GT-SUITE USERS CONFERENCE
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FLUID DYNAMICS TRANSIENT RESPONSE
SIMULATION OF A VEHICLE EQUIPPED WITH A
TURBOCHARGED DIESEL ENGINE USING GT-POWER

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STEADY STATE ANALYSIS – FULL LOAD CURVE

TRANSIENT ANALYSIS

TRANSIENT ANALYSIS: RESULTS WITH 2ND, 3RD, 4TH AND 5TH GEARS

TRANSIENT ANALYSIS: PARAMETRIC EVALUATIONS

 REMARKS AND CONCLUSIONS
The improvement of passenger cars equipped with turbocharged diesel engines has asked for a better understanding and optimisation of the fluid dynamics phenomena involved in turbo charging.

As well known, an important effect on such vehicle performance during acceleration phases is due to the so-called “turbolag”, the engine delay to a driver’s request of torque.

Using the 1D GT-Power code various transient phases have been simulated for an Alfa Romeo 147 vehicle with 1.9 JTD engine with a VGT turbocharger, during accelerations from 1000 ERPM to 4500 ERPM with 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} and 5\textsuperscript{th} gears.

The control of the variable geometry turbine has been implemented in the model using GT-Power control objects only, in order to keep the set-up as easy as possible. The implemented control reproduces the real ECU strategy.
INTRODUCTION

THE SIMULATION RESULTS, IN TERMS OF ENGINE TORQUE, VEHICLE SPEED, ETC, HAVE BEEN COMPARED WITH VEHICLE EXPERIMENTAL DATA, PROVIDED BY FGP ITALY, AND THE AGREEMENT IS SATISFACTORY.

AS RESULT, THE ACTIVITY HAS SHOWN THE KEY ROLE PLAYED BY THE TURBOCHARGER INERTIA.

AFTER THIS FIRST STEP OF VALIDATION OF THE MODEL AND THE CONTROL METHODOLOGY, A SERIES OF PARAMETRIC ANALYSES HAS BEEN PERFORMED. THE EFFECT OF TURBOCHARGER INERTIA MANUFACTURE SCATTERING, FINAL DRIVE GEAR, VEHICLE WEIGHT AND VOLUME DOWNSTREAM OF THE COMPRESSOR ON THE VEHICLE-ENGINE SYSTEM BEHAVIOUR HAS BEEN EVALUATED.
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INTAKE SYSTEM:
- AIR FILTER
- COMPRESSOR
- INTERCOOLER
- MANIFOLD

EXHAUST SYSTEM:
- MANIFOLD
- TURBINE
- EXHAUST NOZZLE

TURBOCHARGER CONTROL
INTAKE SYSTEM:
- AIR FILTER
- COMPRESSOR
- INTERCOOLER
- MANIFOLD

EXHAUST SYSTEM:
- MANIFOLD
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- EXHAUST NOZZLE

TURBOCHARGER
CONTROL
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GT-POWER MODEL VALIDATION WITH EXPERIMENTAL DATA

ENGINE M729 1910 16V JTD

EXPERIMENTAL
GT-POWER
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TRANSIENT ANALYSIS

ADDITIONAL REQUIRED DATA FOR TRANSIENT ANALYSIS

1910 16V JTD ENGINE
- ENGINE INERTIA
- TURBOCHARGER INERTIA

ALFA ROMEO 147 VEHICLE
- VEHICLE MASS
- FRONT AREA AND CX
- WHEELS INERTIA
- FINAL GEAR AND GEARS RATIOS

TRANSIENT SIMULATION PHASES


2) THE SECOND PHASE IS THE PHYSICAL TRANSIENT: THE INPUT SIGNAL, CORRESPONDING TO A FUEL STEP FROM PART LOAD TO FULL LOAD, IS APPLIED TO THE ENGINE AND THE VEHICLE-ENGINE SYSTEM CHANGES DEPENDING ON ITS PHYSICAL LAWS.
TURBOCHARGER CONTROL FOR TRANSIENT ANALYSIS

INTAKE SYSTEM:
- AIR FILTER
- COMPRESSOR
- INTERCOOLER
- MANIFOLD

EXHAUST SYSTEM:
- MANIFOLD
- TURBINE
- EXHAUST NOZZLE

TURBOCHARGER CONTROL
1) A TURBINE RACK POSITION CONTROL IS NEEDED TO ADJUST THE BOOST PRESSURE DURING THE TRANSIENT.


![Diagram of turbocharger control system]

- **RACK ACTUATOR**
  - 0.1 = MINIMUM TURBINE OPENING
  - 1 = MAXIMUM TURBINE OPENING

- **BOOST SENSOR**
- **PID**
- **LIMITER**
- **STEADY STATE RACK**
- **SUM**
- **ENGINE RPM SENSOR**
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BOOST PRESSURE: THE COMPARISON BETWEEN THE STEADY-STATE AND TRANSIENT BOOST PRESSURES SHOWS THE ENGINE DELAY TO A DRIVER’S REQUEST OF TORQUE, DUE TO THE SO-CALLED “TURBOLAG”.

![Graph showing transient and steady-state boost pressures for an engine. The graph illustrates the differences in boost pressure as a function of RPM, highlighting the turbo lag effect. The graph compares steady-state and transient pressures for vehicle 147 with an engine M729 1910 16V JTD.]
TRANSIENT ANALYSIS: RESULTS II GEAR

CONTROL STRATEGY: THE PID CONTROL (PID RACK) ADJUSTS TO GET THE TARGET BOOST PRESSURE (STEADY-STATE BOOST PRESSURE) WORKING ON STEADY-STATE MAP (STEADY-STATE RACK). THE RESULTANT SIGNAL (ACTUATOR RACK) OPERATES ON THE TURBINE RACK POSITION. THE GRADUAL ADJUSTMENT OF THE ACTUATOR RACK AVOIDS THE OVERBOOST PRESSURE AND ITS OSCILLATIONS.

ENGINE M729 1910 16V JTD – VEHICLE 147

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EXPERIMENTAL RESULTS

THE EXPERIMENTAL VEHICLE TORQUE IS DERIVED FROM ACCELERATION MEASUREMENTS, SOLVING THE MOTION EQUATION.

GT-POWER RESULTS

ENGINE M729 1910 16V JTD – VEHICLE 147
THE TURBOLAG PHENOMENON IS MAINLY RELATED TO THE TURBOCHARGER INERTIA.
TRANSIENT ANALYSIS: RESULTS II GEAR

TYPICAL VEHICLE RESULTS ARE THE VEHICLE SPEED, VEHICLE ACCELERATION AND VEHICLE JERK (ACCELERATION DERIVATIVE).

[Graph showing vehicle speed, acceleration, and jerk over time for a specific vehicle and gear.]
TRANSIENT ANALYSIS: RESULTS III GEAR

147 car 19 JTD 16v - Acceleration in 3rd gear

GT-POWER RESULTS

ENGINE M729 1910 16V JTD – VEHICLE 147

EXPERIMENTAL RESULTS
TRANSIENT ANALYSIS: RESULTS IV GEAR

ENGINE M729 1910 16V JTD - VEHICLE 147

- STEADY-STATE
- IV GEAR

STEADY-STATE BOOST PRESSURE
TRANSIENT BOOST PRESSURE
STEADY-STATE RACK
ACTUATOR RACK
PID RACK

BOOST PRESSURE [mbar]

TURBINE RACK POSITION [-]

RPM

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TRANSIENT ANALYSIS: RESULTS IV GEAR

The calculated transient boost pressure shows a delay compared to the steady-state one. The calculated transient torque reaches the steady-state values in advance for the employed combustion model (full load combustions).

**GT-POWER RESULTS**

Engine Torque [Nm]

**EXPERIMENTAL RESULTS**

Engine M729 1910 16V JTD – Vehicle 147
TRANSIENT ANALYSIS: RESULTS V GEAR

ENGINE M729 1910 16V JTD - VEHICLE 147

- STEADY-STATE
- V GEAR

BOOST PRESSURE [mbar]

TURBINE RACK POSITION [-]

RPM

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**TRANSIENT ANALYSIS: RESULTS V GEAR**

GT-POWER RESULTS

THE CALCULATED TRANSIENT BOOST PRESSURE HAS NOT A DELAY COMPARED TO THE STEADY-STATE ONE. THE CALCULATED TRANSIENT TORQUE EXCEEDS THE STEADY-STATE VALUES FOR THE EMPLOYED COMBUSTION MODEL (FULL LOAD COMBUSTIONS).

EXPERIMENTAL RESULTS

ENGINE M729 1910 16V JTD – VEHICLE 147
IN TERMS OF BOOST PRESSURE THE FLUID DYNAMICS EFFECT OF TURBOLAG IS CORRECTLY CALCULATED BY THE CODE.
TRANSIENT ANALYSIS: RESULTS II, III, IV AND V GEARS

Based on engine speed the turbolag seems to be greater for lower gears. Actually the turbolag in terms of time is longer for the higher gears because the engine speed increases more slowly.
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REMARKS AND CONCLUSIONS
THE EFFECT OF THE FOLLOWING PARAMETERS ON THE MODEL HAS BEEN EVALUATED:

- **TURBOCHARGER INERTIA** with 2\textsuperscript{nd} gear, analysing a possible manufacture scattering of ± 5% and ± 10% for the same turbocharger.

- **HIGH PRESSURE INTAKE SYSTEM VOLUME** with 2\textsuperscript{nd} gear, reducing the length of the pipes between compressor and intercooler and between intercooler and intake manifold (reduction from 6.3 to 4.3 litres of high pressure volume).

- **VEHICLE WEIGHT** with 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} and 5\textsuperscript{th} gears, increasing its value of 200 kg.

- **FINAL GEAR RATIO** with 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} and 5\textsuperscript{th} gears, increasing its value of 10%.
TRANSIENT ANALYSIS: TURBOCHARGER INERTIA EFFECT

THE TURBOCHARGER INERTIA EFFECT, DUE TO THE MANUFACTURE SCATTERING, IS LIMITED IN TERMS OF BOOST PRESSURE OR VEHICLE PERFORMANCE.

ENGINE M729 1910 16V JTD – VEHICLE 147

VEHICLE SPEED

VEHICLE ACCELERATION

VEHICLE JERK
**TRANSIENT ANALYSIS: HIGH PRESSURE VOLUME EFFECT**

**DURING TRANSIENT THE EFFECT OF HIGH PRESSURE VOLUME REDUCTION (32%) IS LIMITED IN TERMS OF BOOST PRESSURE.**

**IN STEADY-STATE CONDITION THE PIPES LENGTH REDUCTION CHANGES THE BEHAVIOUR OF THE VOLUMETRIC EFFICIENCY AND THEN THE ENGINE TORQUE. THE TRANSIENT ENGINE TORQUE IS AFFECTED BY THE STEADY-STATE CURVE.**
DURING TRANSIENT THE VEHICLE WEIGHT INCREASES THE ENGINE DELAY TO A DRIVER’S REQUEST OF TORQUE.

ENGINE M729 1910 16V JTD - VEHICLE 147
DURING TRANSIENT THE VEHICLE FINAL GEAR RATIO INCREASES THE ENGINE DELAY TO A DRIVER’S REQUEST OF TORQUE.

ENGINE M729 1910 16V JTD - VEHICLE 147
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TRANSIENT SIMULATION REMARKS

THE TRANSIENT SIMULATION REQUIRES A VERY GOOD AND DETAILED STEADY-STATE MODEL.

THE SETTING OF THE CONTROL PARAMETERS (PID) HAS BEEN CARRIED OUT IN 2ND GEAR, WHERE THE CONTROL HAS TO BE FASTER FOR THE HIGHER ENGINE-VEHICLE ACCELERATION; THE DETECTED PARAMETERS DON’T CHANGE FOR THE SIMULATIONS WITH THE OTHER GEARS.

THE PARAMETRIC ANALYSIS FOR DIFFERENT GEARS IS VERY SIMPLE: IT IS ENOUGH TO CHANGE THE GEAR NUMBER.

THE GT-POWER CALCULATION TIME ON PC (INTEL PENTIUM 4 - CPU 1500 MHZ) VARIES FROM 30 MINUTES (II GEAR) TO 90 MINUTES ABOUT (V GEAR) FOR THE ANALYZED CONFIGURATION.
CONCLUSIONS

BY THE USE OF ONE DIMENSIONAL GT-POWER CODE IT IS POSSIBLE:

- TO ANALYZE ENGINE-VEHICLE TRANSIENTS, ALSO CONSIDERING THE RESPONSE DELAY FOR TURBOCHARGED ENGINES, DUE TO THE TURBOLAG EFFECT.

- TO STUDY THE PERFORMANCE SUPPLIED BY THE ENGINE-VEHICLE SYSTEM FOR DIFFERENT ENGINE OR VEHICLE PARAMETERS.

BY THIS CALCULATION METHODOLOGY IT IS POSSIBLE TO DEFINE THE BEST FLUID DYNAMICS LAYOUT FOR THE INTAKE AND EXHAUST MANIFOLDS AND TURBOCHARGER TYPE FOR TURBOCHARGED ENGINES, EVALUATING THE Steady-State AND TRANSIENT PERFORMANCE.
ACKNOWLEDGEMENTS

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