GT-Suite Users International Conference
Frankfurt a.M., October 10th 2005

THE POTENTIAL OF ELECTRIC EXHAUST GAS TURBOCHARGING FOR HD DIESEL ENGINES

F. Millo, F. Mallamo, E. Pautasso (POLITECNICO DI TORINO, ITALY)

G. Dellora, G. Ganio Mego (IVECO S.P.A., ITALY)

J. Bumby, S. Crossland (UNIVERSITY OF DURHAM, UK)

O. Ryder (HOLSET TURBOCHARGERS, UK)

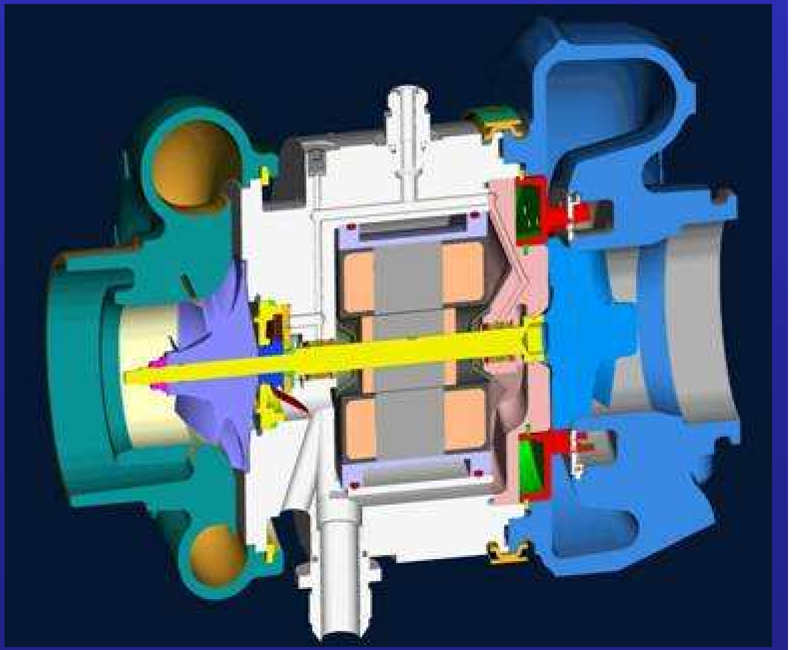
L. Jaeger, L. Montali (IVECOMOTORENFORSHUNG LTD, CH)

Presentation overview

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

INTRODUCTION

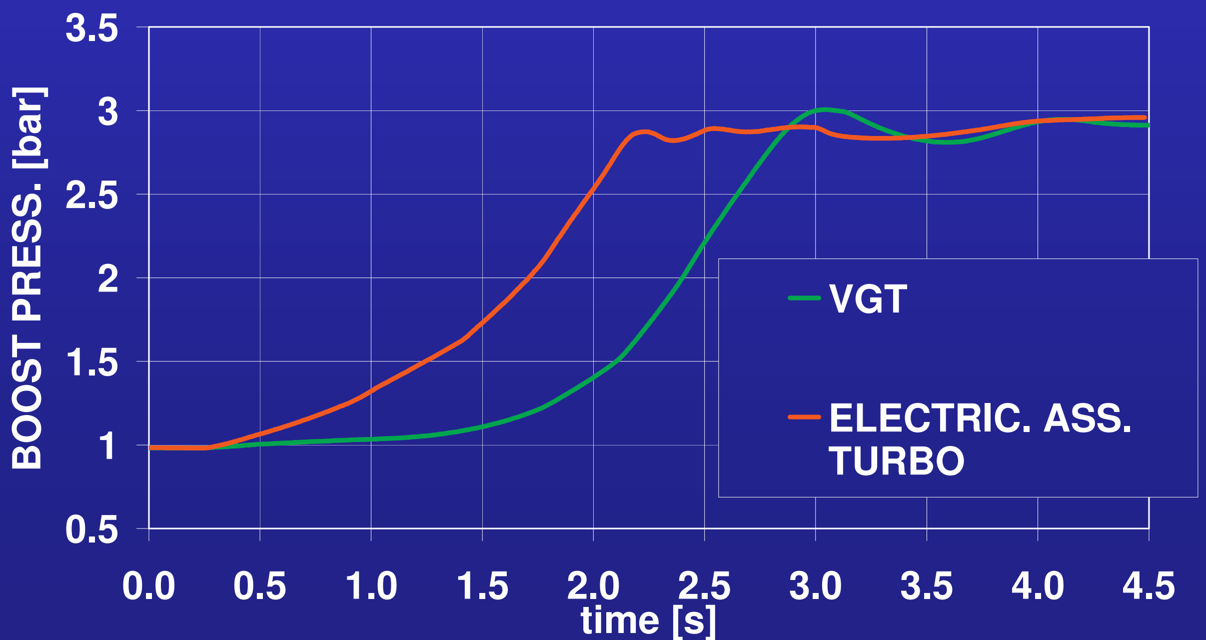
THE AIM OF THE RESEARCH PROJECT WAS TO ANALYSE THE POTENTIAL OF AN ELECTRIC ASSISTED TURBOCHARGER FOR A HEAVY-DUTY DIESEL ENGINE, REPLACING THE CURRENT VARIABLE GEOMETRY TURBINE WITH A FIXED GEOMETRY TURBINE AND CONNECTING TO THE TURBO SHAFT AN ELECTRIC MACHINE WHICH CAN OPERATE BOTH AS AN ELECTRIC MOTOR AND AS AN ELECTRIC GENERATOR



- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

INTRODUCTION

THE ELECTRIC MACHINE OPERATES AS A MOTOR WHEN THE INTERNAL COMBUSTION ENGINE SPEEDS UP FROM IDLE AND AFTER GEAR SHIFTS IN ORDER TO HELP THE TURBOCHARGER TO ACCELERATE AND SO TO REDUCE THE TURBO-LAG, REDUCING PARTICULATE EMISSIONS DURING TRANSIENTS, ENHANCING THE ENGINE PERFORMANCE AND SO ALLOWING ENGINE DOWNSIZING.



- **Introduction**
- **Contest**
- **Building the engine and vehicle model**
- **Analysis of possible fuel consumption reductions and performance enhancements**
- **Conclusions**

INTRODUCTION

THE ELECTRIC MACHINE OPERATES AS A GENERATOR WHEN IT IS POSSIBLE TO EXTRACT FROM THE EXHAUST GASES MORE ENERGY THAN THAT WHICH IS NECESSARY TO REACH THE TARGET BOOST PRESSURE.

THE ELECTRIC ENERGY WHICH IS PRODUCED IS PROVIDED TO THE VEHICLE ELECTRIC SYSTEM REDUCING THE ELECTRIC LOAD ON THE ALTERNATORS AND SO THE AUXIALIARY POWER REQUIREMENT, WITH AN OBVIOUS FUEL CONSUMPTION REDUCTION.

MOREOVER, THE TORQUE ABSORBED BY THE ELECTRIC MACHINE ALLOWS THE CONTROL OF THE TURBO SPEED, WITHOUT THE NEED FOR A WASTEGATE OR A VGT.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

INTRODUCTION

HOWEVER, THE POTENTIAL OF THIS KIND OF SYSTEM IS STRONGLY DEPENDENT ON THE DRIVING CYCLE (I.E. REGENERATION PERIODS WHEN THE ELECTRIC MACHINE OPERATES AS A GENERATOR SHOULD BE LONG ENOUGH TO PRODUCE AND STORE THE ENERGY THAT WILL BE REQUIRED TO SPEED-UP THE TURBOCHARGER DURING THE ACCELERATION TRANSIENTS OF THE INTERNAL COMBUSTION ENGINE).

THEREFORE, A DETAILED SIMULATION MODEL IS REQUIRED IN ORDER TO ASSESS THE SYSTEM POTENTIAL.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

CONTEST:

THE ELEGT PROJECT

ELECTRIC EXHAUST GAS TURBOCHARGER

RESEARCH PROJECT FUNDED BY THE RESEARCH DIRECTORATE OF THE EUROPEAN UNION COMMISSION

- **PROJECT CO-ORDINATOR : IVECO S.p.A.**

PARTNERS :

1) IVECO S.p.A.	(IVECO)	I
2) Iveco Motorenforschung LTD	(IMF)	CH
3) HOLSET Engineering LTD	(Holset)	UK
4) Thien-E-motors LTD	(Thien)	A
5) ATE GMBH	(ATE)	D
6) University of Durham	(Durham)	UK

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL

CURRENTLY IN PRODUCTION HD DIESEL ENGINE (IVECO CURSOR 8) WITH VGT WAS USED AS A REFERENCE

- MAX. BMEP 20.6 BAR
- SPEC. OUTPUT 33 KW / dm^3

MAIN ENGINE FEATURES

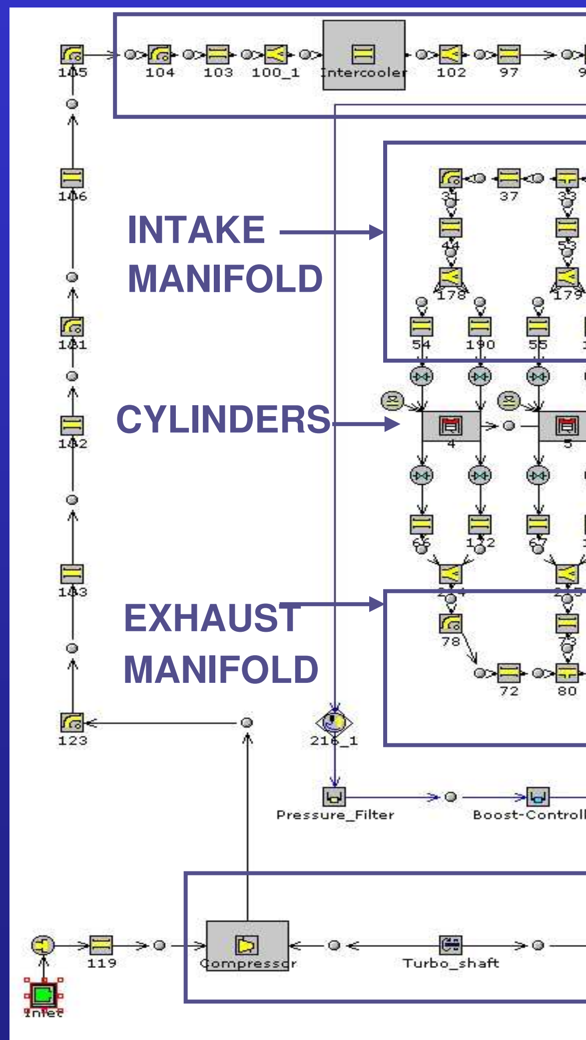
IVECO CURSOR 8

CYCLE	DIESEL 4 STROKE
N° CYLINDERS	6 IN LINE
DISPLACEMENT [dm^3]	7.8
BORE [mm]	115
STROKE [mm]	125
COMPRESSION RATIO	17:1
MAXIMUM TORQUE [Nm]	1280 AT 1080 RPM
MAXIMUM POWER [kW]	259 AT 2400 RPM
AIR INTAKE SYSTEM	SINGLE STAGE TURBOCHARGER (WITH VGT AND AFTERCOOLER)

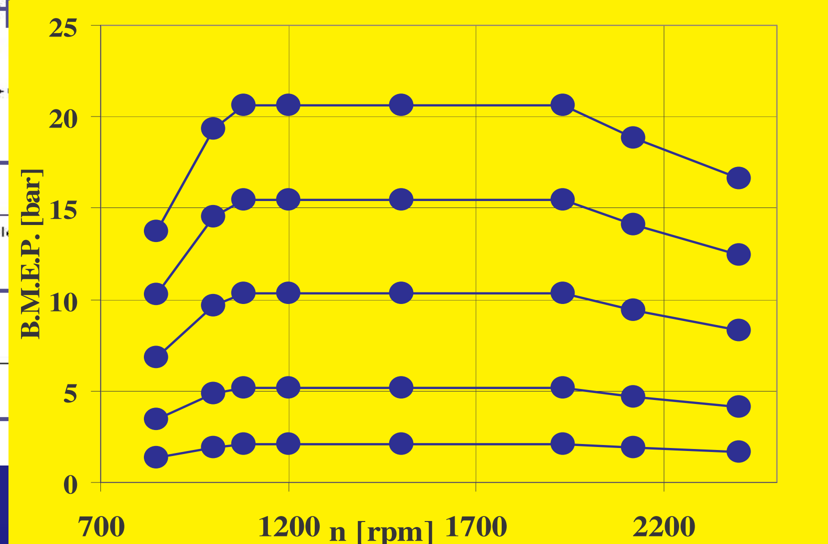
- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL

DETAILED GT-POWER MODEL



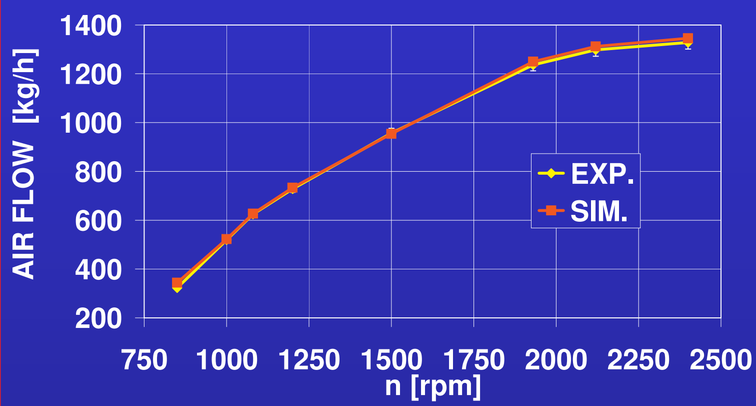
8 ENGINE SPEEDS AND 5 LOAD LEVELS FOR A TOTAL OF 40 OPERATING POINTS USED FOR MODEL VALIDATION



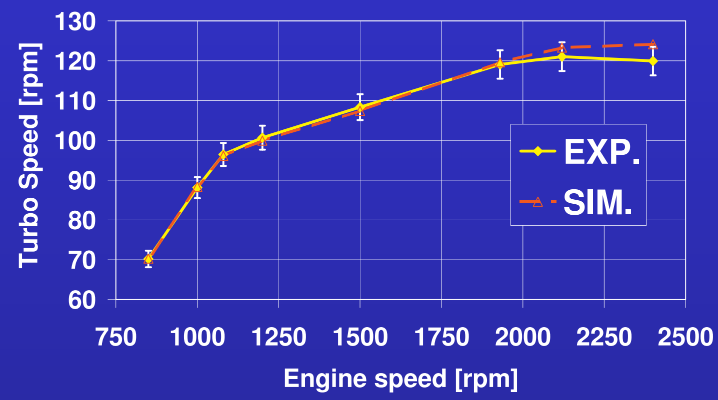
- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ENGINE MODEL VALIDATION FULL LOAD OPERATING CONDITIONS

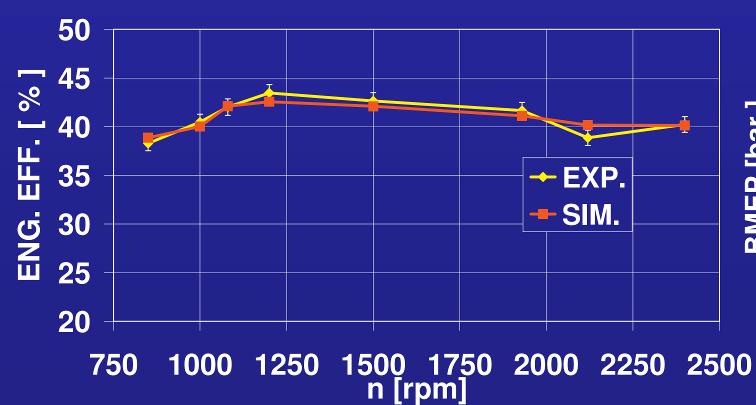
AIR MASS FLOW



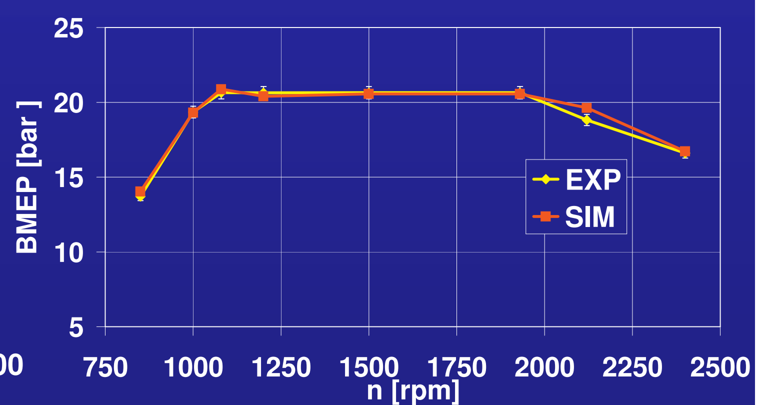
TURBO SPEED



ENGINE EFFICIENCY



BMEP



- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

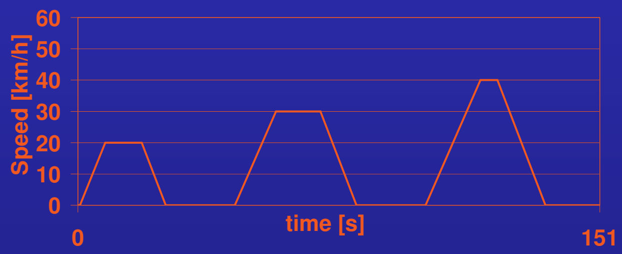
BUILDING THE ENGINE AND VEHICLE MODEL: VEHICLE MODEL

SIMULATED VEHICLE :

URBAN BUS (12 tons UNLOADED, 16.5 tons FULL LOADED)

AUTOMATIC GEARSHIFT WITH TORQUE CONVERTER

COUPLED ENGINE + VEHICLE MODEL INITIALLY VALIDATED ON SIMPLE DRIVING CYCLES

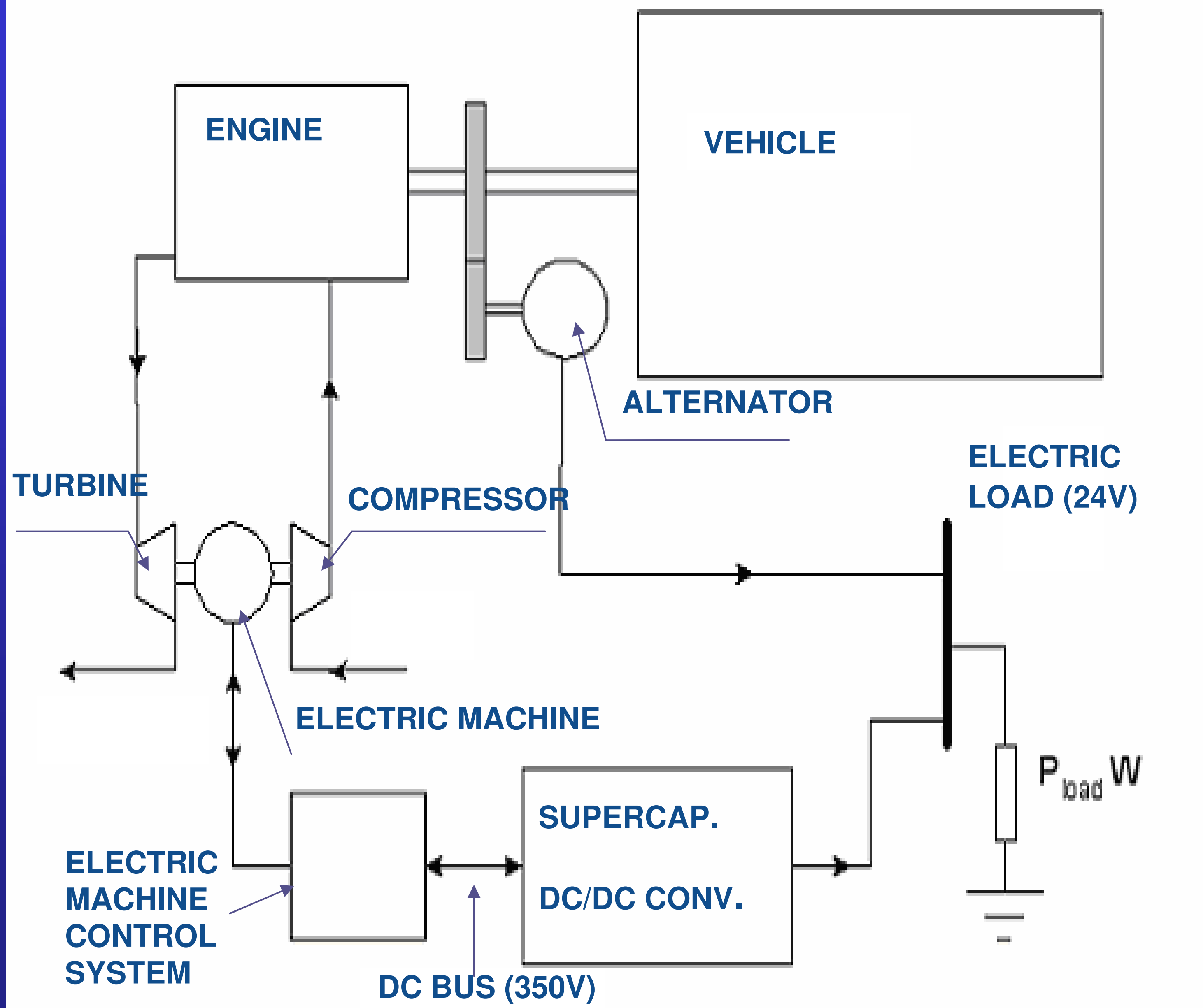


COUPLED ENGINE-VEHICLE MODEL VALIDATION

DRIVING CYCLE	EXP. FUEL CONS. [L/100KM]	SIM. FUEL CONS. [L/100KM]
SORT1	49.2 ÷ 46.8	47.7
SORT2	42.2 ÷ 38.2	42. 9

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT SYSTEM ARCHITECTURE

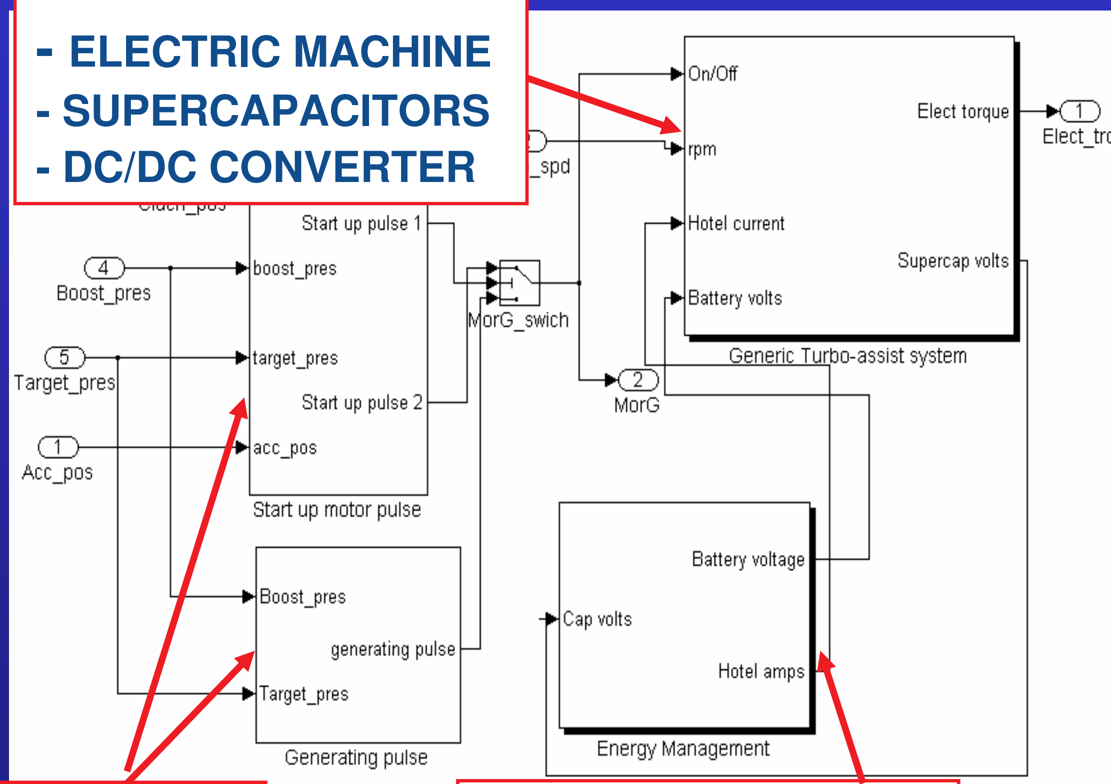


- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT SYSTEM ARCHITECTURE

SIMULINK MODEL OF ELECTRIC SUBSYSTEMS (UNIV. OF DURHAM) COUPLED WITH ENGINE AND VEHICLE GT-POWER MODEL (POLITECNICO DI TORINO)

- ELECTRIC MACHINE
- SUPERCAPACITORS
- DC/DC CONVERTER



ELECTRIC MACHINE CONTROL SYSTEM

ENERGY MANAGEMENT CONTROL SYSTEM

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ELECTRIC MACHINE MAIN FEATURES

MOTOR	TORQUE & POWER	CONST. TORQUE (1 Nm) UP TO 60.000 rpm, CONST. POWER (6.3 kW) UP TO 120.000 rpm
	USAGE	INTERMITTENT (3 s USE IN A 20 s CYCLE)
GENERATOR	TORQUE & POWER	CONSTANT GENERATING POWER (7.6 kW)
	USAGE	CONTINUOUS
MOTOR/ GENERATOR	VOLTAGE	350 Volts
	MAXIMUM DESIGN SPEED	130.000 rpm
	MAXIMUM OVERSPEED	143.000 rpm

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM

AT FIRST THE ELECTRICAL POWER GENERATED BY THE ELEGT SYSTEM IS USED TO CHARGE THE SUPERCAPACITORS. WHEN THEIR SOC (STATE OF CHARGE) IS HIGHER THAN 0.65 THEY START TO PROVIDE TO THE VEHICLE ELECTRIC SYSTEM THE POWER USUALLY GENERATED BY ONE ALTERNATOR.

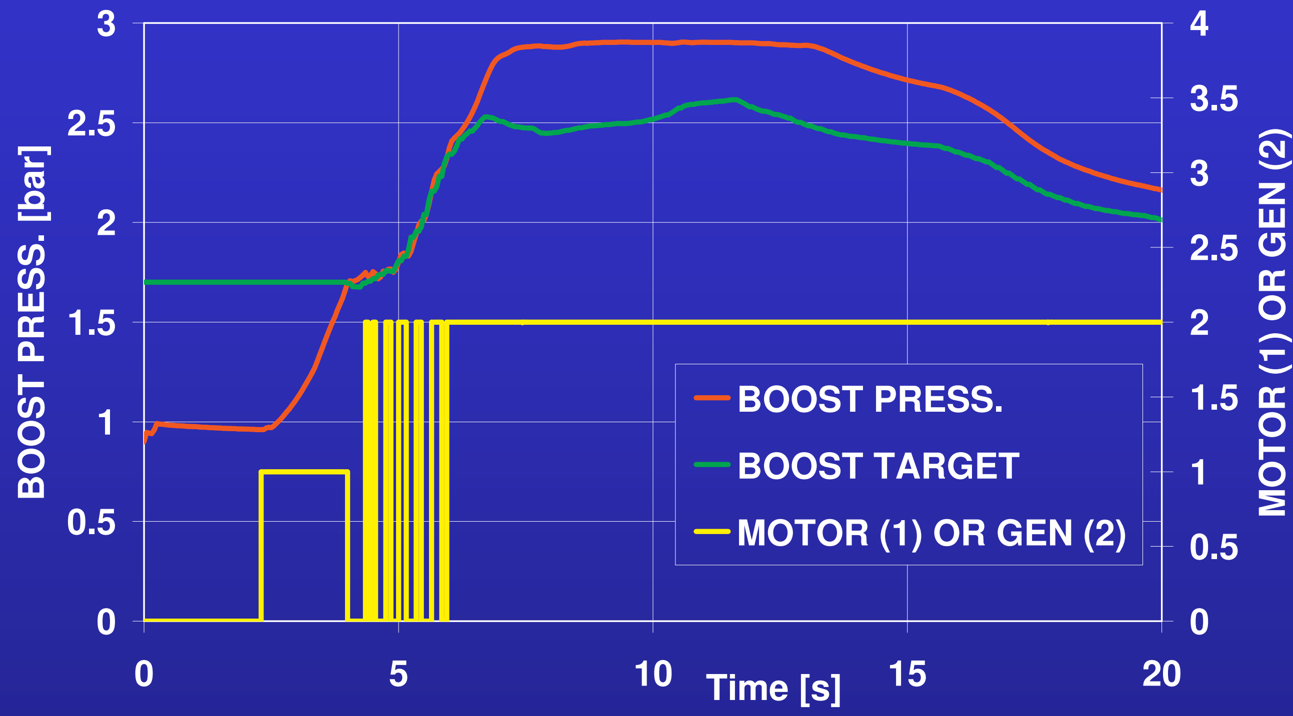
IF THE SYSTEM GENERATES CONTINUOUSLY THE SOC LEVEL CONTINUES TO INCREASE. WHEN IT RISES ABOVE THE 0.85 LEVEL, ALSO THE SECOND ALTERNATOR ELECTRIC POWER CAN BE SAVED.

ON THE CONTRARY IF THE SYSTEM GENERATES DISCONTINUOUSLY OR DOESN’T GENERATE AT ALL THE SOC LEVEL DECREASES AND WHEN IT GOES BELOW A LOWER LIMIT THE LOAD REQUIRED TO THE SUPERCAPACITORS IS SET TO ZERO, AS, CONSEQUENTLY, THE POWER ADDED TO THE ENGINE.

THE INSTANTANEOUS ELECTRIC POWER PROVIDED BY THE ELEGT SYSTEM IS CALCULATED DURING THE WHOLE DRIVING CYCLE.

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

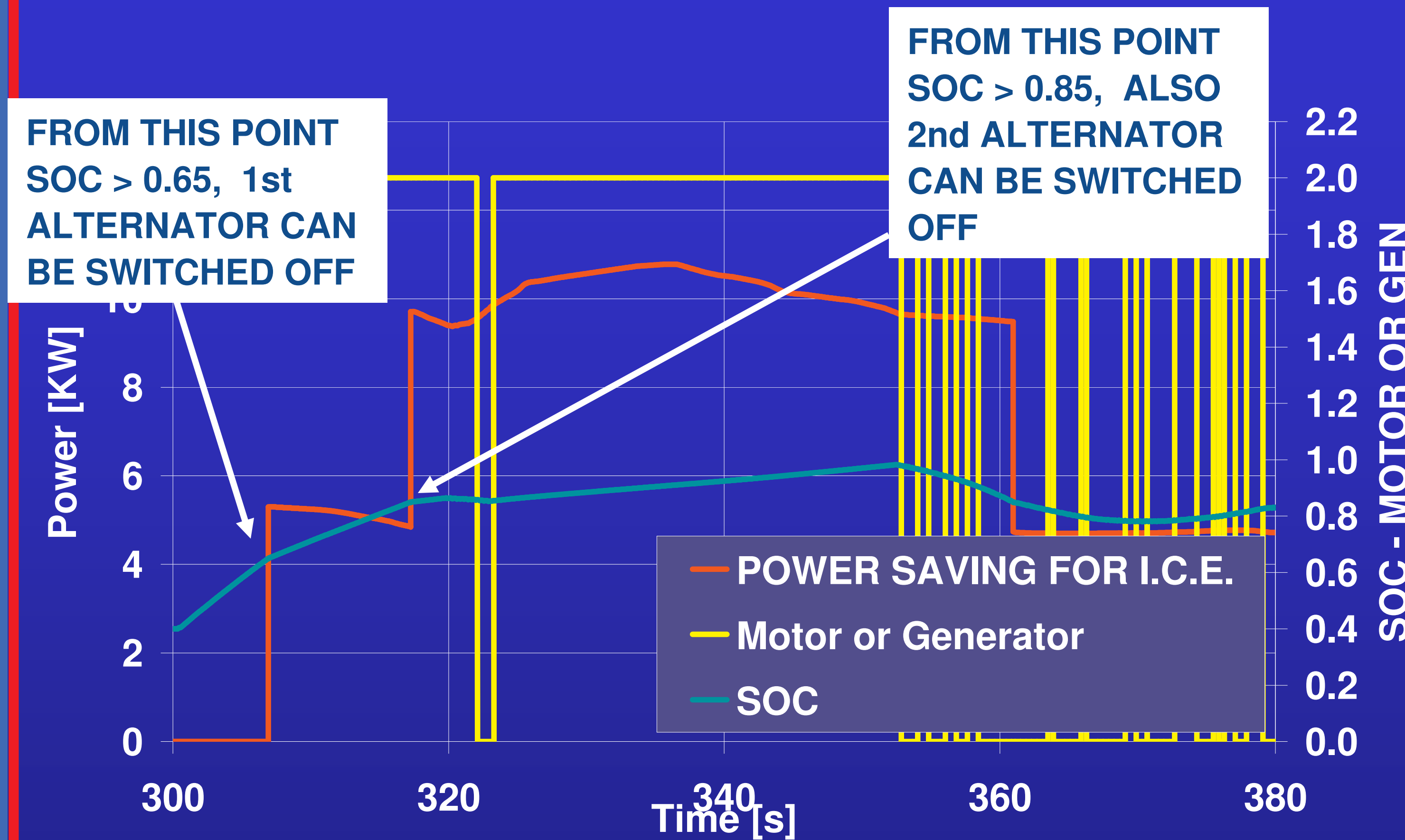
BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM



EXAMPLE OF CONTROL STRATEGY DURING THE FIRST 20 s OF THE HWFET DRIVING CYCLE

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM



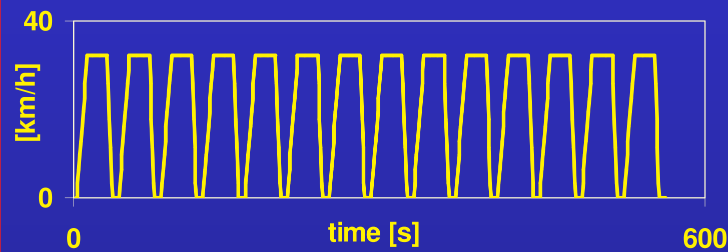
EXAMPLE OF CONTROL STRATEGY DURING A PERIOD OF 80 s IN THE HWFET DRIVING CYCLE

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

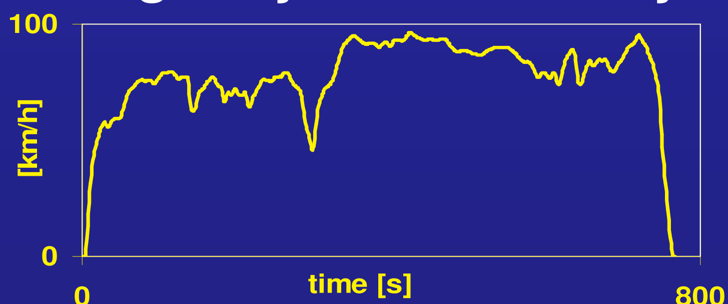
ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

CONSIDERED DRIVING CYCLES

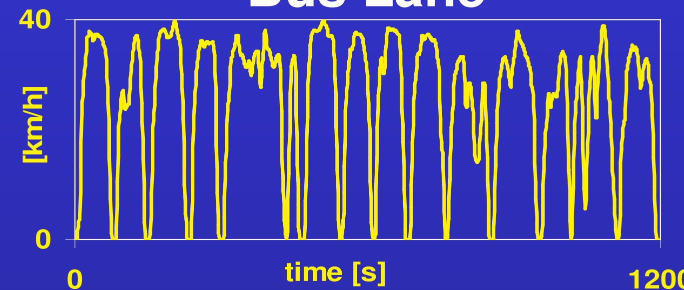
CBD
Central Business District



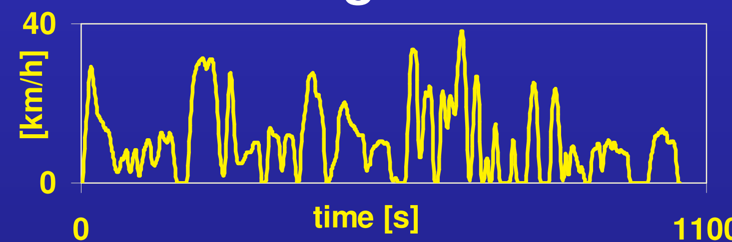
HWFET
Highway Fuel Economy



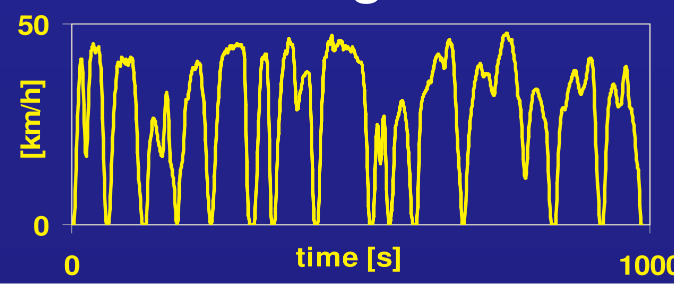
TRL03
Bus Lane



TRL08
Bus in congested traffic



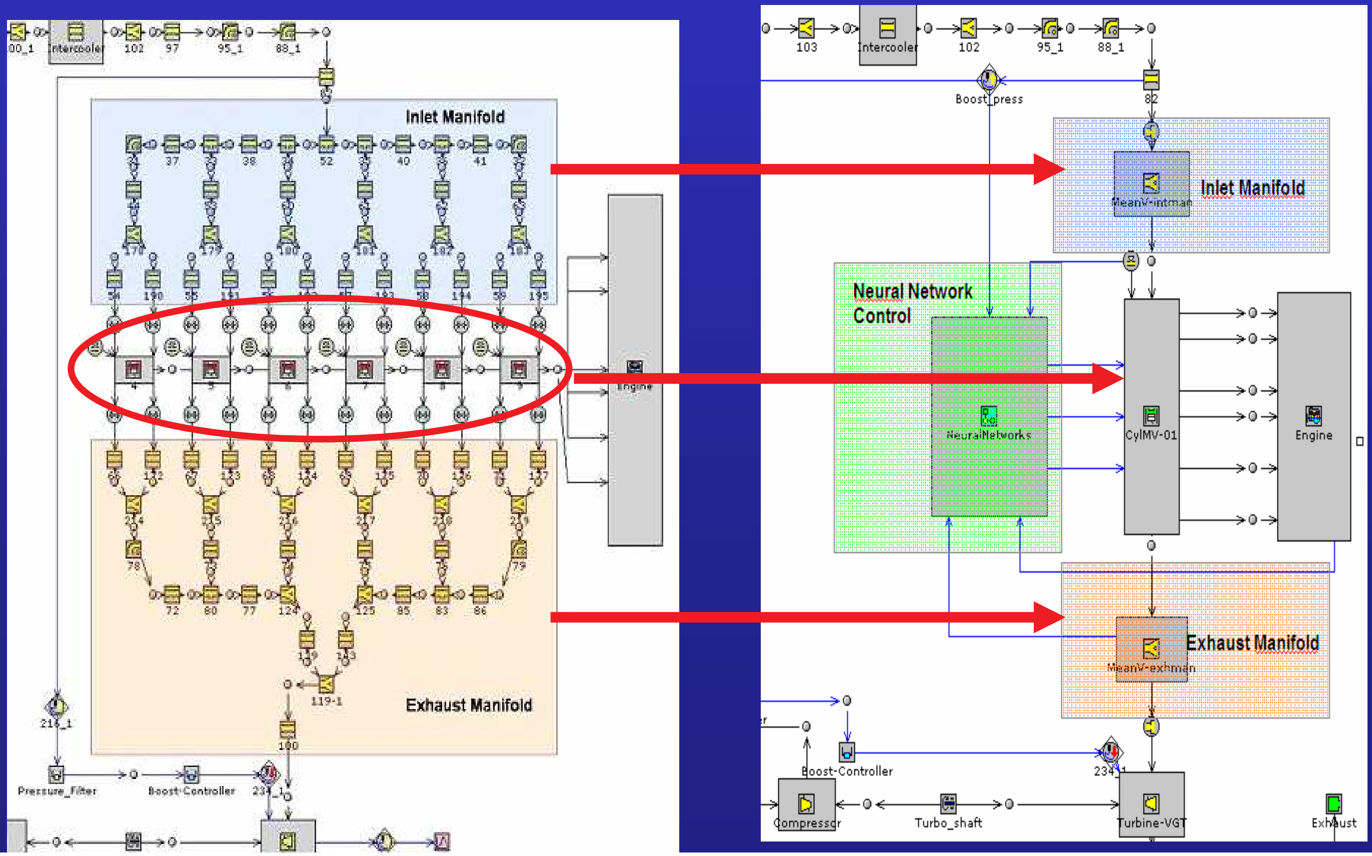
TRL09
Bus in non-congested traffic



- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SINCE THE DETAILED ENGINE MODEL IS APPROX. 250 TIMES SLOWER THAN REAL TIME, A MEAN VALUE MODEL WAS BUILT IN ORDER TO REDUCE THE COMPUTATIONAL TIME, BY COMBINING MULTIPLE CYLINDERS INTO A SINGLE MAP-BASED ONE, AS WELL AS SEVERAL INTAKE AND EXHAUST COMPONENTS INTO TWO MANIFOLD COMPONENTS.



- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

IN ORDER TO PROPERLY TRAIN THE NEURAL NETWORKS WHICH ARE USED IN THE MEAN VALUE MODEL, A QUITE LARGE NUMBER (ABOUT 1000) OF OPERATING POINTS WERE SIMULATED WITH THE DETAILED MODEL, FOLLOWING A DOE LATIN HYPERCUBE SCHEME.

THE INPUT VARIABLES FOR THE NEURAL NETWORKS WERE THE FOLLOWING:

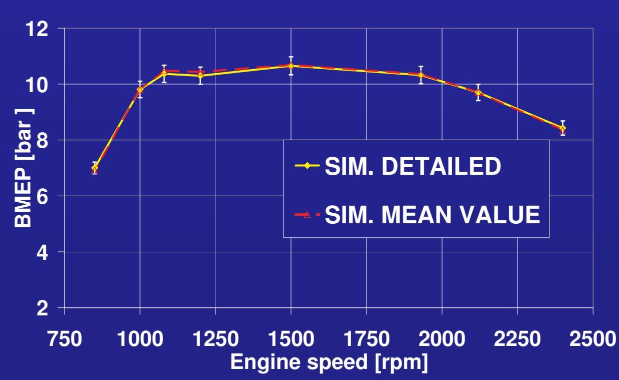
–– ENGINE SPEED (FROM 800 TO 2400 RPM),

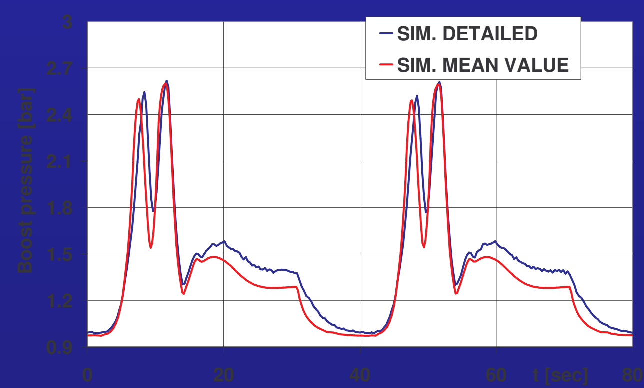
–– FUEL INJECTION RATE (FROM 15 TO 150 MG/CYCLE),

–– INTAKE MANIFOLD PRESSURE (FROM 0,9 TO 2,8 BAR),

–– EXHAUST MANIFOLD PRESSURE (FROM 1,1 TO 2,45 BAR).

AFTERWARDS, THE MEAN VALUE MODEL RELAIBILITY WAS TESTED BOTH UNDER STEADY STATE AND TRANSIENT OPERATING CONDITIONS





- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

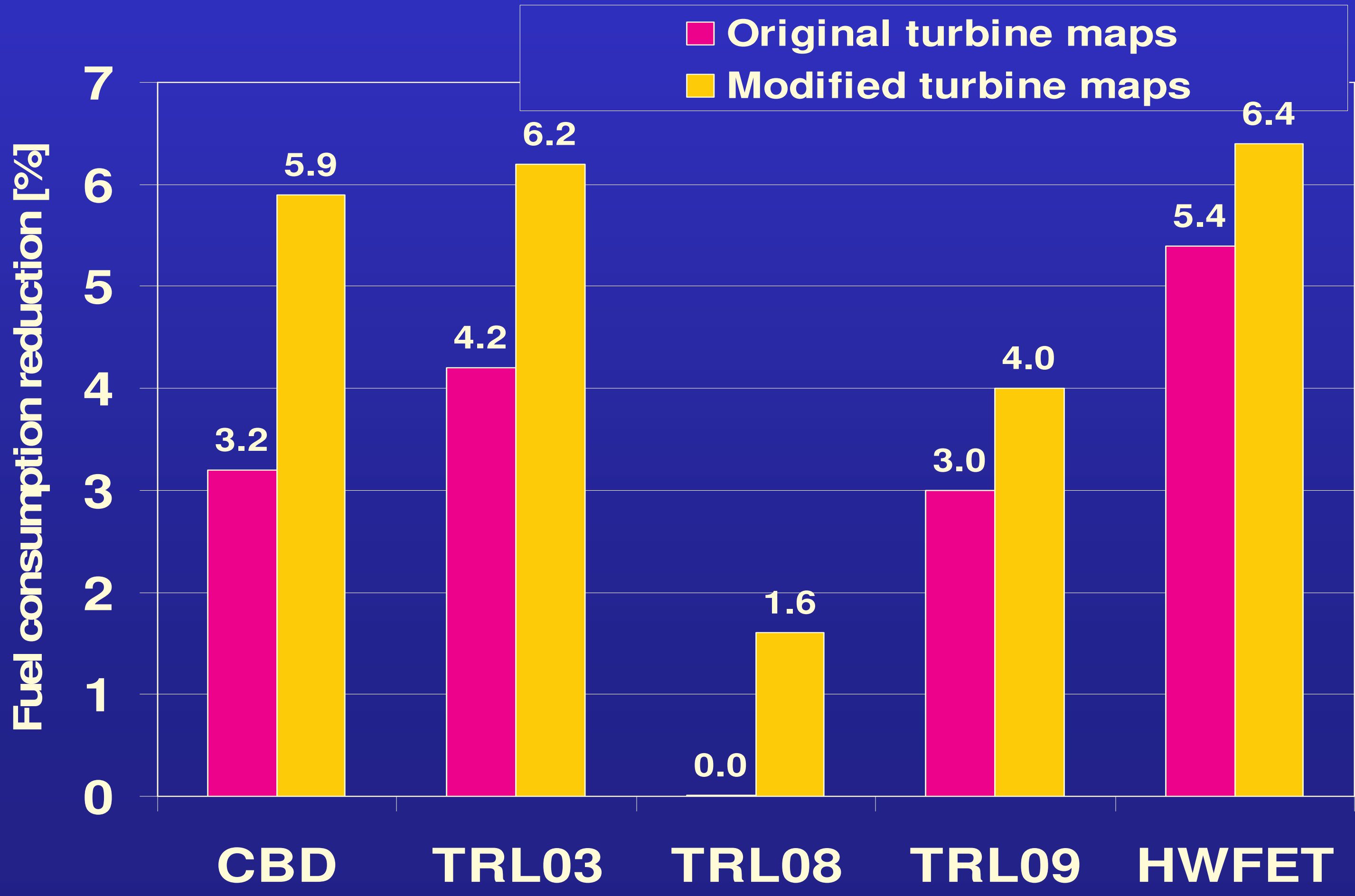
- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

MODIFIED TURBINE MAPS



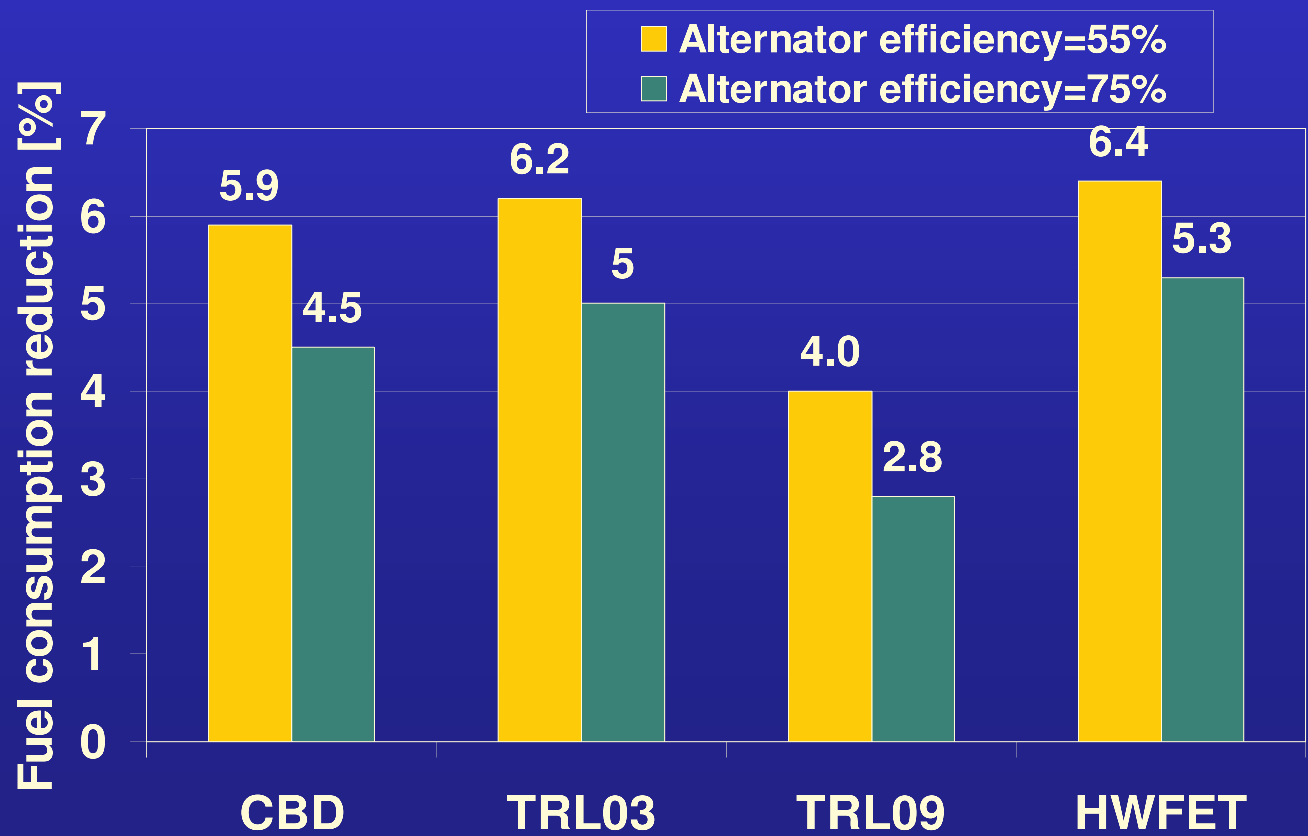
- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

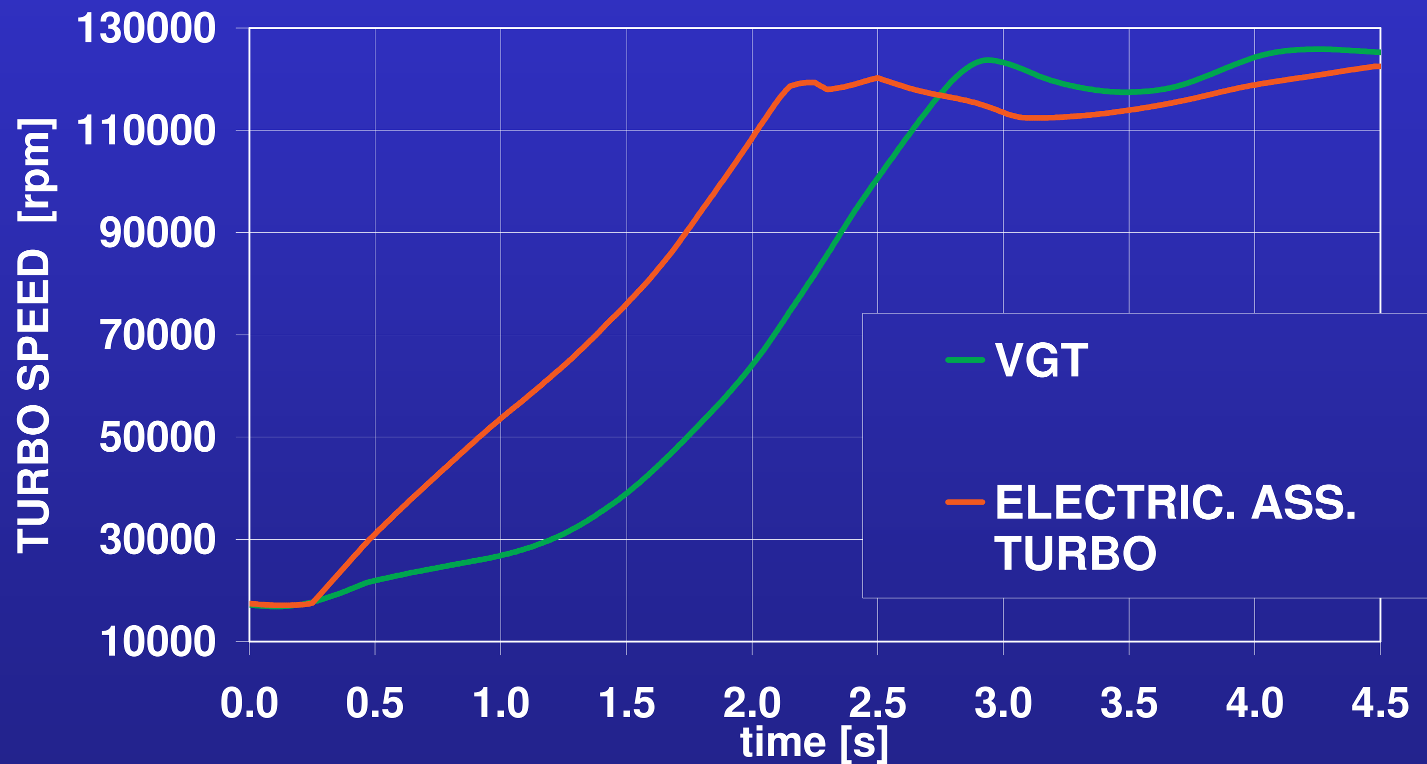
ALTERNATOR AVER. EFFIC. 75% INSTEAD OF 55%



- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

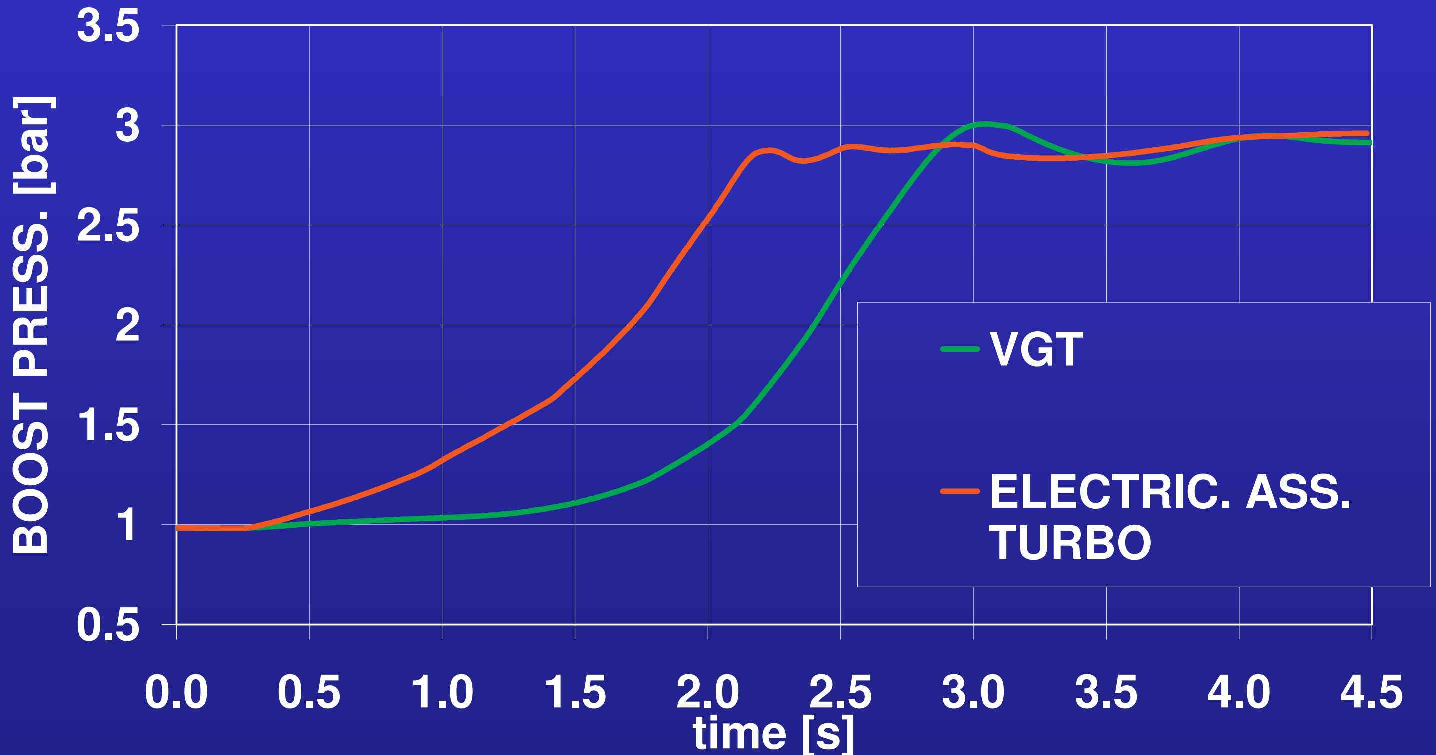
ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

TURBO LAG REDUCTION: TURBO SPEED



ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

TURBO LAG REDUCTION: BOOST PRESSURE



- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- **Conclusions**

CONCLUSIONS

THANKS TO THE USE OF MEAN VALUE MODEL, THE ELEGT SYSTEM POTENTIAL COULD BE ASSESSED ALSO ON COMPLEX, REAL WORLD DRIVING CYCLES, LEADING TO THE FOLLOWING MAIN FINDINGS:

- THE ELEGT SYSTEM ALLOWS A FUEL CONSUMPTION REDUCTION FROM 1.5% TO 5.5% DEPENDING ON THE DRIVING CYCLE;

- THESE VALUES COULD BE INCREASED BY CONSIDERING AN “ON PURPOSE” DESIGNED TURBINE;

- FUEL SAVINGS ARE STILL APPRECIABLE EVEN IF BETTER EFFICIENCY ALTERNATORS ARE CONSIDERED;

- SUBSTANTIAL IMPROVEMENTS DURING THE ACCELERATION TRANSIENTS CAN BE ACHIEVED

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions

ACKNOWLEDGMENTS

THIS WORK HAS BEEN CARRIED OUT WITH THE FINANCIAL SUPPORT OF THE EUROPEAN COMMUNITY IN THE FRAMEWORK OF THE EUROPEAN COMMISSION "GROWTH" PROGRAMME.

CONTRACT N° : 63083

PROJECT N° : G3RD-CT-2002-00788

ACRONYM : ELEGT

TITLE : ELectric Exhaust Gas Turbocharger

GT-Suite Users International Conference

Frankfurt a.M., October 10th 2005

THE POTENTIAL OF ELECTRIC EXHAUST GAS TURBOCHARGING FOR HD DIESEL ENGINES

F. Millo, F. Mallamo, E. Pautasso (POLITECNICO DI TORINO, ITALY)

G. Dellora, G. Ganio Mego (IVECO S.P.A., ITALY)

J. Bumby, S. Crossland (UNIVERSITY OF DURHAM, UK)

O. Ryder (HOLSET TURBOCHARGERS, UK)

L. Jaeger, L. Montali (IVECOMOTORENFORSHUNG LTD, CH)