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ENGINEERING

BOOST SYSTEM SELECTION FOR A HEAVILY DOWNSIZED SPARK IGNITION PROTOTYPE ENGINE

ULTRABOOST

ULTRABOOST – HIGHLY DOWNSIZED PRESSURE CHARGED ENGINE

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Funded by the TSB as part of its Low-Carbon Vehicles Programme

Technology Strategy Board
Driving Innovation

Project aims

- To develop a highly-boosted, downsized, four cylinder engine to provide the torque curve and power output of the naturally-aspirated Jaguar Land-Rover V8 engine:
  - 515 Nm at 3500 rpm and 283 kW / 380 bhp at 6500 rpm
  - The driveability of the original V8 engine is to be maintained
  - To demonstrate a 35% improvement in fuel economy over NEDC
  - Operation at up to 32 bar BMEP will be necessary, with 25 bar at 1000 rpm
  - To meet the targets, prototype is a 2.0 litre capacity with an advanced charging system

PROJECT PARTNERS AND ROLES

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Project lead and management, engine design

- Csaba Salamon, Rob Robinson, Andrew Senior, Matt McAllister, Steve Richardson

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EMS Development, control, 1D engine modelling, design input

- **Jamie Turner**, Richard Pearson, **Nick Luard**, Rishin Patel, Roger Tudor

GE PRECISION ENGINEERING

Engine design, manufacture

- Scott Bredda, Steve Anstey

Shell

Supply of fuels, lubes and combustion expertise

- Bob Head, Roger Cracknell

CD-adapco

CFD analysis

- Mike Lewis, Jason Fernandes

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Boosting system selection, configuration and testing

- **Ricardo Martinez-Botas**, **Alessandro Romagnoli, Colin Copeland**

UNIVERSITY OF BATH

Engine P&E testing

- Sam Akehurst, Andrew Lewis, Chris Brace, Karl Giles

UNIVERSITY OF LEEDS

Combustion modelling expertise

- Alexey Burluka, Graham Conway

DOWNSIZING – PUSHING THE LIMITS

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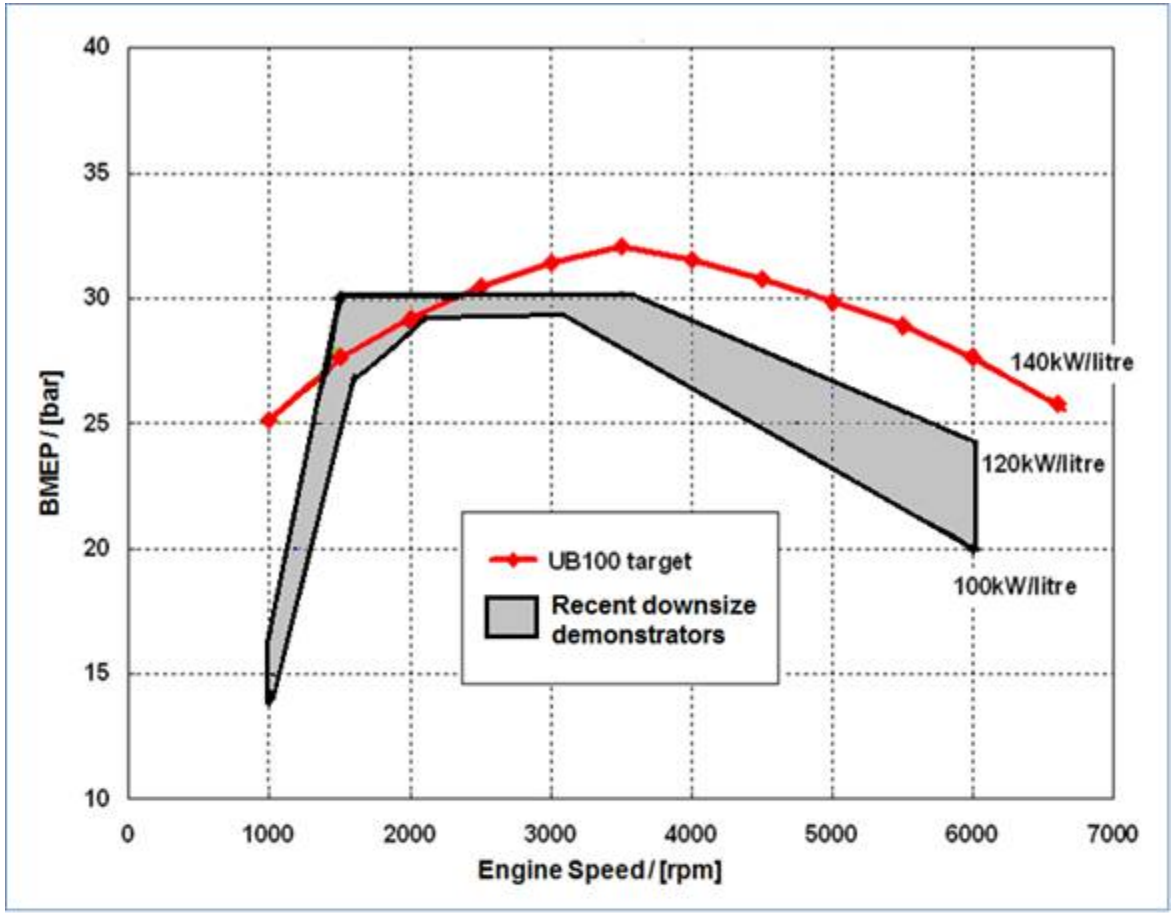
- 25 bar BMEP (400Nm Torque) at 1000rpm
- 515Nm of torque at 3500rpm
- 140 kW/L at 6600 rpm



TRANSIENT RESPONSE TARGETS

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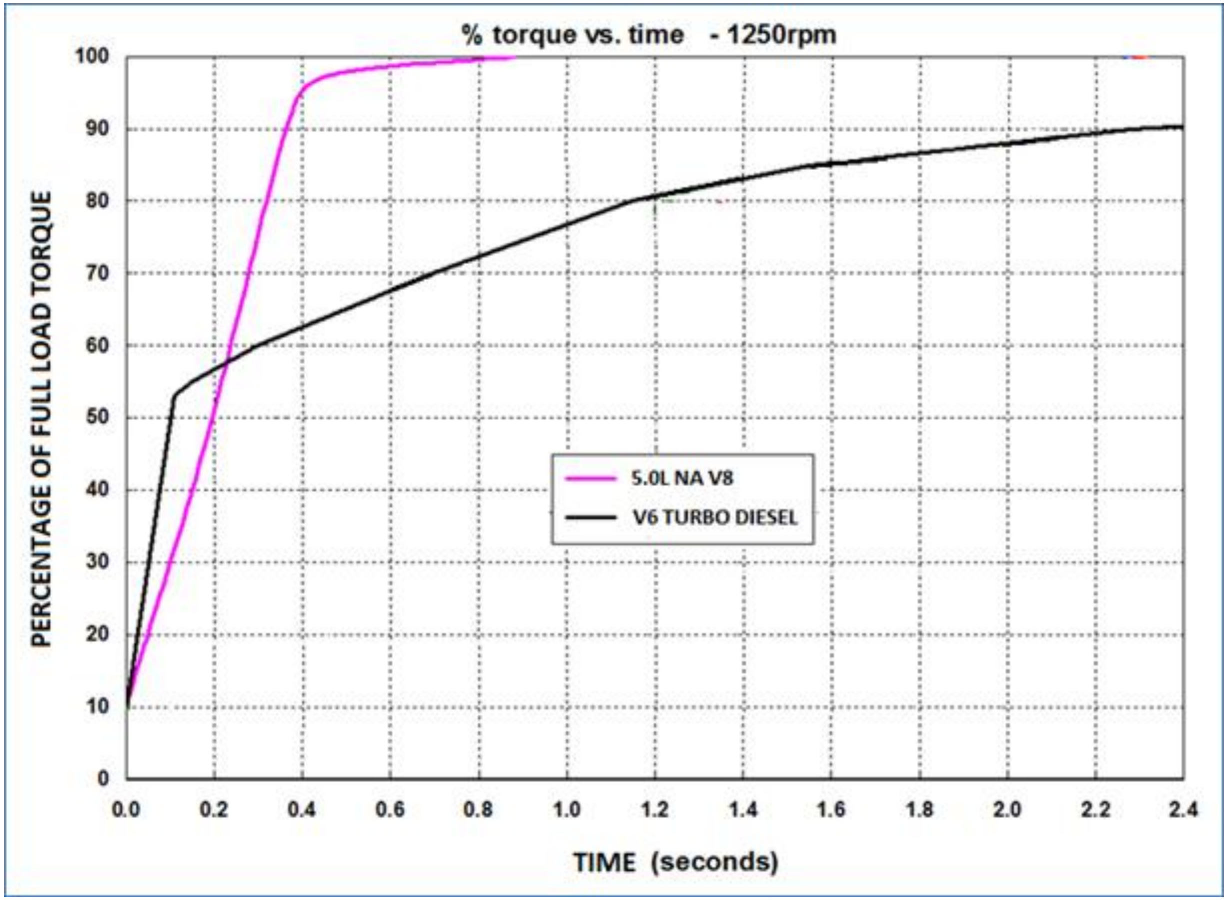
- Assessed in GT-Power model: 10-90% of rated torque at constant rpm
- Naturally aspirated response ~300ms to 90% of rated torque for all speeds (stretch target)
- Minimum acceptable response: twin turbocharged 3.0L V6 diesel



MEETING TARGETS WITH A SINGLE TURBOCHARGER

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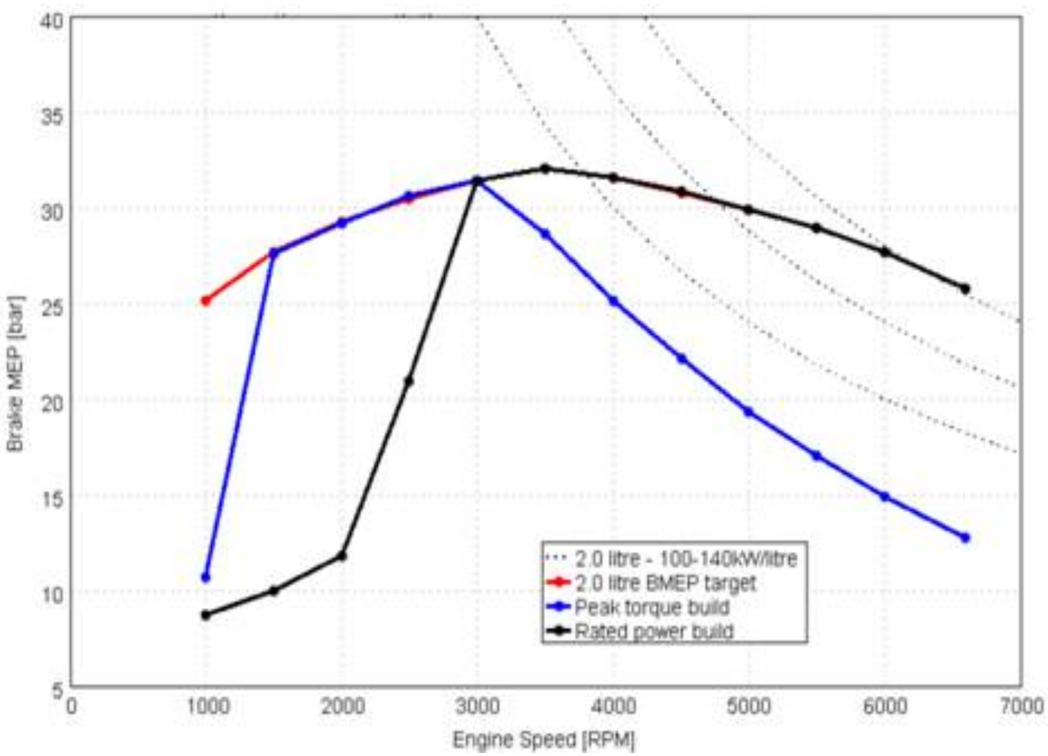
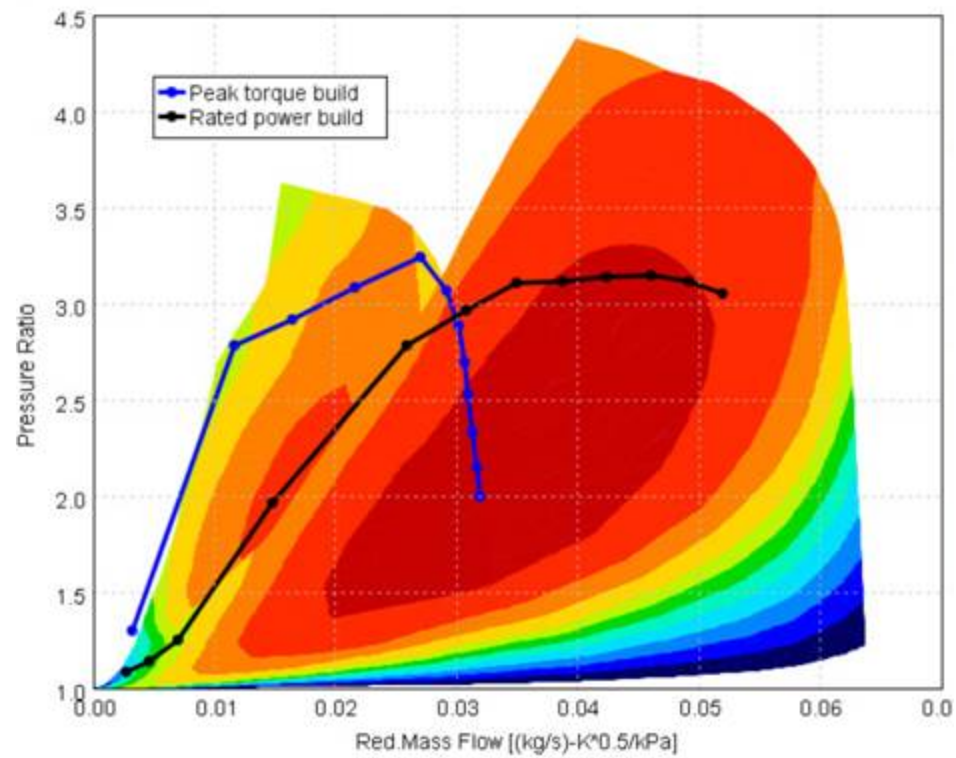
- Initial modelling showed that meeting the entire torque curve with a single stage turbocharger was impossible.
- Map width at high boost pressure a limiting factor





PARALLEL OR TWIN-SERIES ?

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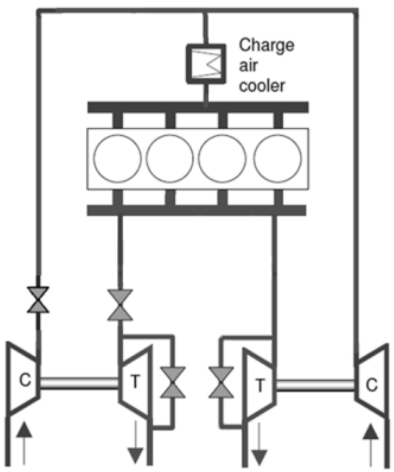
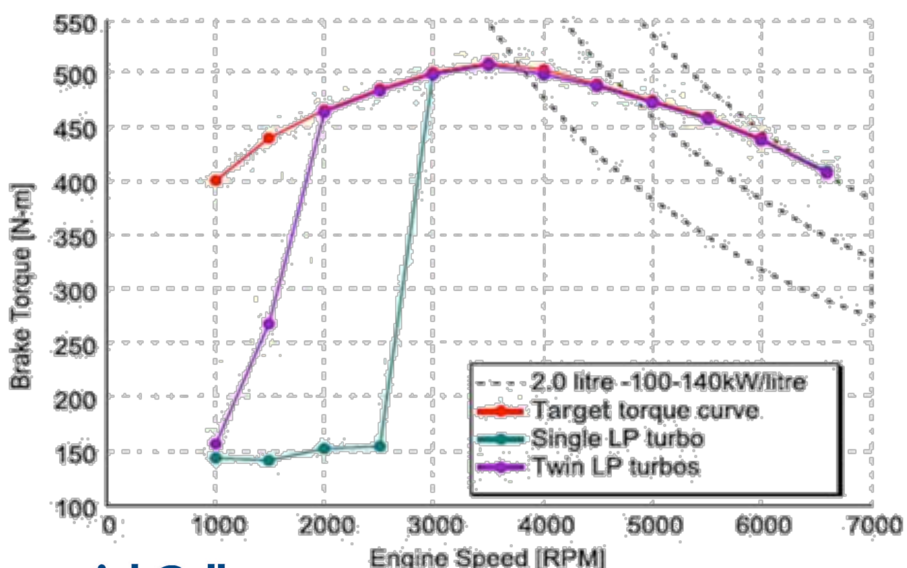
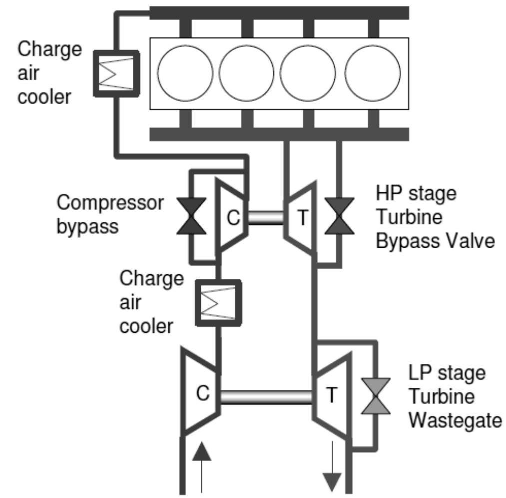
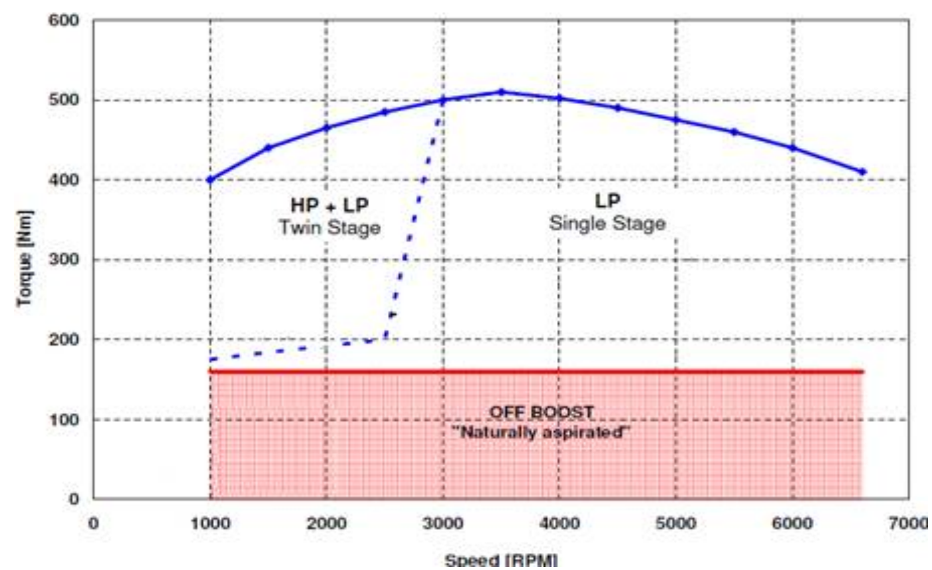
TWO-STAGE PARALLEL SEQUENTIAL





TWO-STAGE SERIES





CONFIGURATION REASONING

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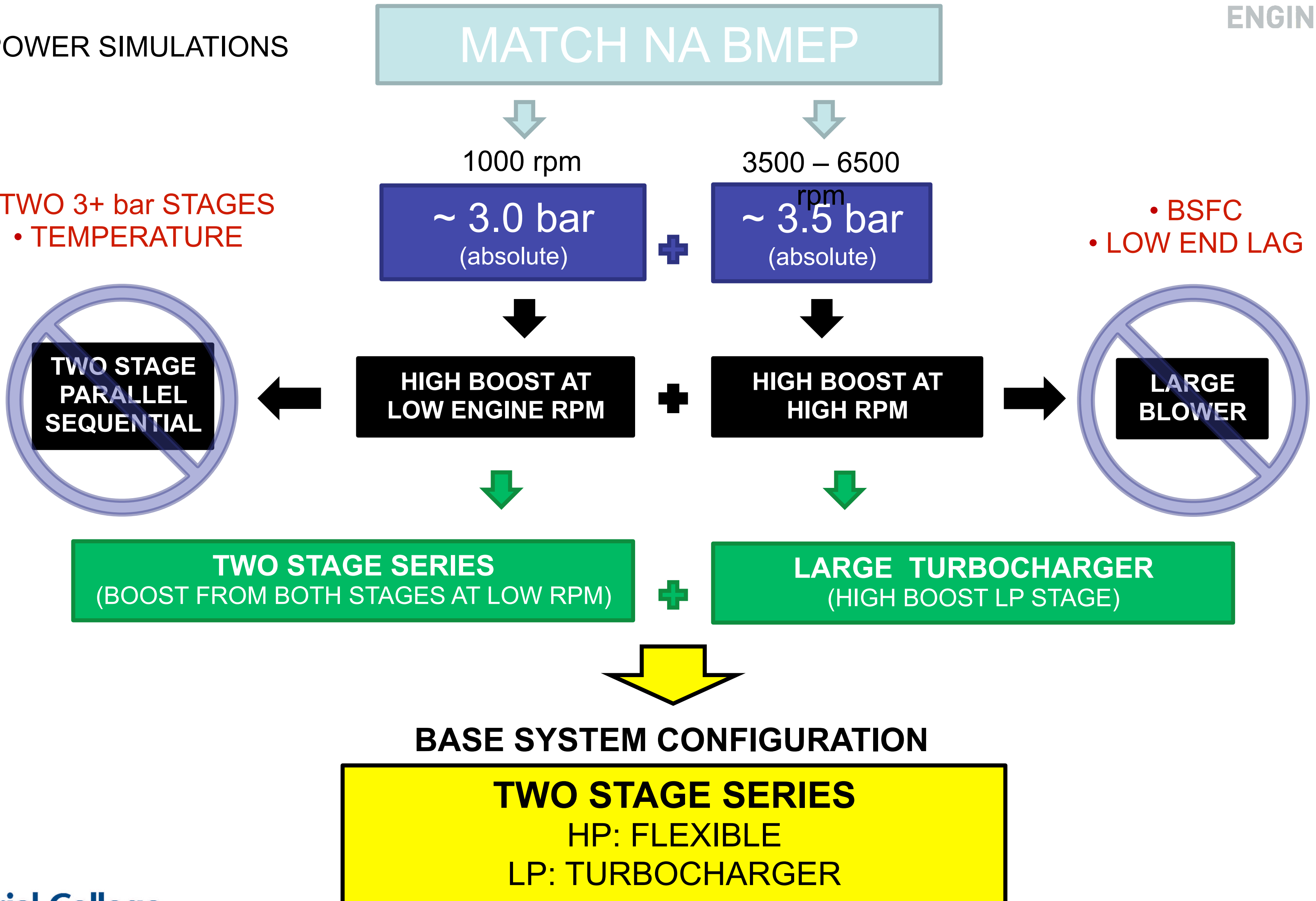
GT-POWER SIMULATIONS



PERFORMANCE ASSESSMENT USING MODEL

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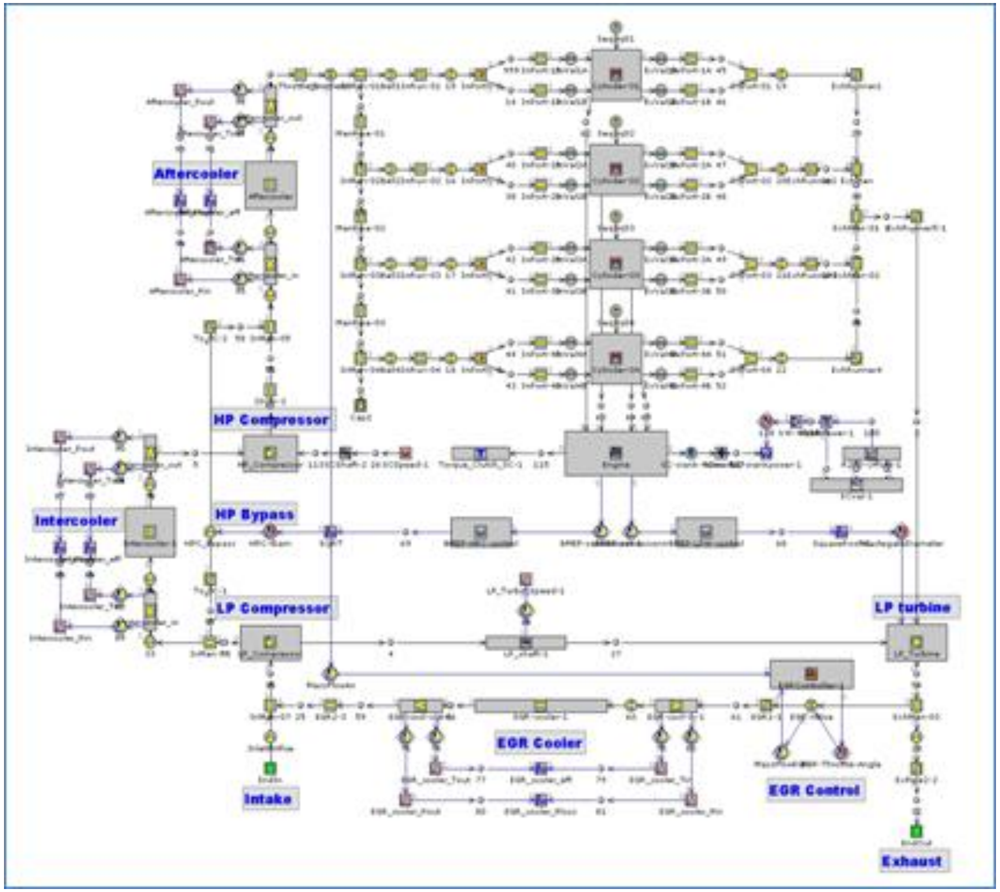

GT-Power Model

- Extensive modelling carried out by Lotus Engineering
- λ=1 condition maintained
- Two stage charge cooling
- Initially air-to-air coolers with 100mbar loss and 0.85 effectiveness
- Spark Ignition Wiebe combustion model
- EGR supplied by a long route, cooled circuit
  - All run with 10% EGR excluding constant rpm transient response
  - 15 mini-mapping points were used to evaluate the part-load fuel economy over the New European Drive Cycle (NEDC)

SOME TWO STAGES CONSIDERED

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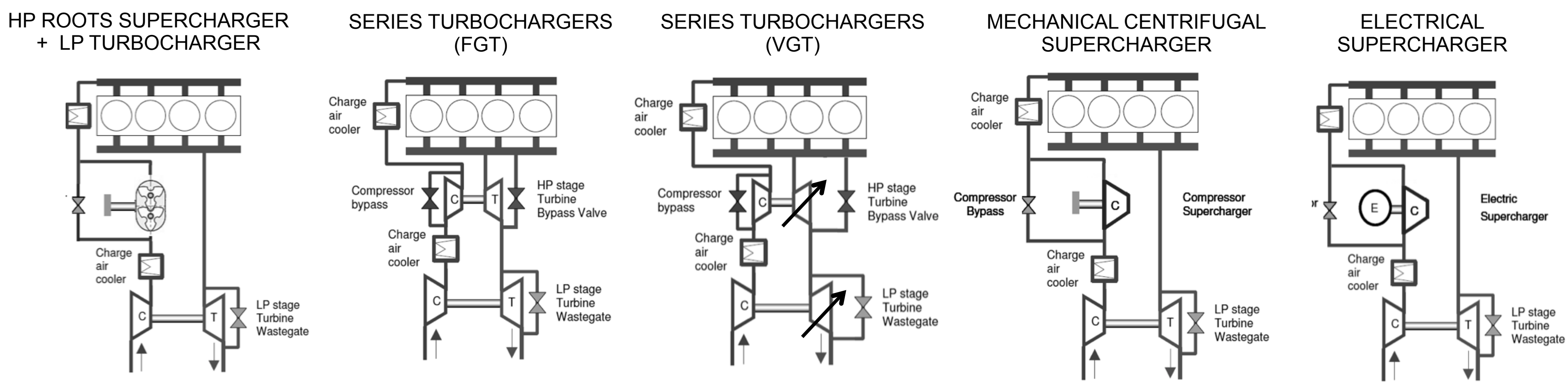
- Two stages in series are required to meet full load torque curve target
- All required a large LP turbocharger to reach high boost pressure
- HP stages considered:
  - Supercharger: Rotrex centrifugal, Eaton TVS (different gear ratios, two speed and variable speed drives)
  - Turbocharger: Honeywell Wastegate (FGT) and Variable geometry (VGT)
  - E-booster: Integral Power SuperGen, Aeristech and CPT VTES



TWO STAGE ARRANGMENTS

THREE STAGES CONSIDERED

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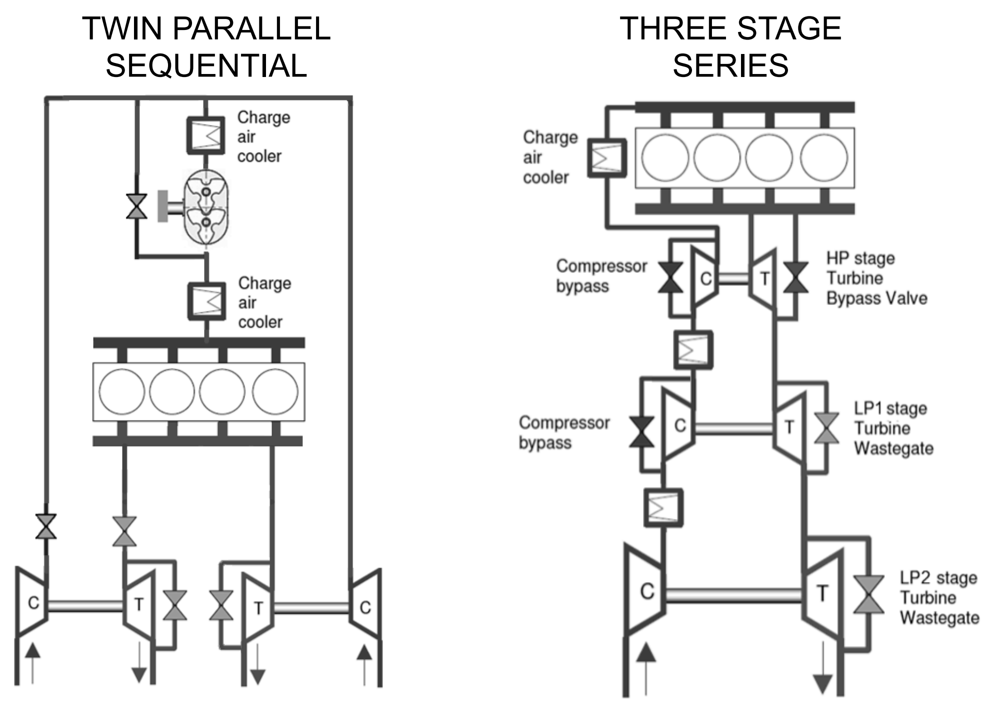
- Three boosting stages in series or series-parallel
- Parallel LP turbochargers help with transient response
- Three stages in series are complex to match and optimize



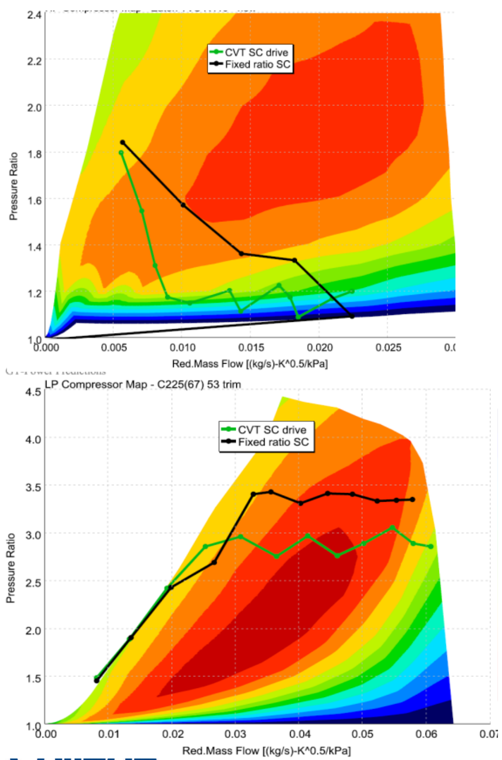
THREE STAGE ARRANGMENTS

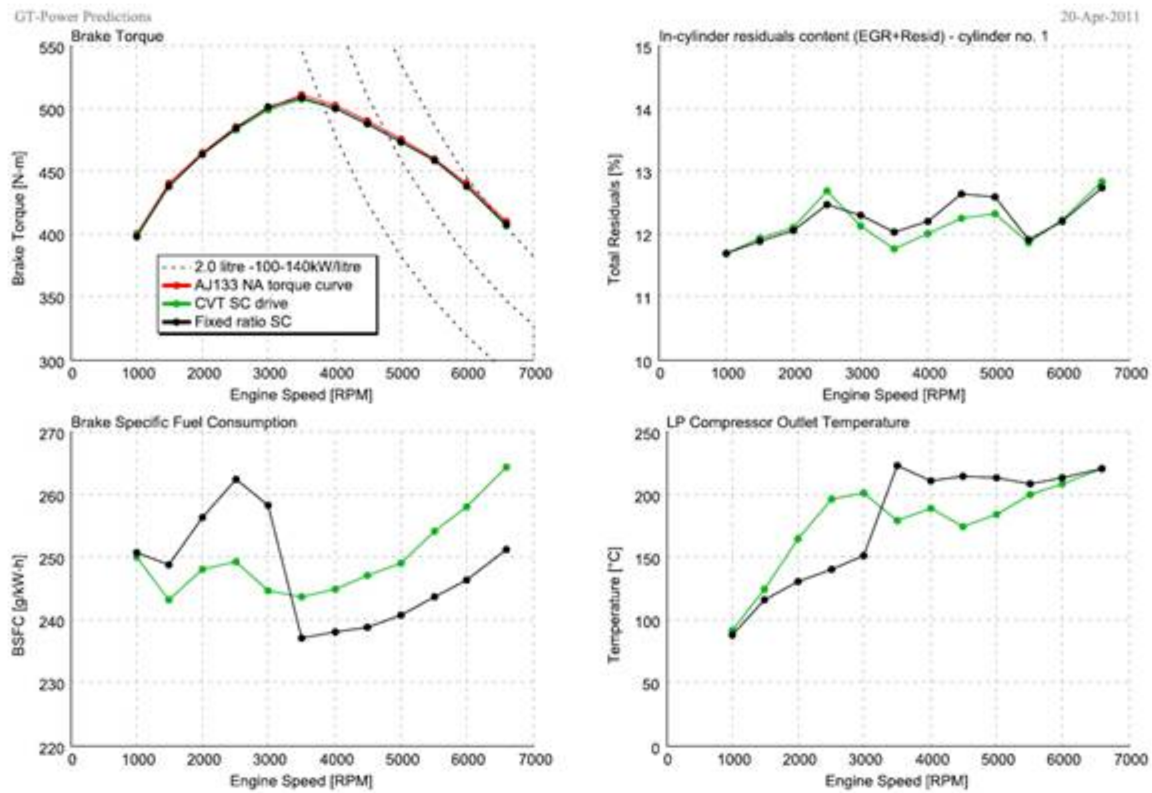
EXTENSIVE MODELLING

LOTUS ENGINEERING

Detailed modelling of an extremely large array of options:

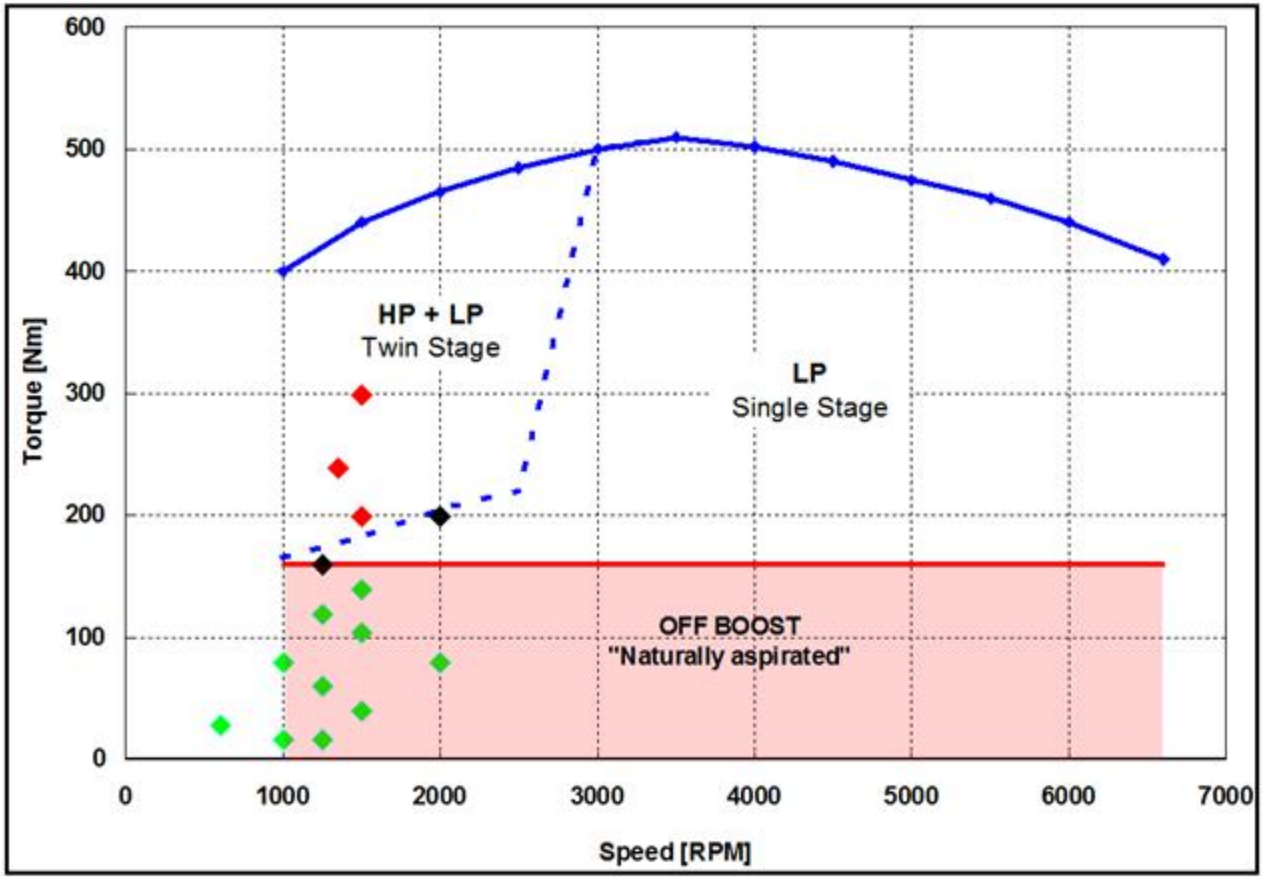
- Technologies: turbochargers, e-booster, novel superchargers, etc
- Other options: VGT, Twin entry, supercharger drive ratio, variable and two speed superchargers, effect of EGR, charge cooler, etc.
- All assessments were made in view of the aims of **this** project





PART LOAD FUEL ECONOMY

- Three out of the 15 mini-map points required two stages indicating low NEDC residence in this region.
- Less than 1% difference in NEDC fuel economy between a supercharger (with a clutch) and a turbocharger on the high pressure stage



TRANSIENT RESPONSE

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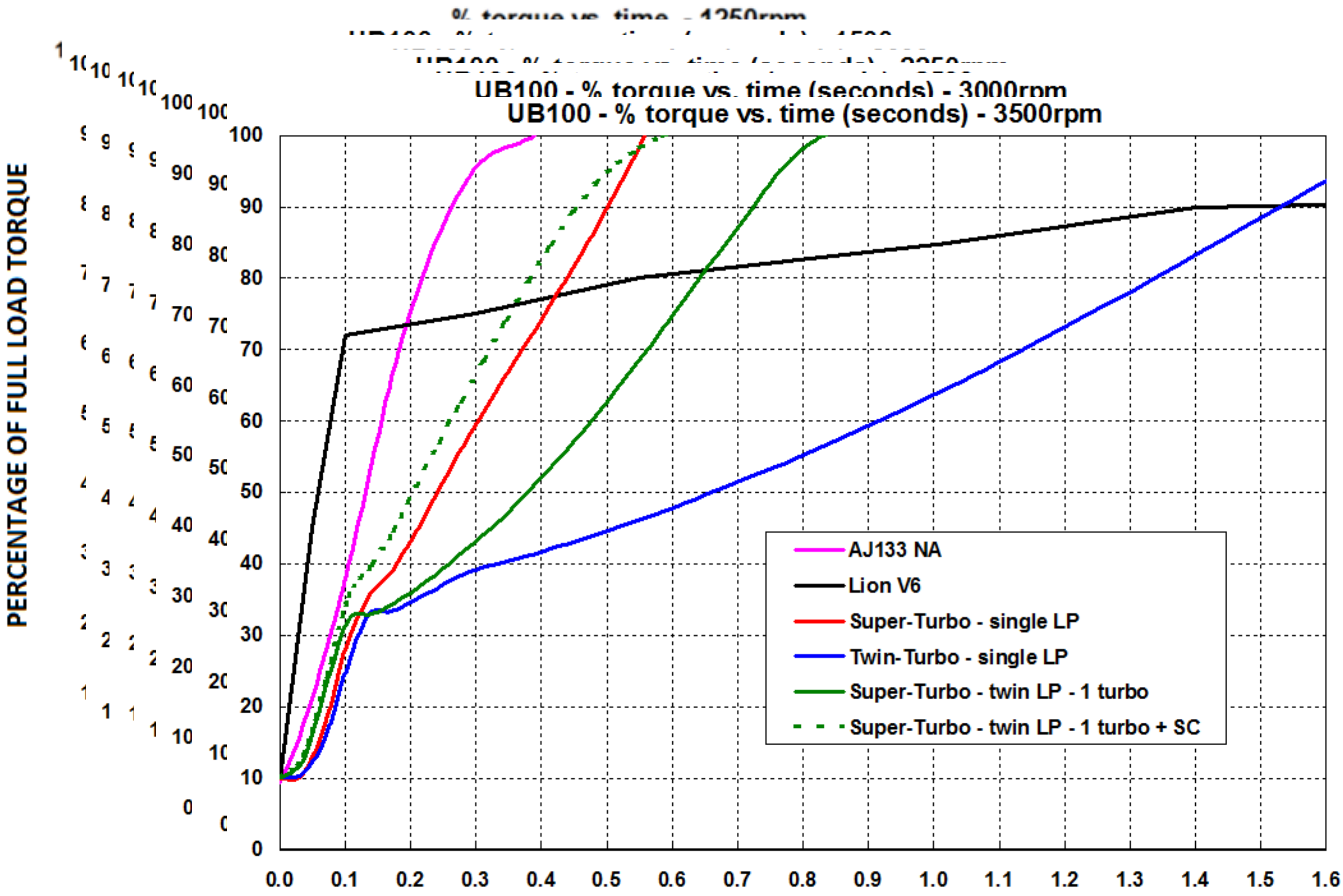

BOOST SYSTEM SELECTION PROCESS

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- 17 weighted criteria were used to judge each boost system
- Criteria weightings linked to overall vehicle requirements

	IMPORTANCE					
	Vehicle Requirements →	Driveability Target	Fuel Economy	Emissions	Delivery & Packaging	Criteria Weight
BOOSTING SYSTEM ASSESSMENT CRITERIA	Downsize Enabler (BMEP)					
	BSFC (Part Load)					
	BSFC (Full Load)					
	Low End Torque					
	Transient Response					
	PMEP					
	Residuals					
	Inter-Cooling					
	Altitude					
	Catalyst Warm Up					
	Vehicle Arch. Impact					
	Cost					
	Package Size					
	Weight					
	Control Complexity					
	Technology Readiness					
	NVH					

RANKING CHART

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	IMPORTANCE →																	
BOOSTING SYSTEM		BMEP	BSFC (PART LOAD)	BSFC (FULL LOAD)	LOW END TORQUE	TRANSIENT RESPONSE	PUMPING LOSS	RESIDUALS	ALTITUDE	INTER-COOLING	CATALYST WARM UP	IMPACT ON VEHICLE ARCHITECTURE	COST	PACKAGE SIZE	WEIGHT	CONTROL COMPLEXITY	READINESS	NVH
TWO STAGE TURBOCHARGING	FGT HP+ FGT LP																	
	VGT HP + FGT LP																	
POSITVE DISPLACEMENT SUPERCHARGER + LP TURBOCHARGER	ROOTS + FGT																	
	TWO-SPEED ROOTS + FGT																	
	VARIABLE SPEED ROOTS + FGT																	
	LONTRA + FGT																	
CENTRIFUGAL SUPERCHARGER + LP TURBOCHARGER	ROTREX + FGT																	
ELECTRIC SUPERCHARGER + LP TURBOCHARGER	VTES + FGT																	
	SUPERGEN + FGT																	
	AERISTECH +FGT																	
THREE STAGE BOOSTING SYSTEMS	THREE STAGE SERIES FGT																	
	THREE STAGE TURBO: PARALLEL-SERIES																	
	EATON + TWO STAGE PARALLEL FGT																	
	EATON + TWO STAGE PARALLEL VGT																	

CUSTOMER PRIORITIES

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	IMPORTANCE →						
BOOSTING SYSTEM	LAYOUT	BSFC (PART LOAD)	BSFC (FULL LOAD)	LOW END TORQUE	TRANSIENT RESPONSE	NVH	PERFORMANCE RATING
TWO STAGE TURBOCHARGING	FGT HP+ FGT LP						
	VGT HP + FGT LP						
POSITVE DISPLACEMENT SUPERCHARGER + LP TURBOCHARGER	EATON + FGT						
	TWO SPEED EATON + FGT						
	VARIABLE SPEED (CVT) EATON + FGT						
THREE STAGE BOOSTING SYSTEMS	THREE STAGE SERIES FGT						
	THREE STAGE TURBO: PARALLEL-SERIES						
	EATON + TWO STAGE PARALLEL FGT						
	EATON + TWO STAGE PARALLEL VGT						
INTEGRAL POWERTRAIN SUPERGEN	IPT + FGT						

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ULTRABOOST

OPTION RATING SUMMARY

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TECHNICAL PERFORMANCE	ENGINE ATTRIBUTES
	VARIABLE SPEED (CVT) EATON + FGT
	TWO SPEED EATON + FGT
	IPT + FGT
	EATON + FGT
	EATON + TWO STAGE PARALLEL VGT
	EATON + TWO STAGE PARALLEL FGT
	FGT HP+ FGT LP
	VGT HP + FGT LP
	THREE STAGE TURBO: PARALLEL-SERIES
	THREE STAGE SERIES FGT

CUSTOMER PRIORITY RATING
VARIABLE SPEED (CVT) EATON + FGT
IPT + FGT
EATON + TWO STAGE PARALLEL VGT
TWO SPEED EATON + FGT
EATON + FGT
EATON + TWO STAGE PARALLEL FGT
VGT HP + FGT LP
THREE STAGE TURBO: PARALLEL-SERIES
FGT HP+ FGT LP
THREE STAGE SERIES FGT

COMMERCIAL AND TECHNICAL	FINAL RATING
	EATON + FGT
	VARIABLE SPEED (CVT) EATON + FGT
	TWO SPEED EATON + FGT
	FGT HP+ FGT LP
	IPT + FGT
	VGT HP + FGT LP
	EATON + TWO STAGE PARALLEL FGT
	EATON + TWO STAGE PARALLEL VGT
	THREE STAGE TURBO: PARALLEL-SERIES
	THREE STAGE SERIES FGT

RECOMMENDATIONS

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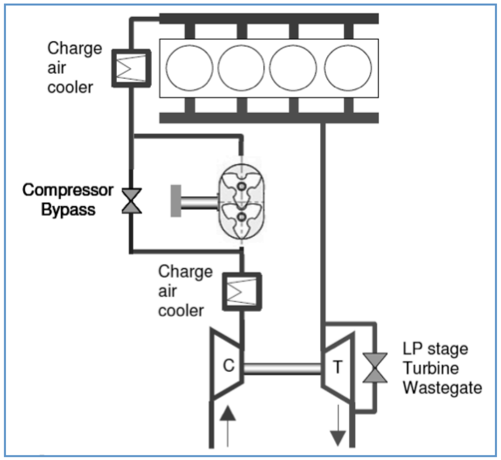
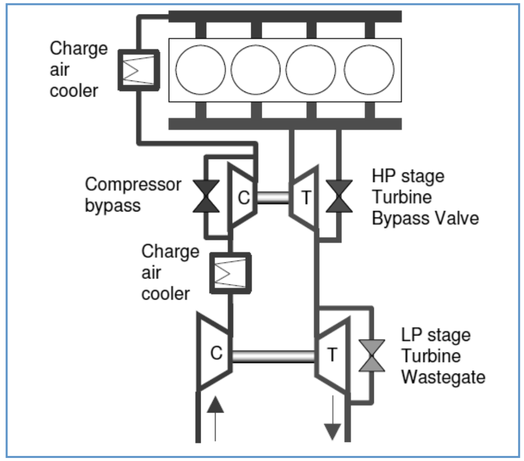
TURBO-SUPER:
HP Eaton TVS Supercharger w clutch + LP GT30 FGT Turbocharger



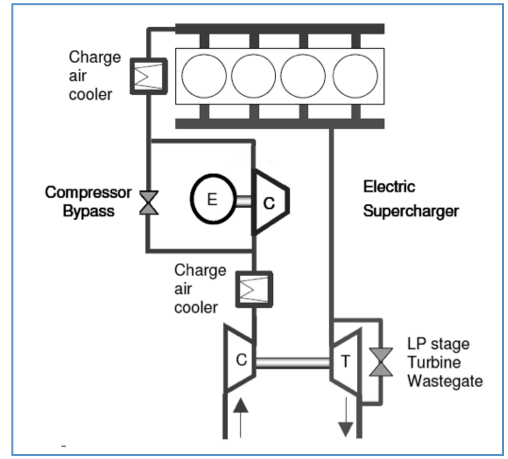
- The two-stage Turbo-Super is ranked best overall
- Using well proven technologies best combination of:
    - Low end torque
    - Transient response
    - Fuel economy.
- Variable speed (CVT) drive would improve BSFC

TWIN-TURBO:
HP Honeywell GT14 Turbocharger + LP GT30 FGT Turbocharger



- Rated highly due to:
    - BSFC
    - Cost
    - Size
    - Commercial readiness.
- Transient response quite poor in comparison to other options.
- Addition of a VGT interesting but expensive option

SUPERGEN-TURBO:
HP Integral Power SuperGen + LP GT30 FGT Turbocharger



- Rates highly in the performance criteria
- Very good transient response
- Device is currently in a development phase

CONCLUSIONS

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- The Turbo-Super demonstrates excellence in a number of areas over competing options.
- Addition of a CVT drive shows some improvements in key areas such as part load BSFC.
- Twin turbocharging starts to struggle in very heavily downsized engines, unless compromises are made in low or high rpm regions of the torque curve.
- VGT turbo technology does bring advantages but requires added expense and development for gasoline.
- Initial modelling suggest IPT SuperGen could supply excellent transient response over rivals
- Three stage series turbocharger performance poor in a number of areas