Transient and Map-Based Driving Cycle Calculation with GT-SUITE

GT-User Conference
9th November 2009, Frankfurt Airport
Dipl.-Ing. Andreas Schmid, IVK University Stuttgart
Dr.-Ing. Michael Grill, FKFS
Dipl.-Ing. Hans-Jürgen Berner, FKFS
Prof. Dr.-Ing. Michael Bargende, FKFS
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Introduction

Calculating the expected fuel consumption of a new vehicle in driving cycles is a major simulation goal.
Introduction

Dynamic Map-based simulation:
- Engine fuel consumption and emissions are measured or simulated at specific operation points (i.e. BMEP 2bar / 2000 RPM)
- Maps are used as interpolation basis

Neural Networks:
- Training neural networks in respect to different simulation boundary conditions (Temperature, Ignition Point….)
- Steady state conditions

Dynamic transient simulation:
- Direct operation of a GT-POWER engine model in a driving cycle simulation
- No steady state conditions
**Introduction**

**Comparison Basis:**
- Comparison of map-based and transient simulation of a SI-Engine

**Why not Neural Networks?:**
- Reasonable boundary conditions?
  - Inlet Temperatures: 20 – 60°C? Resolution?
  - Outlet Cam Timing Variation?
  - Engine Knock? → Ignition Point Variation
  - Enrichment?
  - Turbine response?
  - External EGR-Rates?
  - Inlet Cam Timing Variation?
  - Inlet Cam Timing Variation?

**• Explosion of neural network training points**
**• No time advantage using neural networks when considering future simulation needs!**
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
GT-Suite Model

Highly modular GT-Suite Model is used

- Easy exchange of engine Model
  ➔ GT-Power engine model or map based model
- Different cars possible
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Transient Simulation

Overview

• GT-Power Model of 1.8l DI-SI engine with a single turbocharger is used
• Model is integrated in the modular GT-Suite Model
• Acceleration pedal position is directly applied as “throttle signal”
• Crank angle of 50% burn point is adjusted at 8 °CA after FTDC
• A predictable burn-rate model is used (EGR, Geometry etc.)
• Warm-up strategies are not considered (comparison!)
• Very difficult to control ➔ Main ECU functions have to be considered

➔ Long simulation duration ~ approx. 5-7 days for NEDC
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Map-based Simulation

Overview

- Identical GT-Power Model of 1.8l DI-SI engine with a single turbocharger is used
- Engine fuel map is calculated at the whole operating range of the engine
- “hot” engine conditions are used
- Simulated fuel consumption is integrated in map-based GT-Drive engine state object
- Standard GT-interpolation in fuel-maps are used

→ Short simulation duration of driving-cycle calculation but engine map calculation is approx. 2-3 days, even at basic simulation conditions!
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Comparison

Basic conditions of simulation:

• Comparison cycle: NEDC
• Warm-up strategies are not considered
• No enrichment at start-up is used
• Automatic transmission strategy is used for best fuel economy
• identical medium-sized car is used for both simulation
Vehicle Speed

- Transient simulation
- Map based simulation
Fuel Consumption 1

Apparent Deviations!
Fuel Consumption 2

Compensation over the NEDC!

Time [s]

Fuel Consumption [l/100km]

Transient simulation

Map based simulation
Temperature Turbine

![Graph showing Turbine Inlet Temperature over time]

- **Turbine Inlet Temperature [K]**
- **Time [s]**

 transient simulation
Temperature Catalytic Converter

![Graph showing temperature over time for the catalytic converter. The x-axis represents time in seconds (s), and the y-axis represents temperature in degrees Kelvin (K). The graph includes a section marked with a dashed red circle, highlighting a specific period of interest. The line represents a transient simulation.](image-url)
Comparison

Comparison results:

- Just small deviations in overall fuel consumption
- Deviations during simulation just have minor effect on overall fuel consumption because of compensation

Surprising Results?

- NEDC is quite stationary
- Fuel consumption reacts linear ➔ interpolation possible
  ➔ Identical Model ➔ Same results!
Comparison

Transient simulation necessary?

- Warm-up strategies
- Emissions (especially NO\textsubscript{x}) nonlinear!
- Acceleration behavior of “Downsizing” engines
- Turbine response behavior
- Customer driving cycles with high engine loads
- CAI/HCCI simulation / high EGR
- Max. allowed temperature \(\Rightarrow\) transient necessary enrichment
- Min. allowed catalytic converter temperature over cycle
- Exhaust gas treatment strategies

\(\Rightarrow\) Transient simulation essential for future simulation needs!
Transient Simulation

Example: Acceleration 60 $\rightarrow$ 100 km/h - Supercharged SI-Engine with anti-knock control

Direct transient simulation $\Rightarrow$ “real”-World simulation!
Overview

1. Introduction
2. GT-Suite Model
3. Transient Simulation
4. Map-based Simulation
5. Comparison
6. Summary
Summary

• Comparison of map-based and transient NEDC simulation was realized
• Neural networks offer no time advantage if all reasonable boundary conditions for future engines are considered
• Only small deviations occur if no warm-up strategy is chosen
• Transient simulation duration is higher compared to map-based simulation if maps are existent
• Transient simulation is very difficult to handle
• But transient simulation offers an enormous application range
• For future simulation needs transient simulation is an essential tool
Transient and Map-Based Driving Cycle Calculation with GT-SUITE

GT-User Conference
9th November 2009, Frankfurt Airport
Dipl.-Ing. Andreas Schmid, IVK University Stuttgart
Dr.-Ing. Michael Grill, FKFS
Dipl.-Ing. Hans-Jürgen Berner, FKFS
Prof. Dr.-Ing. Michael Bargende, FKFS