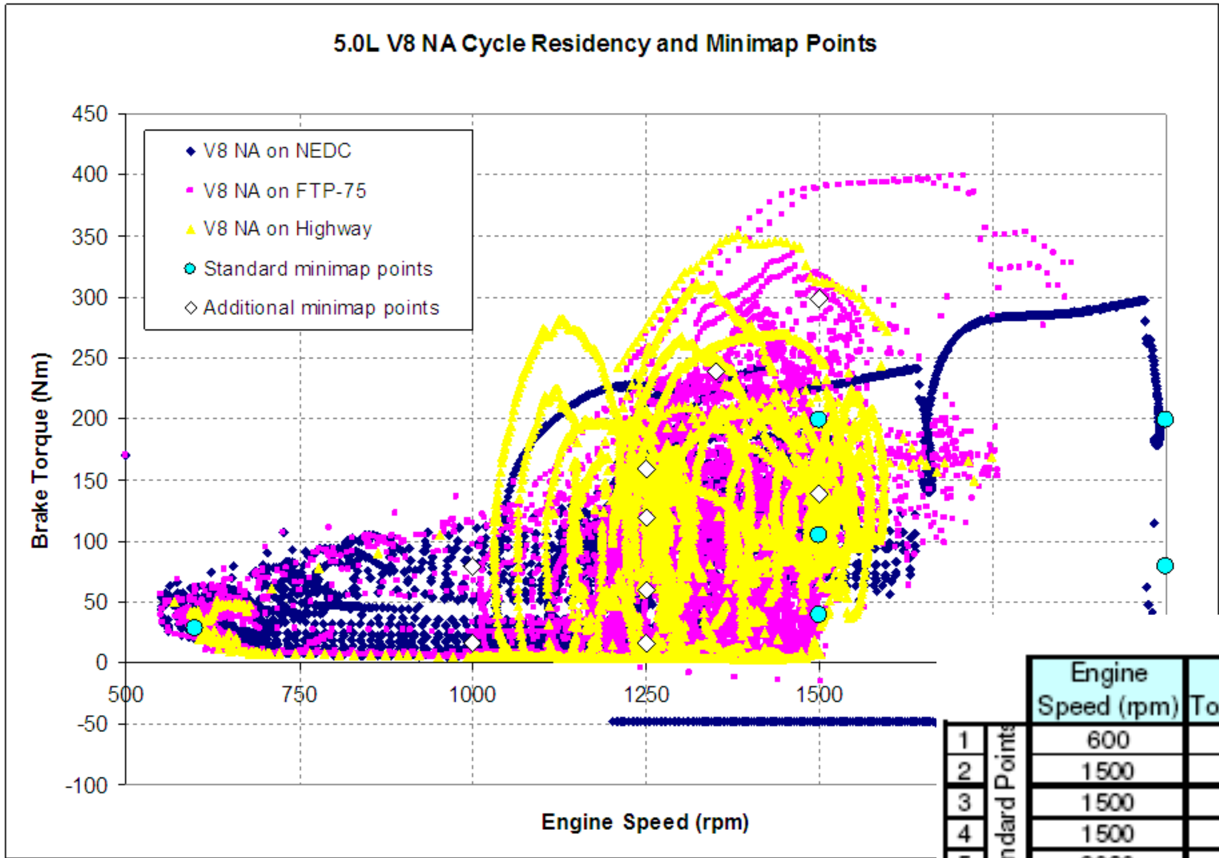
This led to an early project decision to design the first iteration of Ultraboost (so-called 'UB100') as a 2.0 litre engine

- *Based on BMEP, maximum cylinder pressure and maximum charge pressure*
- *With scope to redesign it to a different capacity for a second iteration ('UB200')*

Project Target: Power Curve for JLR AJ133 NA V8



Level of Downsizing – Test Point Determination



Cycle residency plot was used to determine bins to establish 15 speed and load sites

Six standard minimap points with nine additional points

		Engine Speed (rpm)	Brake Torque (Nm)	5l bmep (bar)	2l bmep (bar)	Cycle Weightings NEDC 1180	FTP-75 1878	Highway 766
1	Standard Points	600	28	0.7	1.8	0.291	0.236	0.016
2		1500	40	1.0	2.5	0.013	0.113	0.043
3		1500	104	2.62	6.5	0.099	0.061	0.167
4		1500	199	5.0	12.5	0.025	0.032	0.076
5		2000	80	2.0	5.0	0.001	0.000	0.000
6		2000	199	5.0	12.5	0.008	0.000	0.000
7	Additional Points	1250	16	0.4	1.0	0.109	0.153	0.084
8		1000	16	0.4	1.0	0.079	0.082	0.034
9		1000	80	2.0	5.0	0.089	0.022	0.008
10		1250	159	4.0	10.0	0.023	0.036	0.117
11		1350	239	6.0	15.0	0.023	0.036	0.047
12		1500	298	7.5	18.8	0.014	0.018	0.015
13		1250	119	3.0	7.5	0.043	0.073	0.134
14		1250	60	1.5	3.8	0.124	0.084	0.077
15		1500	139	3.5	8.8	0.046	0.055	0.182
			Fuelcut (>1000rpm, <-10Nm)			0.015	0.000	0.000

Major Tasks

Combustion system: deliver a knock-tolerant combustion system operating at up to 130-135 bar maximum mean peak cylinder pressure

- *Without the requirement for significant compression ratio reduction, i.e. ≥ 9.0:1*
- *To be proven at the UB100 design level*

Boosting system: deliver a boosting system that is capable of producing a boost pressure of up to 3.5 bar absolute

- *To achieve specific outputs of >250 Nm/litre and 142 kW/litre*
- *With best in class transient response and minimal parasitic losses*
- *To be adopted at the UB200 design level*

Design, develop, build and test the concept engines

- *In two specification levels*

Prove that the chosen technology package is capable of delivering a 35% reduction in tailpipe CO_2 over the NEDC

- *Relative to an AJ133 5.0 litre V8 NA gasoline engine*
- *When operating in a Land Rover product*

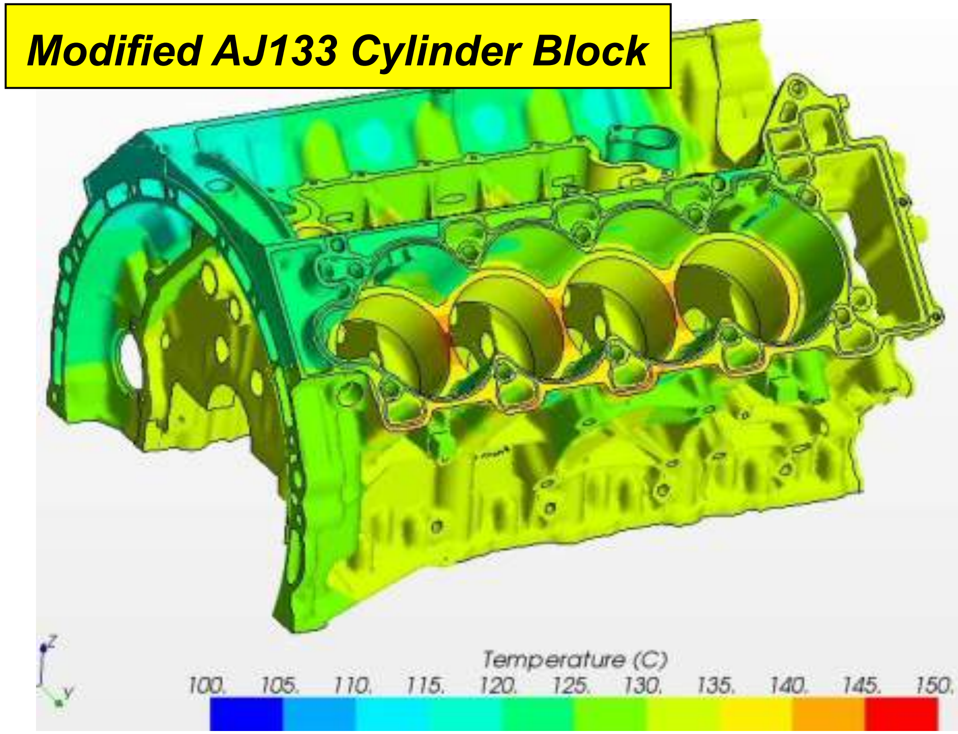
Ultraboost – Cylinder Block and Head

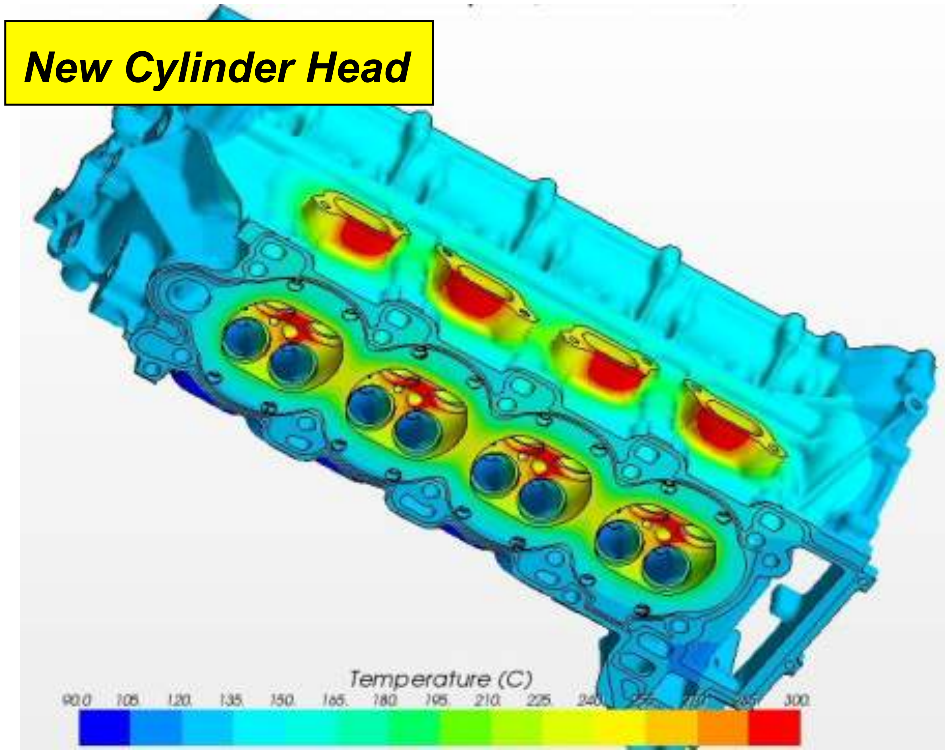
Cylinder block is a modified AJ133 V8 unit

- *Fitted with a flat-plane crankshaft and siamesed liner pack to reduce bore diameter*
- *Uses the standard water, oil and HP fuel pumps, main bearings, fuel rail etc.*

Cylinder head is completely new

- *Retains the fast-acting dual cam phasers and chain drive from AJ133 donor*
- *B bank is blanked off and the coolant flow is bypassed (via water-cooled manifold)*

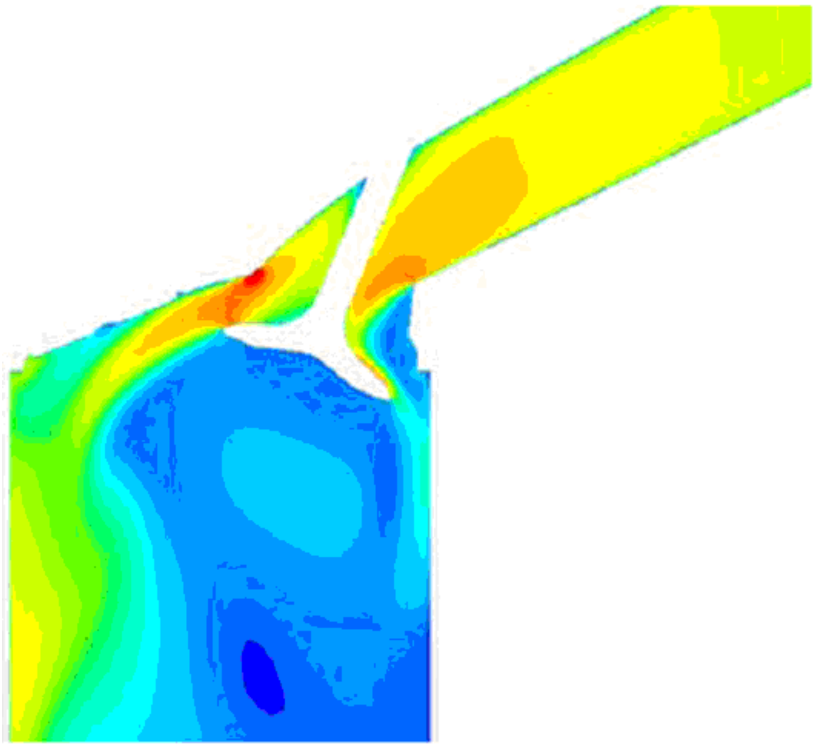


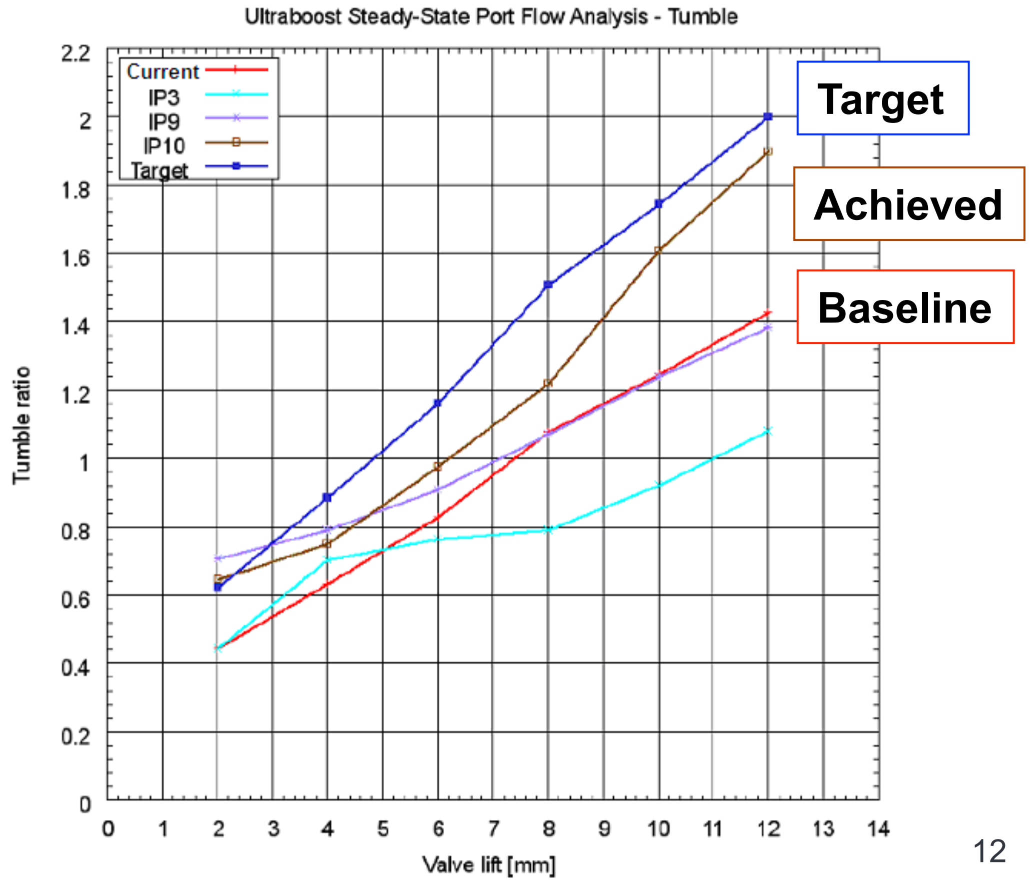


Intake Port Design and CFD

Ambitious ‘stretch’ targets were set for simultaneous high flow and tumble

- *Detailed steady state and transient analysis was performed by CD-adapco in order to arrive at an optimum*
- *Cylinder head has machining stock for a variety of machined ports to be tested*

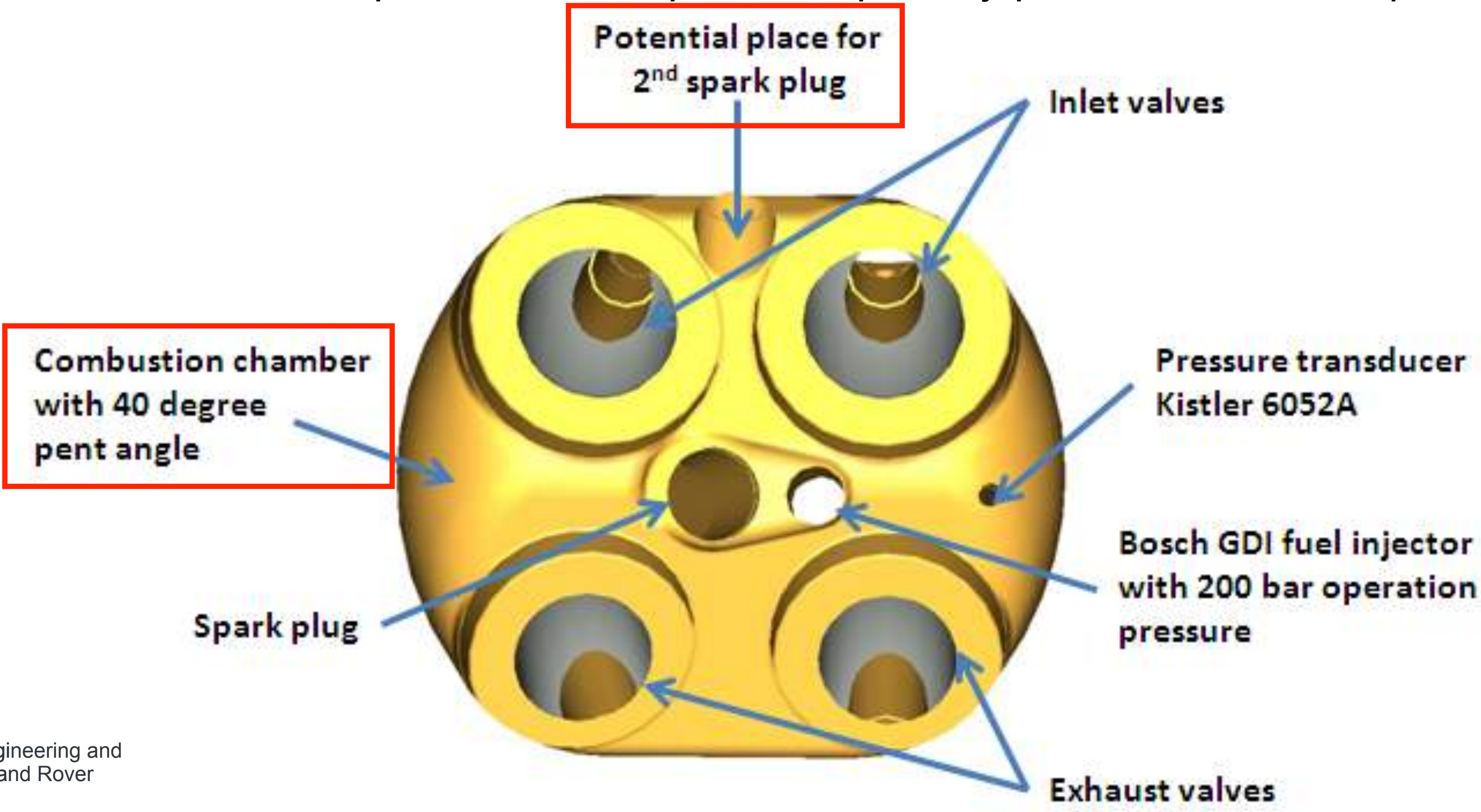




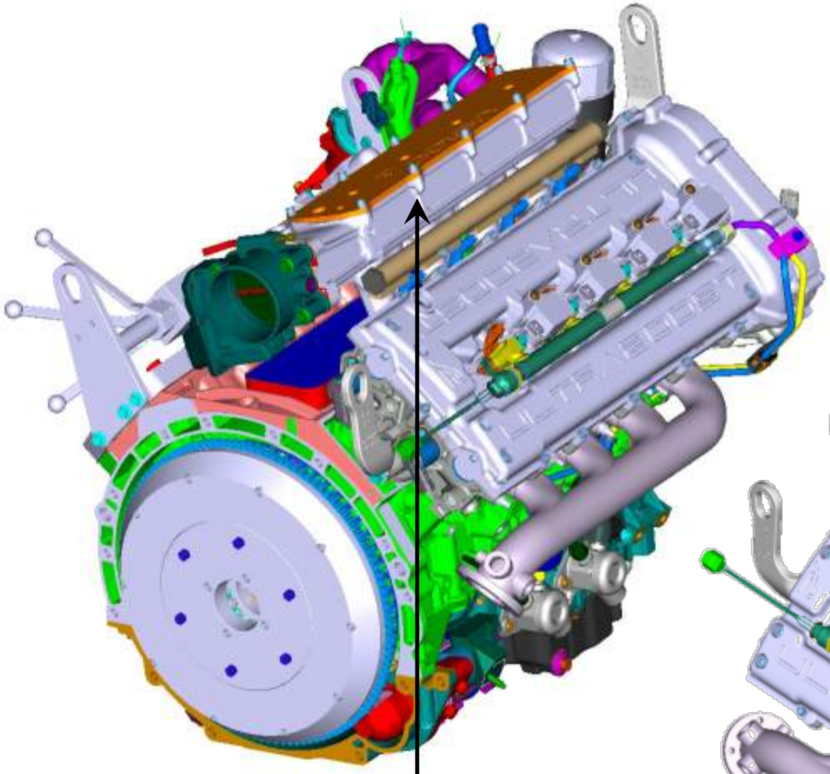
Ultraboost Combustion Chamber Layout

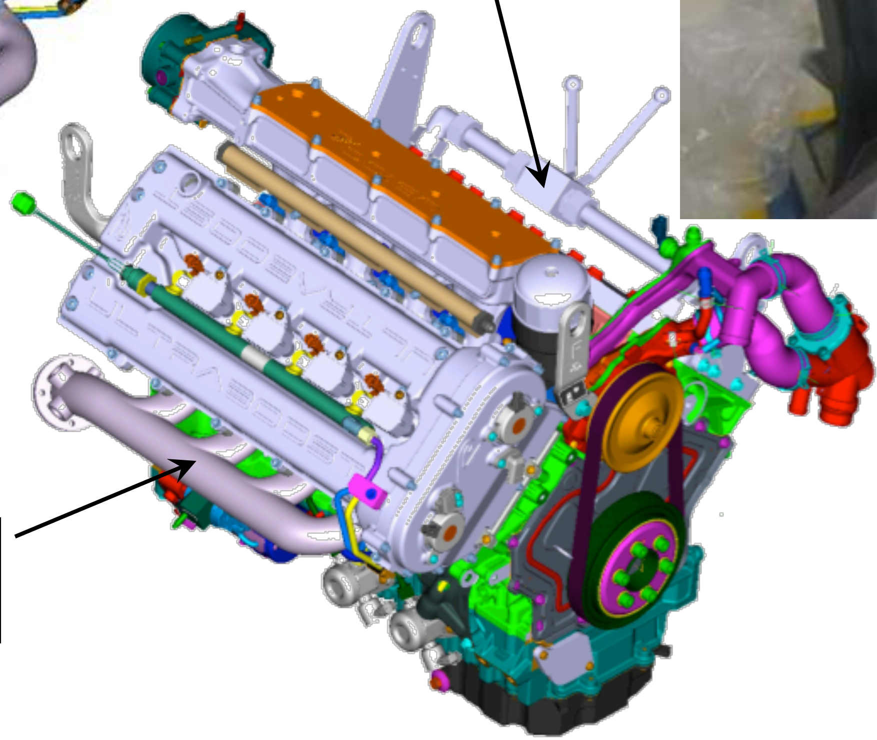
'Asymmetric' layout for injector and central spark plug

- *200 bar Bosch solenoid injector – same as AJ133*
- *Orientation is essentially standard AJ133*
- *Absence of under-port DI leaves space for optimally-positioned second spark plug*



UB100 – Views





Coolant bypass pipe for B bank

Log intake and exhaust manifolds

First assembled UB100 engine

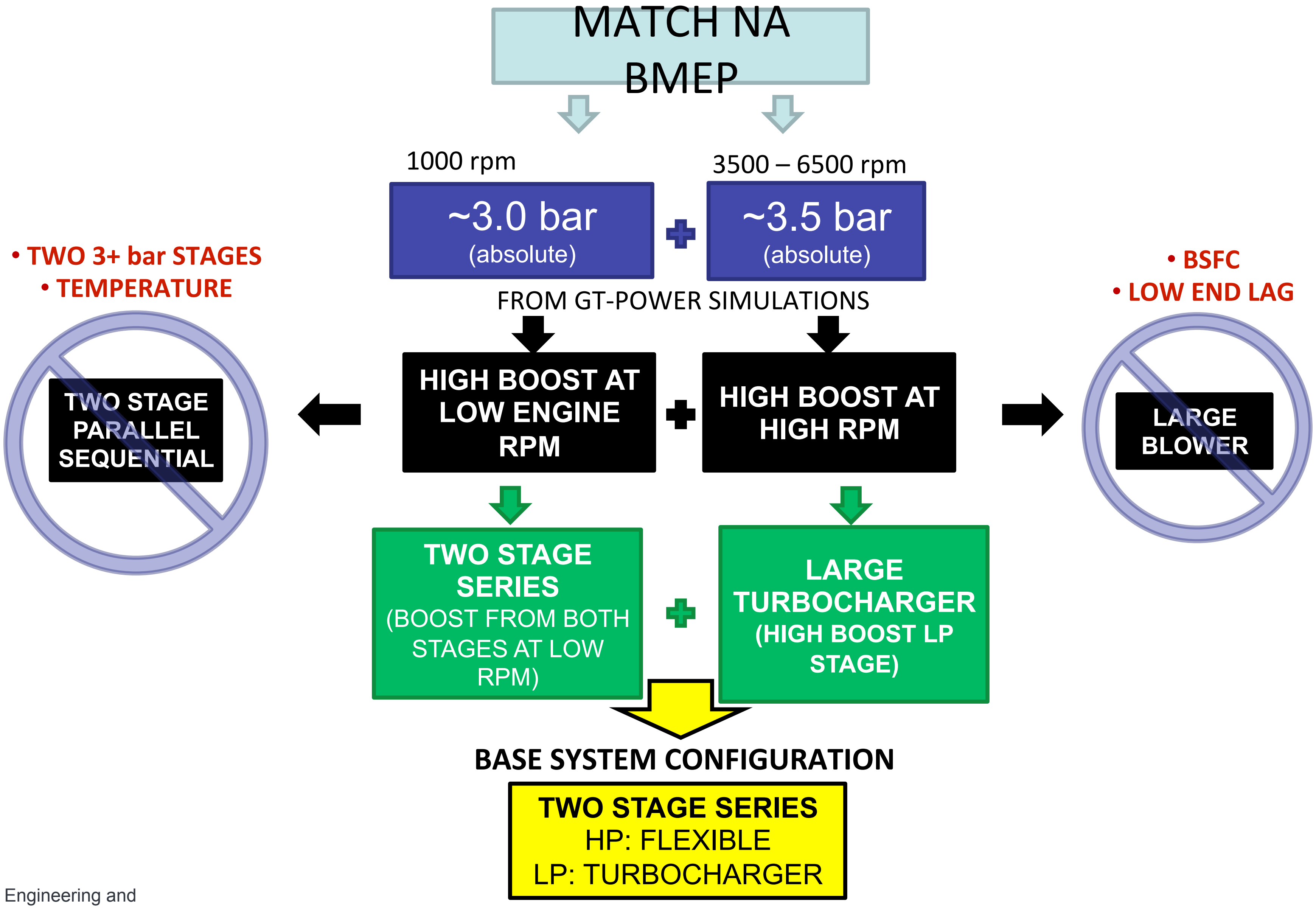
UB100 operates with a test cell Charge Air Handling Unit (CAHU) and cooled EGR supply rig; 1D model provides boundary conditions and brake load for SC

UB100 – General Specification

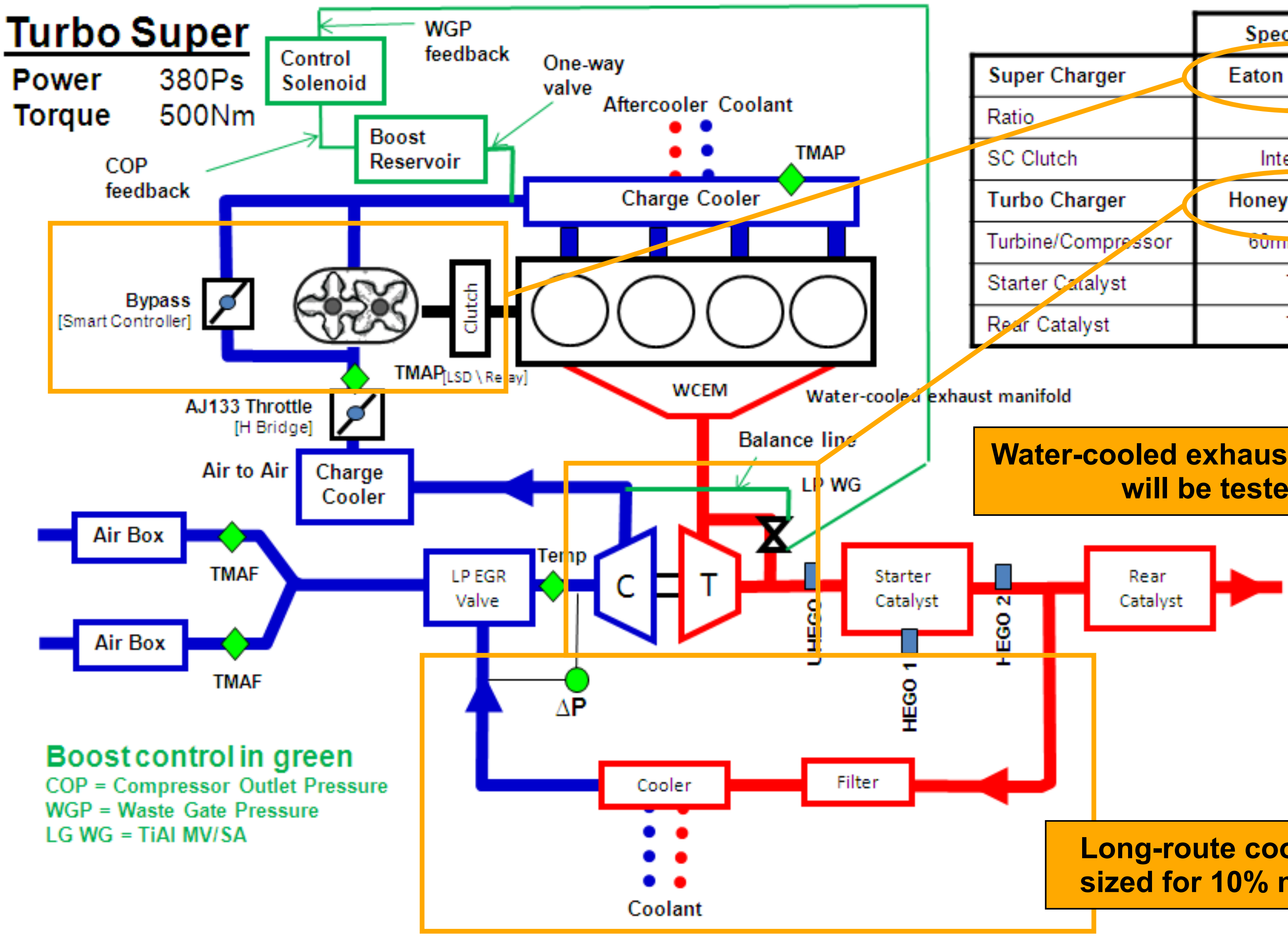
Engine Type	-	In-line 4-cylinder
Capacity	cc	1991
Bore	mm	83
Stroke	mm	92
Compression Ratio	:1	9.0
Firing Order	-	1 – 3 – 4 – 2
Combustion System	-	200 bar Gasoline DI and PFI, cooled EGR, No PCV
Valve Train	-	DOHC, DCVCP and CPS on inlet and exhaust
Specific Power	kW/l @ rpm	142 @ 6500
Specific Torque	Nm/l @ rpm	255 @ 3500
BMEP	bar @ rpm	35 @ 3500 and 25 @ 1000 and 6500

~ 10% undersquare

Broad Charging System Architecture Considerations



Chosen Charging System Schematic – 'Turbo Super'

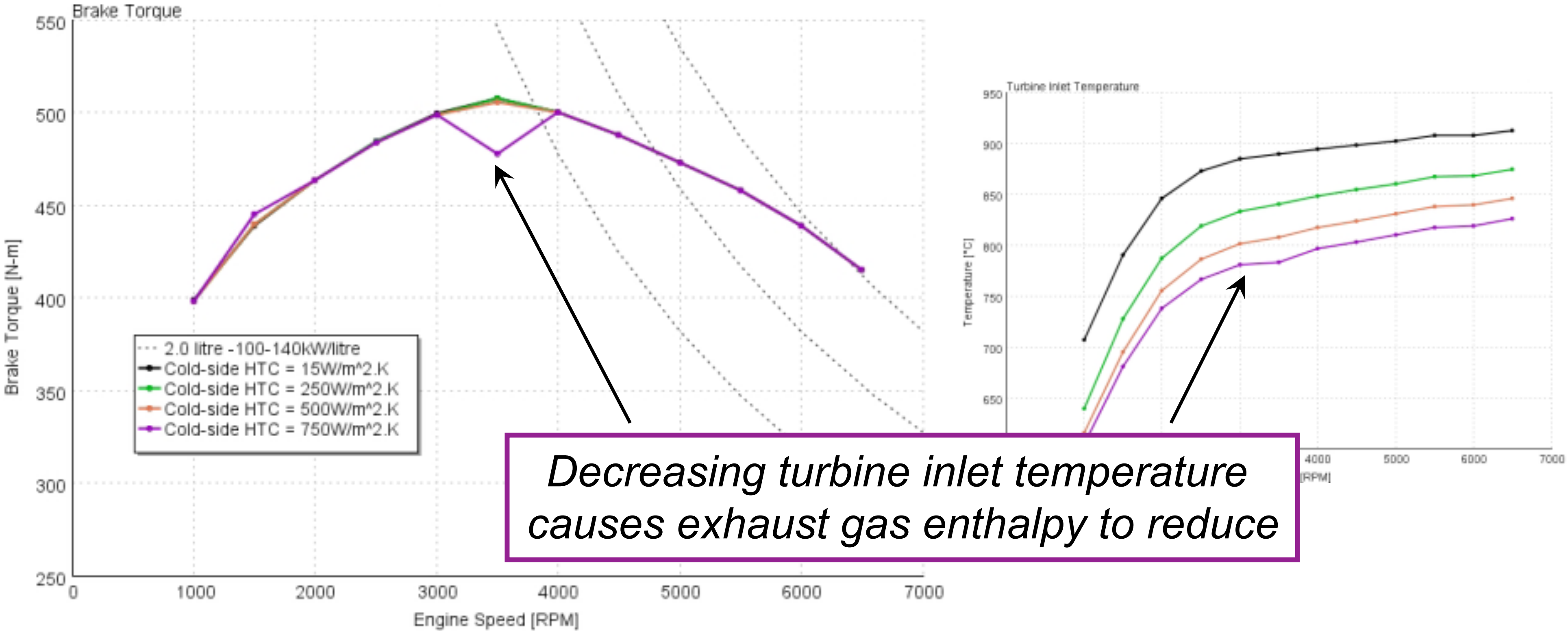


	Specification
Super Charger	Eaton R410 TVS
Ratio	TBD
SC Clutch	Integrated
Turbo Charger	Honeywell GT30
Turbine/Compressor	60mm/67mm
Starter Catalyst	TBD
Rear Catalyst	TBD

Water-cooled exhaust manifold will be tested

Long-route cooled EGR sized for 10% mass flow

WCEM – Effect of Heat Transfer Coefficient



The effect of heat transfer coefficient has been analyzed using GT-Power

- *15, 250, 500 and 750 W/m²k*

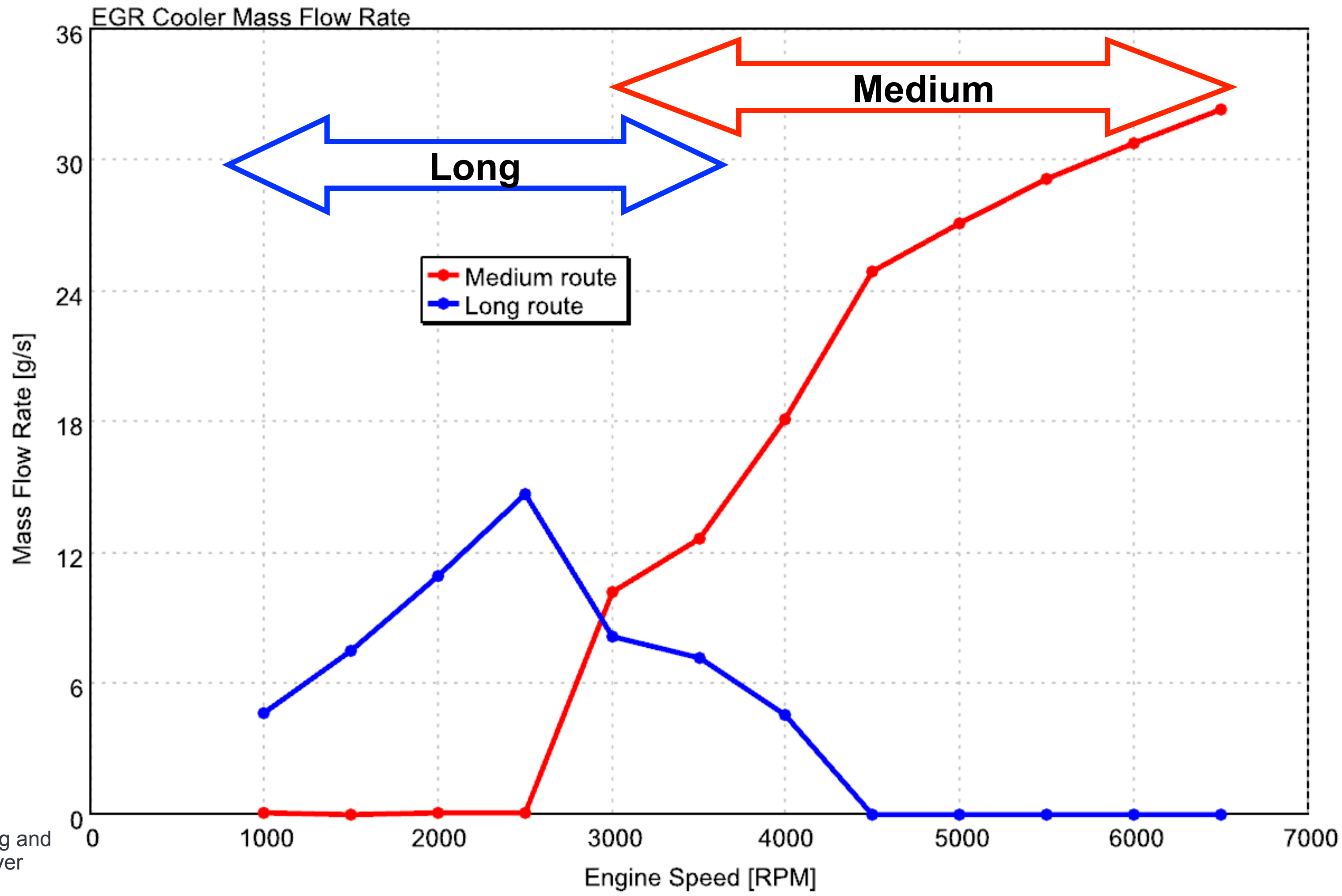
Only at the highest level – above that which would be expected in the water-cooled exhaust manifold – would the target torque *not* be met

- *This is because of the compound charging system adopted*

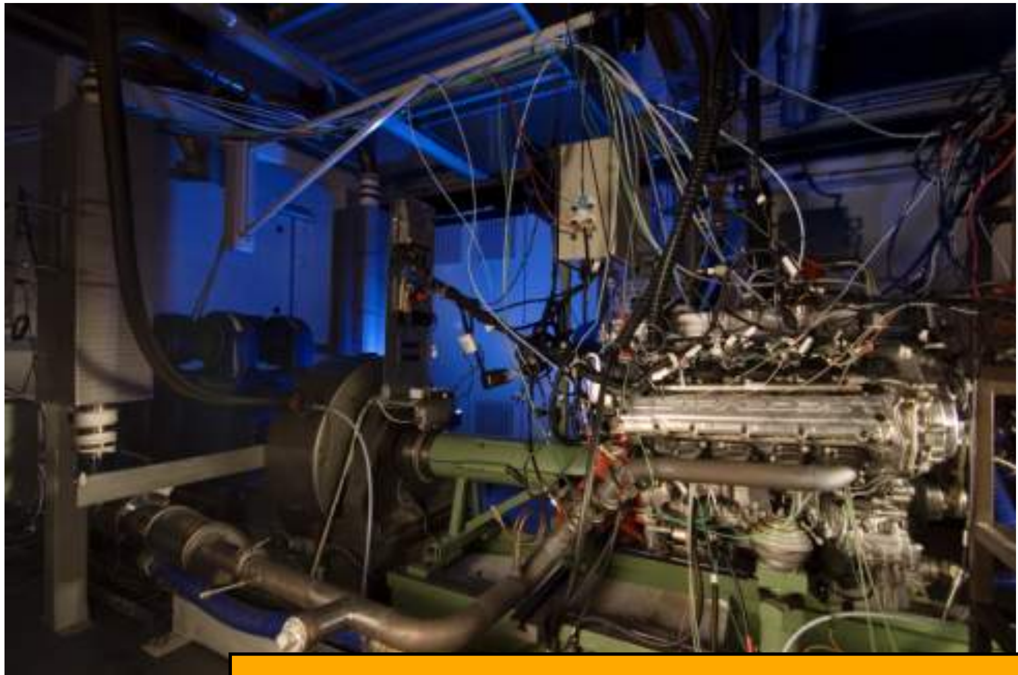
Cooled EGR Route Modelling Investigation

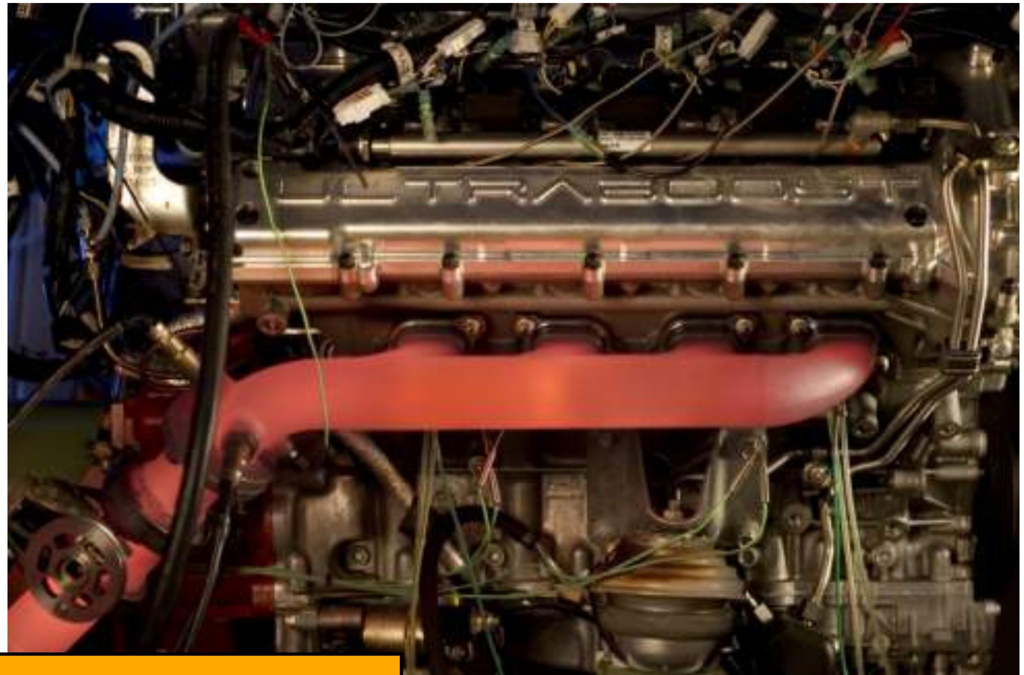
Default is long-route configuration, but other configurations have been modelled

- *A 'hybrid' system could permit greater amounts EGR flow at high speed*



UB100 Engine on the Test Bed



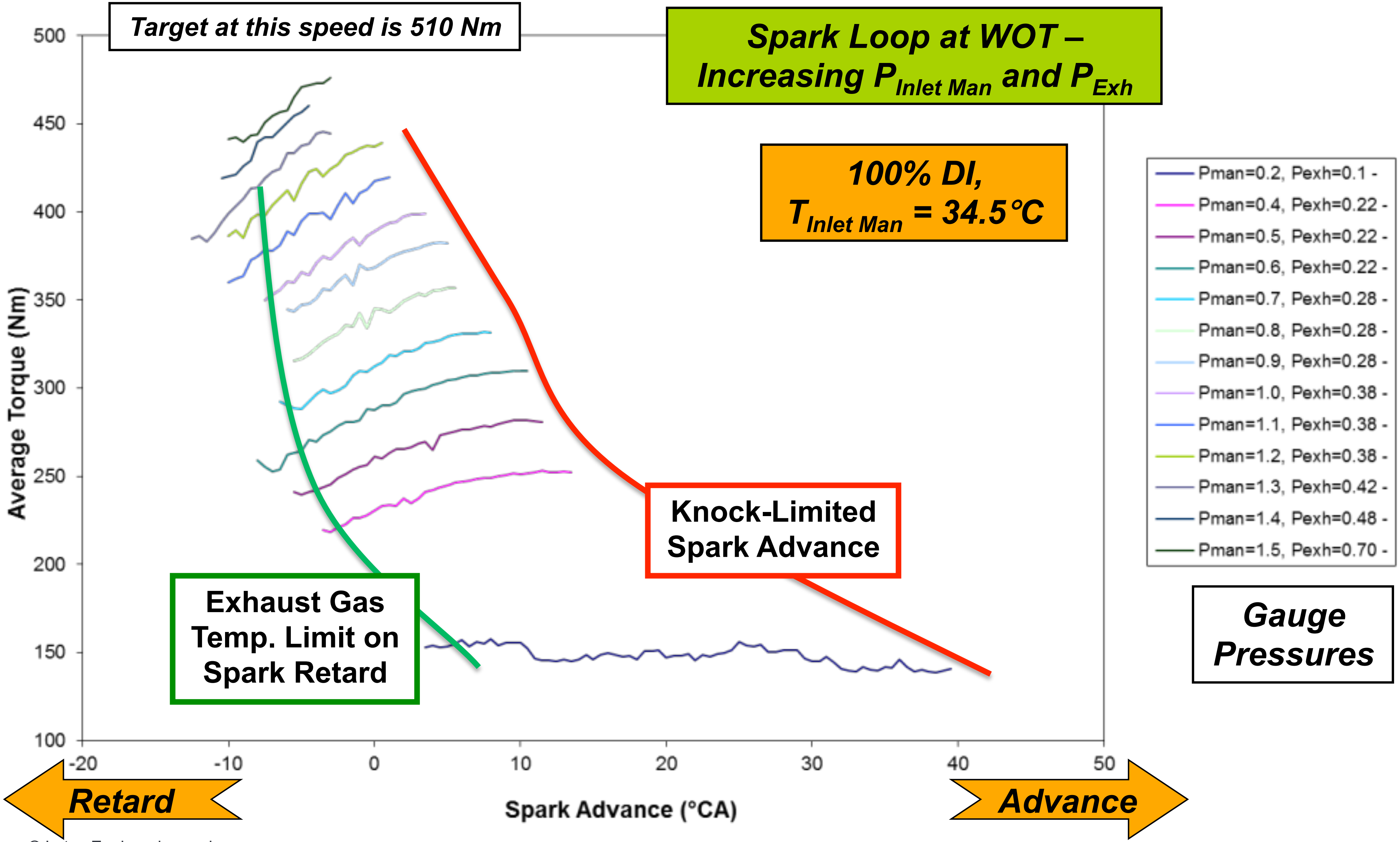


All data reported in this presentation is taken with 95 RON pump gasoline and Lambda = 1 operation

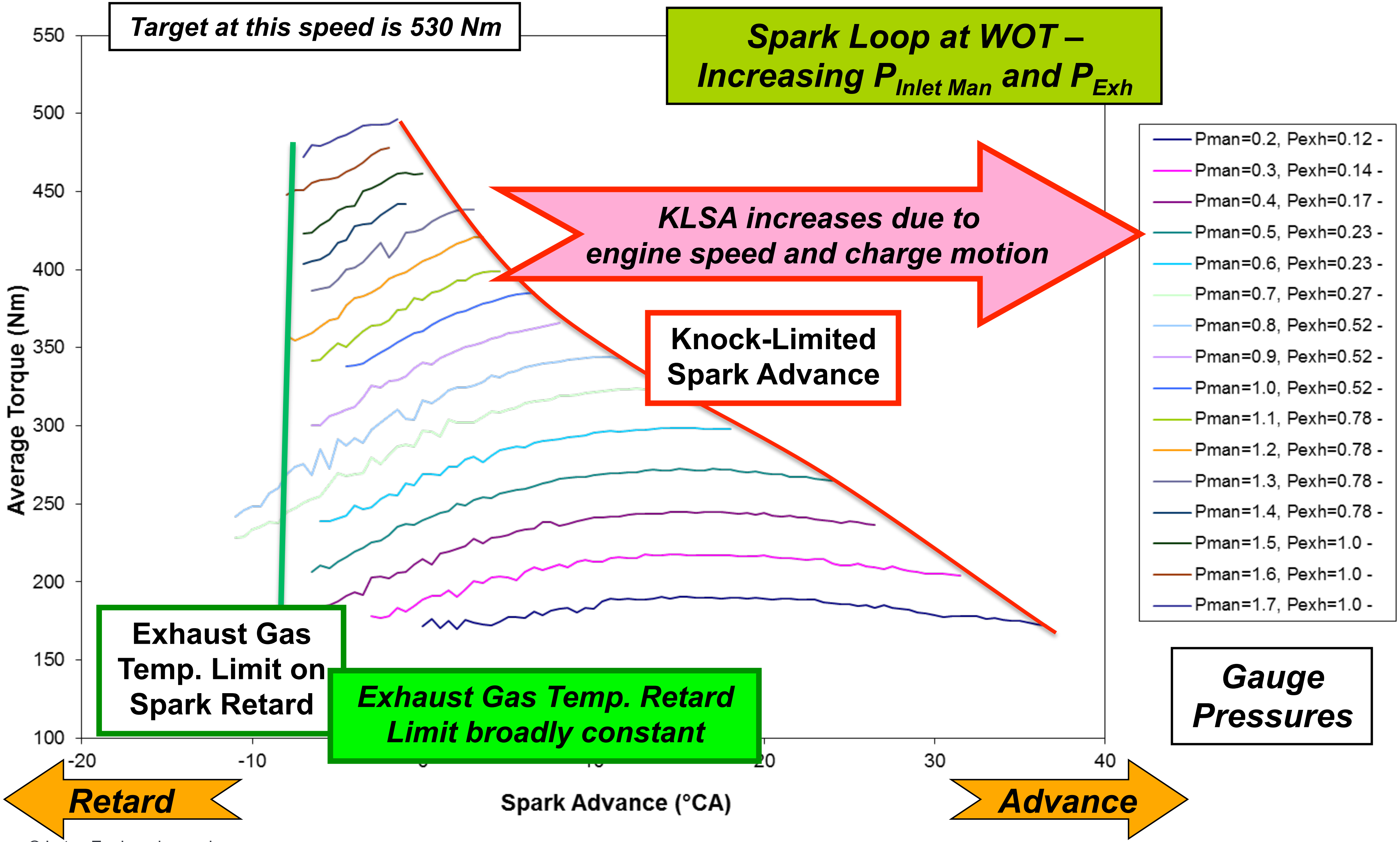
Preignition is near-absent

GE PRECISION ENGINEERING
UNIVERSITY OF BATH
UNIVERSITY OF LEEDS
CD-adapco
Imperial College London
Shell

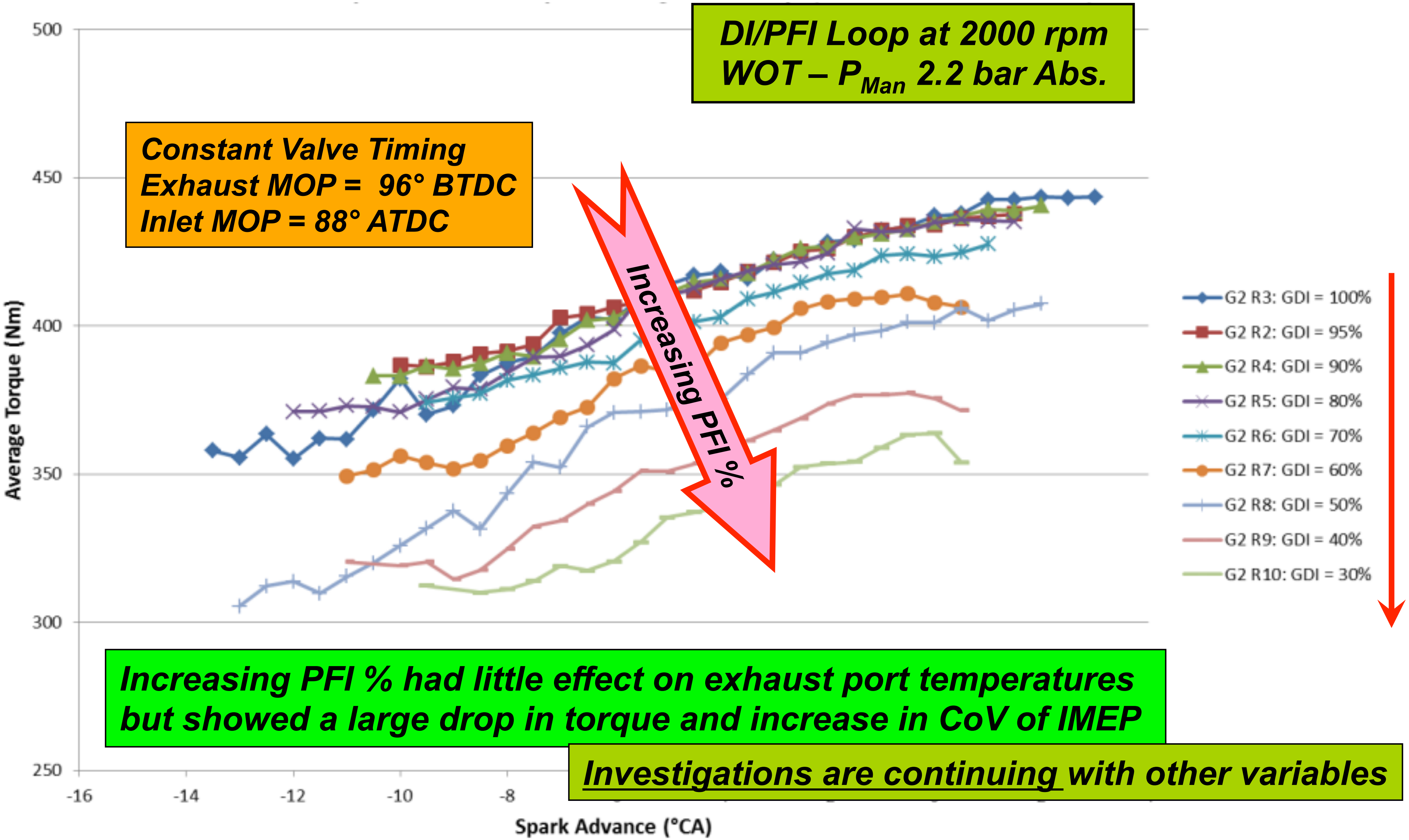
Early Operating Envelope Test at 2000 rpm



Early Operating Envelope Test at 2500 rpm



Engine Torque versus DI/PFI Split Ratio



Increasing PFI % had little effect on exhaust port temperatures but showed a large drop in torque and increase in CoV of IMEP

Investigations are continuing with other variables

High-Load EGR Testing

High-load EGR testing has begun using the CAHU and a newly-commissioned EGR supply rig

- *Actually a motor-driven light-duty diesel engine with '2-stroke' cams and a very high-capacity water-cooled heat exchanger*
- *Designed especially for the task by the University of Bath*

The rig is required to overcome the pressure difference between the manifolds

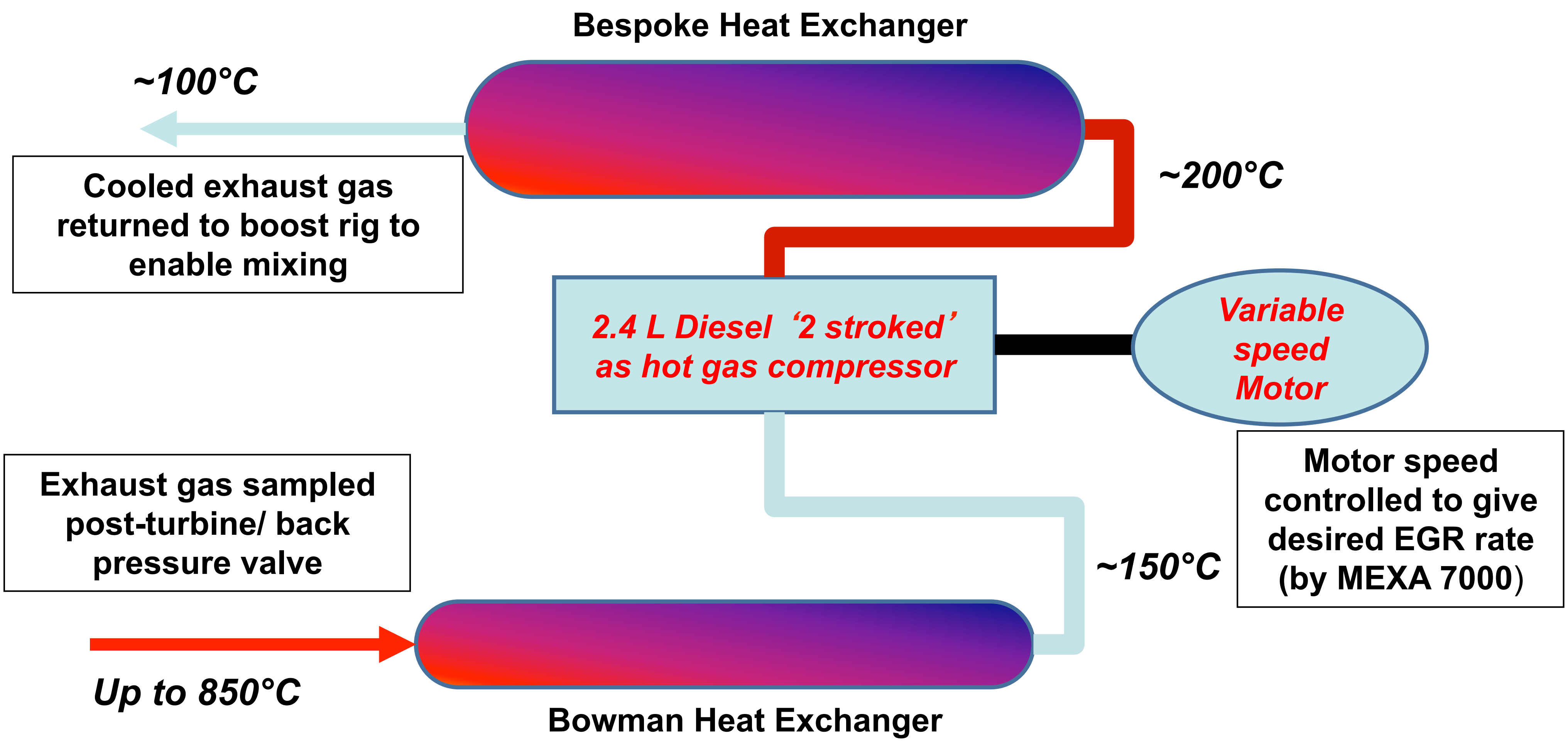
EGR is taken from the exhaust of the Ultraboost engine itself and fed into the intake system upstream of the throttle

- *The EGR is uncatalyzed*
- *Mimics long-route cooled EGR*

The following slides show the results of a series of tests at 2000 rpm

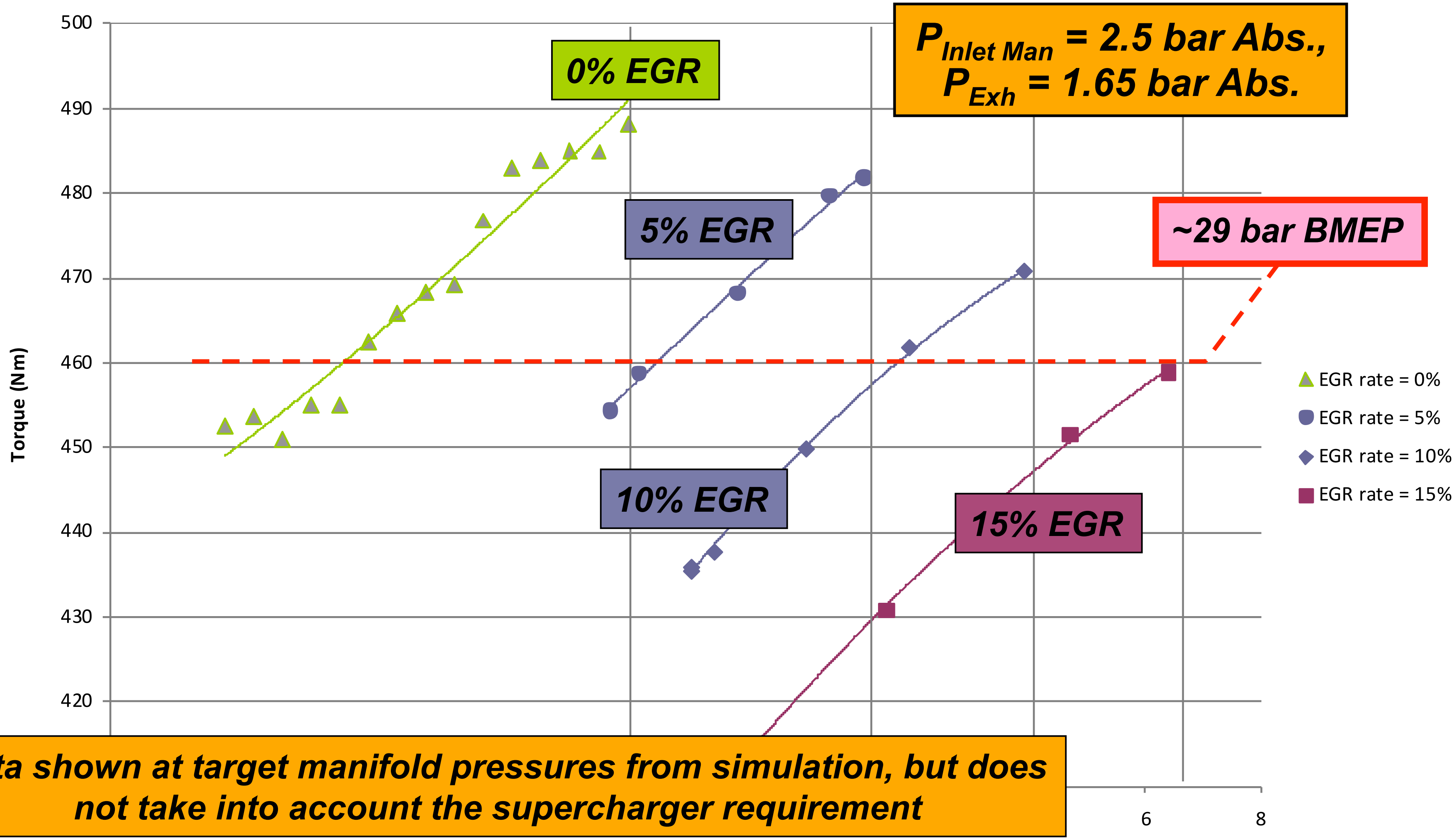
- *Note: <u>all data is at Lambda = 1</u>*
- *Engine is running open breather*

The University of Bath EGR pump



Source: University of Bath at UnICEG, Ford Dunton, 18th April, 2012

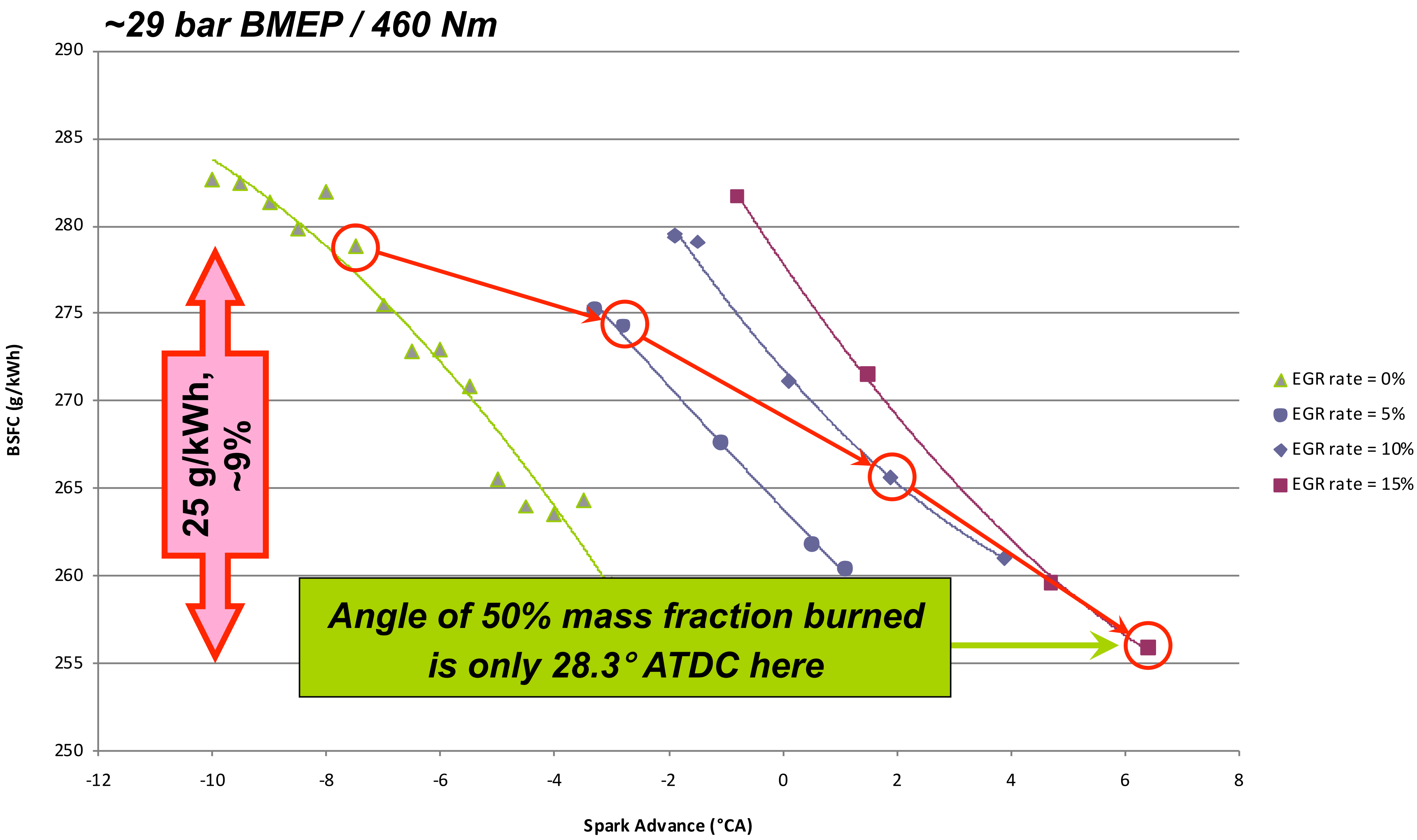
High-Load EGR Loops at 2000 rpm – Torque



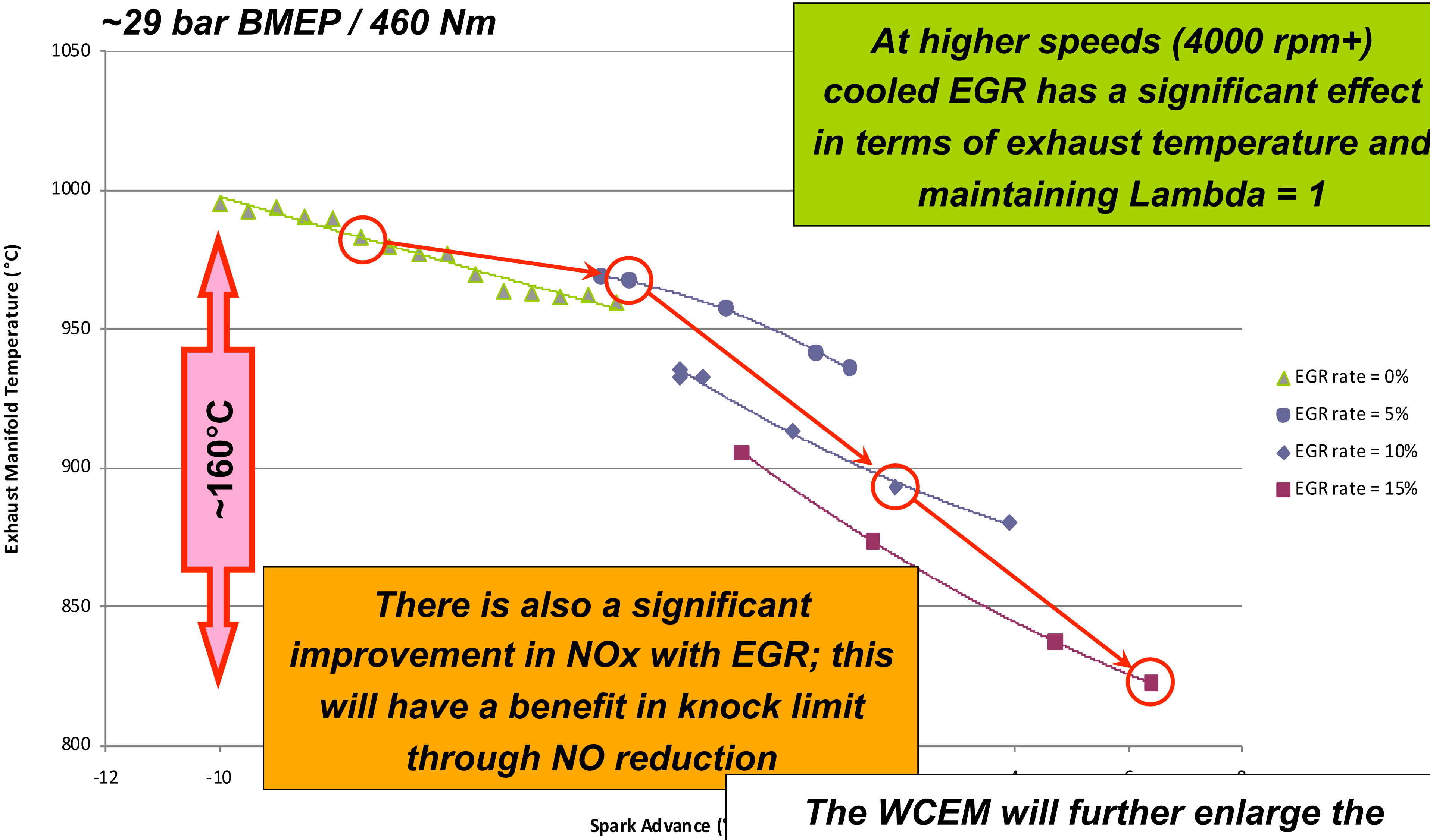
Data shown at target manifold pressures from simulation, but does not take into account the supercharger requirement

Additional torque requirement in the region of 40-50 Nm: an increase in inlet manifold pressure is required at 10% and 15% EGR to achieve torque target

High-Load EGR Loops at 2000 rpm – BSFC



High-Load EGR Loops at 2000 rpm – Exhaust Temp.

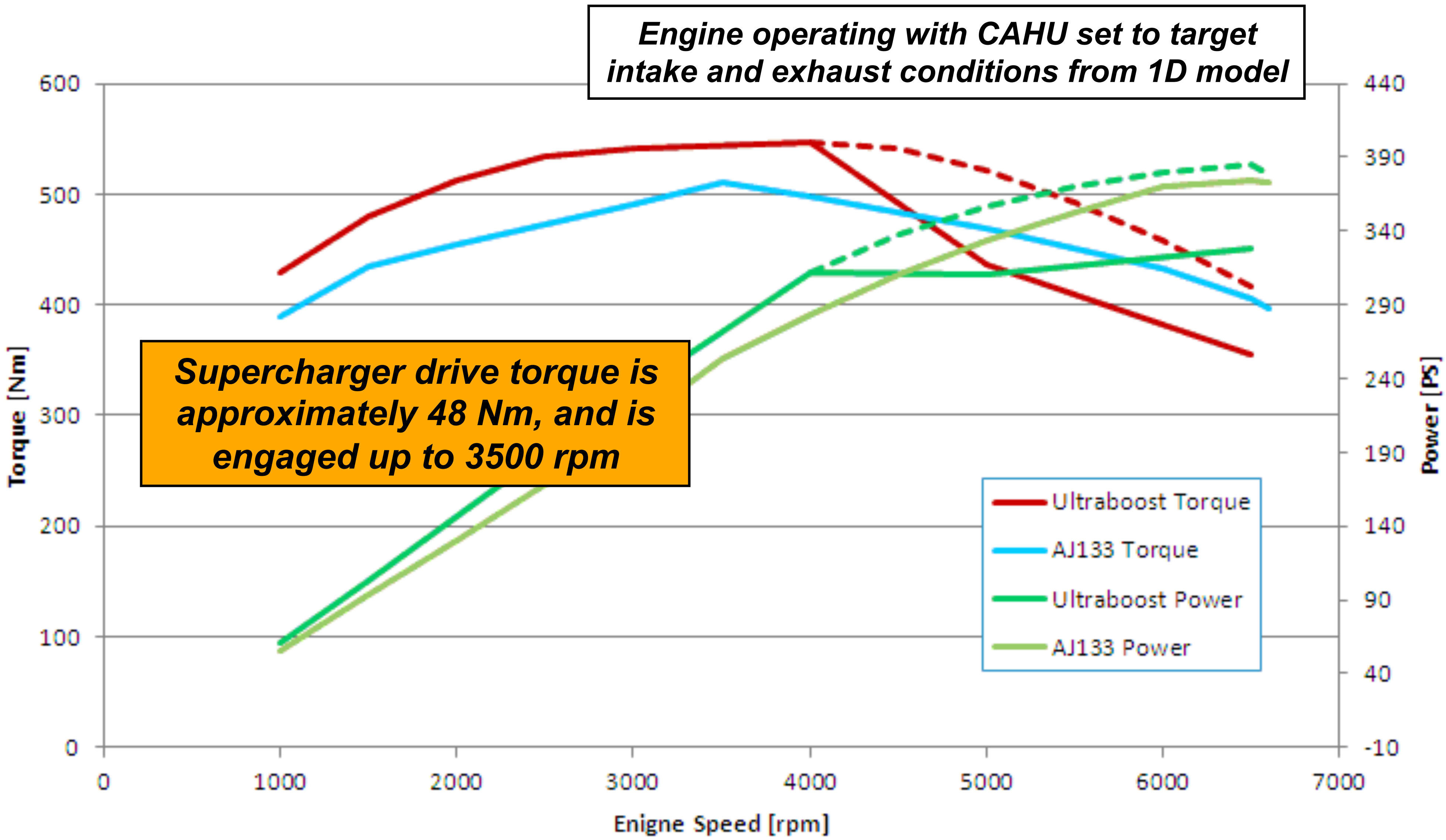


At higher speeds (4000 rpm+) cooled EGR has a significant effect in terms of exhaust temperature and maintaining Lambda = 1

There is also a significant improvement in NOx with EGR; this will have a benefit in knock limit through NO reduction

The WCEM will further enlarge the available Lambda = 1 operating window

Current Torque and Power



Current Fuel Consumption Status: Minimap

Minimap calibration procedure:

- *Boundary conditions:*
  - Coolant outlet temperature = 90°C
  - Oil gallery temperature = 90°C
  - Dyno in torque speed mode
  - Fuelling closed loop Lambda = 1
- *Fuel Pressure sweep with fixed cam timings and SOI*
- *SOI sweep between 270° and 360° at optimum fuel pressure*
- *Cam timing sweep for intake and exhaust with optimised spark timing at each condition to achieve 8° AI50, at optimum fuel pressure and SOI*
- *Ignition timing sweep at optimum conditions*

BSFC improvement shown against AJ133 baseline performance values supplied by JLR

Ongoing program to complete optimization of minimaps

Source: University of Bath at UnICEG, Ford Dunton, 18th April, 2012

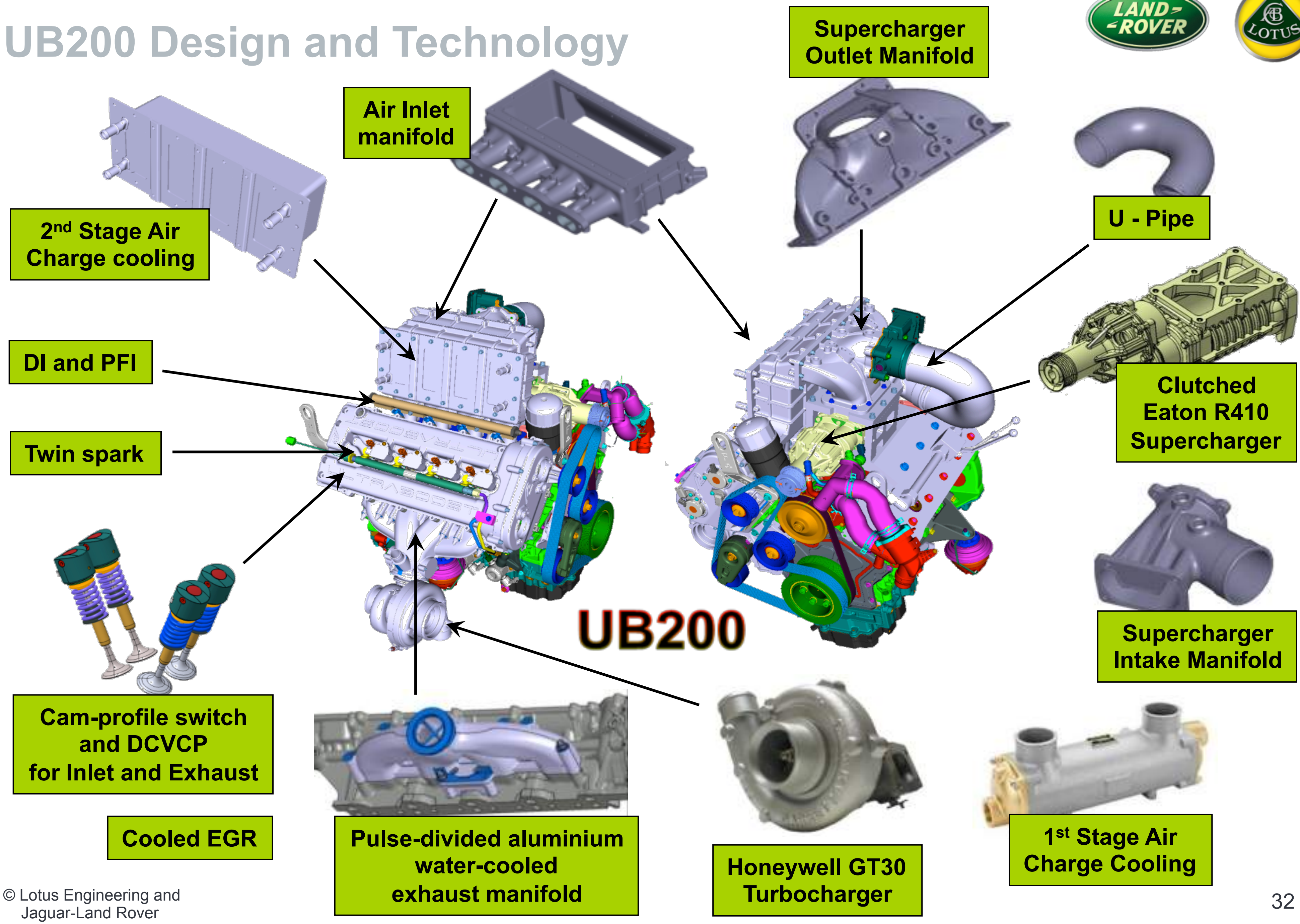
Minimap Optimization Results: Current Status

Currently on track for achieving 35% reduction in fuel consumption and CO_2

UB100-1 – Testing							
BSFC g/kWhr	**BSFC Improvement**	**Fuel Pressure**	**Spark Advance**	**GDI SOI**	**Intake Cam**	**Exhaust Cam**	**Throttle Position**
	%	**bar**	**degCA**	**degCA**			**%**
512.9	-30.9						
334.0	-33.2	40	41	289.6	0	0	4.7
270.3	-9.4	90	21.5	298.4	0	32.67	10.2
BOOSTED							
286.2	-15.6	85	24.5	292.5	0	27.51	9.7
BOOSTED							
536.9	-45.9	40	50	294	0	0	2.3
BOOSTED							
290.1	-13.7	38.5	18	290	0	20.39	5.5
BOOSTED							
BOOSTED							
BOOSTED							
267.8	-6.0	82	18.2	300	0	39.76	12.9
298.0	-23.9	42	26.7	293	0	5.2	5
262.1	-3.0	148	20.7	298	8	43.6	41.1

Source: University of Bath at UnICEG, Ford Dunton, 18th April, 2012

UB200 Design and Technology



Assembled UB200 Engine

UB200 will run in January 2013; UB100 is testing some elements of its charging system and is also conducting fuel formulation testing until then

Conclusions (1)

The 'Ultraboost' project aims to create a 2.0 litre downsized engine to provide the torque curve and power output of the JLR NA 5.0 litre V8

- *515 Nm at 3500 rpm and 283 kW / 380 bhp at 6500 rpm*
- *It is funded by the TSB as part of its Low-Carbon Vehicles Programme*
- *Target is a 35% improvement in fuel economy*

The first-phase UB100 engines have been running for 12 months

- *The second-phase version is the first with a self-contained charging system*
- *Will run in Jan 2013*

The engine has proved to be extremely reliable and resistant to preignition

Its octane appetite appears to be quite low

- *As shown by its knock limit*

All testing has been carried out with 95 RON pump gasoline and at Lambda = 1

- *Good fuel consumption and low exhaust temperatures have been achieved even <u>without</u> cooled EGR*

Conclusions (2)

Up to 15% cooled EGR has been applied via a purpose-built external rig, showing significant benefits

- *Reducing exhaust gas temperature and improving BSFC*
  - Better combustion phasing
  - Reducing need for over-fuelling
    - *Will also be mitigated with water cooled exhaust manifold*
- *Reduced NOx*
- *However, there is a need to increase boost to reach demanded torque*
  - Shifting more demand to boosting hardware

There are other unusual technologies to test, including a novel configuration of twin-spark ignition, which will have the potential to further improve the knock limit and reduce fuel consumption

This is an extremely successful collaborative research project – our thanks go to all the other partners and to the Technology Strategy Board' for funding it

THANK YOU FOR LISTENING

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ULTRABOOST