Modeling a powertrain in Simscape in a modular vehicle component model library

Stuttgart, 24.09.2015, MBtech, Jörn Bader

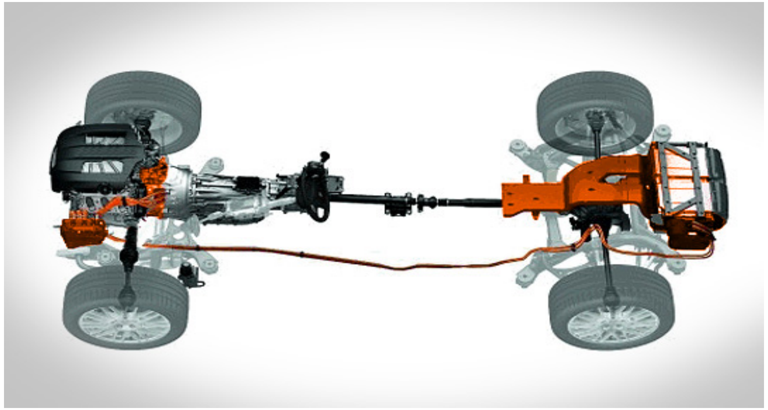
Contents

Introduction – initial situation

Driving performance and consumption simulation - Overview

Model structure and additional details

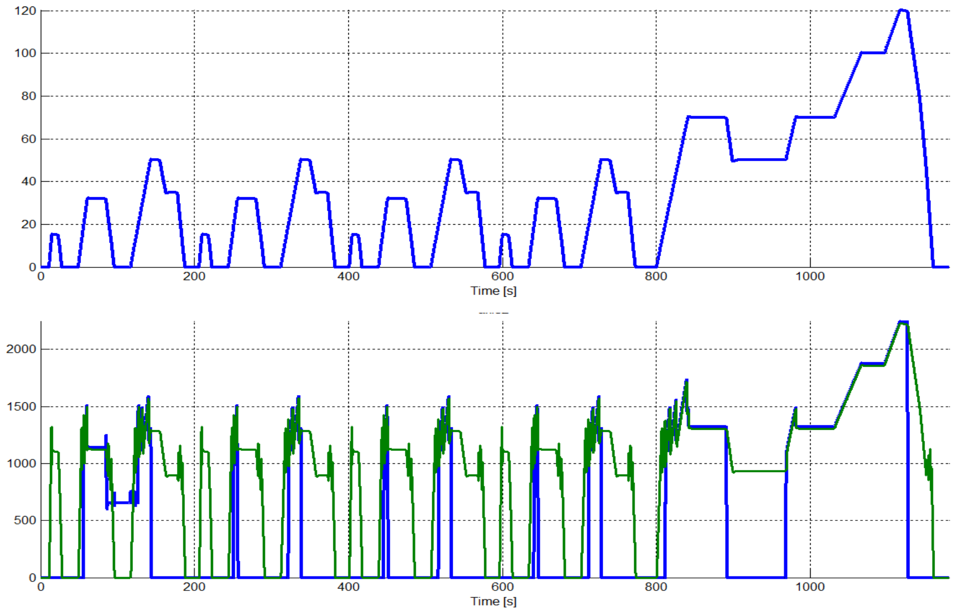
- **Model structure:**
  - Simulation of powertrain concepts
  - Focus on powertrain losses
  - No monitoring of powertrain vibrations
  - Longitudinal dynamics (one wheel)



- **Additional details:**
  - ~ 1000 Subsystems with ~ 1000 parameters
  - < 1 minute for a NEDC simulation
  - > 100 users in several departments with different requirements

Typical results

- Consumption values in l/100km
- Driving performance (e.g. acceleration 0 – 100 kph in seconds)
- Torque flow over time
- Rotation speed over time

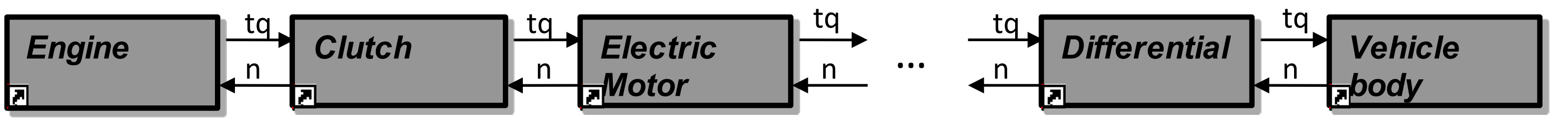


Introduction – initial situation

Initial powertrain in Simulink

Powertrain in Simulink – initial structure (schematic)

- Torque (tq) flow from Engine to Vehicle body
- Rotation speed (n) calculation from Vehicle body back to Engine
- Only one speed calculation in Vehicle body
- Static torque in powertrain
- Dynamic torque calculated at wheel

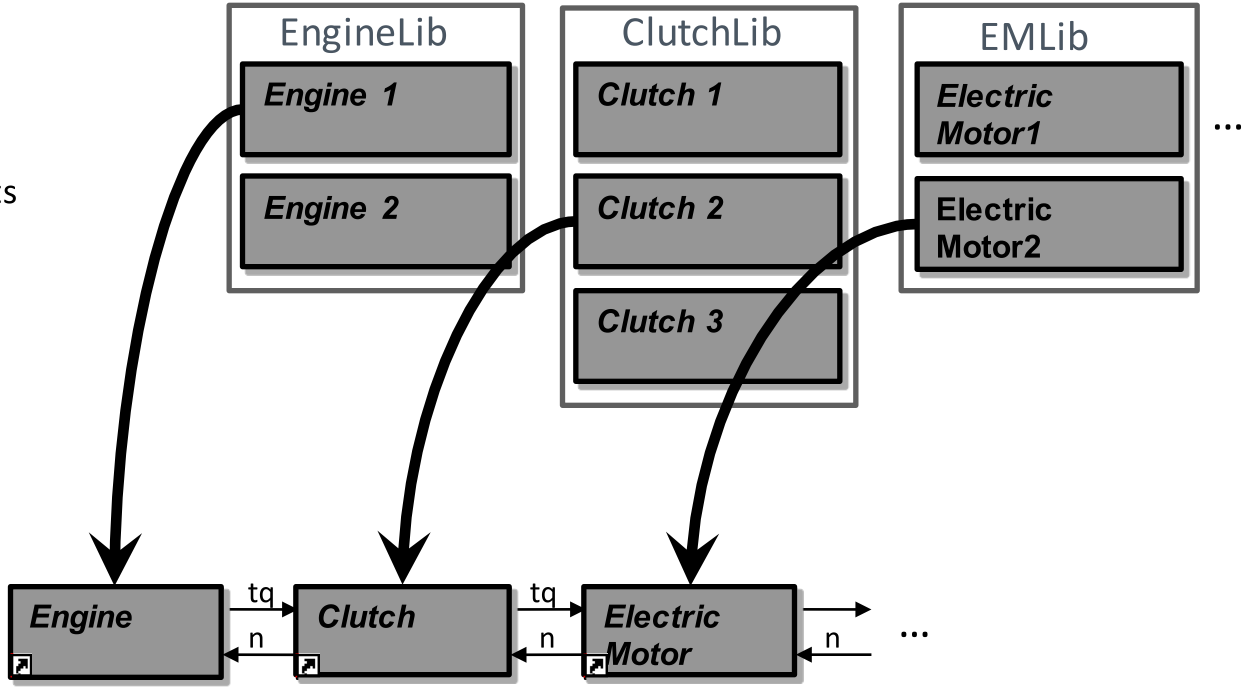


$$\dot{\omega} = tq \div J$$

$$n_{whl} = \int \dot{\omega}$$

Powertrain in Simulink – library structure

- Library structure
- Generic models
- Vehicle data for vehicle fleets
- Automatic configuration for each vehicle
  - Model changes
  - Parameter changes



Switch to a powertrain in Simscape

Motivation

Motivation for a switch to Simscape

General difficulties for models in Simulink

- Enhancements get a lot more complicated for complex models
- Modifications are hard to accomplish among several developers
- Difficult to understand for users
- Lots of adjustments for consistent signal names

Modeling benefits of Simscape

- Simple component interface
  - Less problems with signal names
  - Easier reuse of components
- Physically correct structured modeling
- Easier understanding for users

Motivation for a switch to Simscape

Numerical benefits of Simscape

- Calculation of dynamic torque throughout the whole powertrain
- Numerically more stable calculation of dynamic torque
  - One system of equations for physical model parts
  - Implicit solver
- Local iterations for physical model parts
- Backward calculation possible

Motivation for a switch to Simscape

Dynamic Torque – detailed view

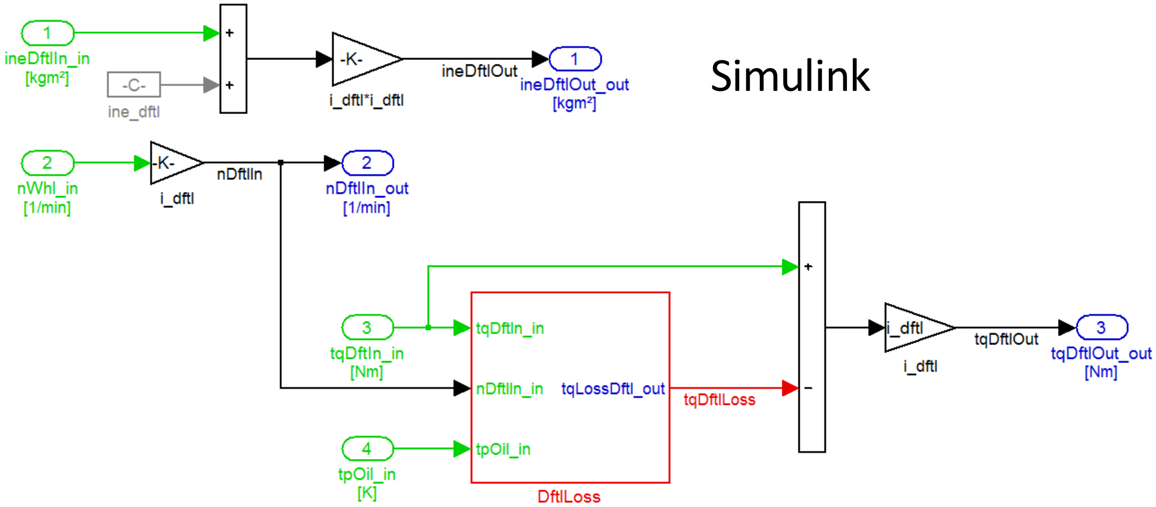
- **Simulink problems:**
  - Dynamic Torque calculated through $tq = J \cdot \dot{\omega} \;\Rightarrow\; n = \frac{30}{\pi} \int \dot{\omega}$
  - Calculation in every component requires at least 7 integrators
  - Calculation explicit / fixed step → high errors or small step size needed
- **Simscape:**
  - Implicit solver for stiff parts of the model
  - Local iterations to minimize simulation errors

→ More stable calculation of dynamic torque

Switch to a powertrain in Simscape

Short example

Transformation example – model of a differential



Simulink

Equations:

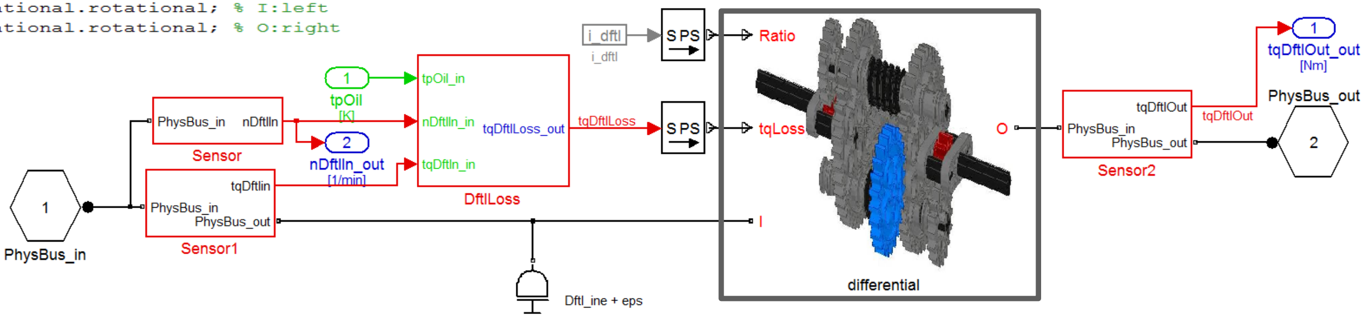
$$n_{DftlIn} = i_{Dftl} \cdot n_{Whl}$$

$$tq_{DftlOut} = (tq_{DftlIn} - tq_{DftlLoss}) \cdot i_{Dftl}$$

Transformation example – model of a differential

```
component differential

    inputs
        i = { 4, '1' }; % Ratio:left
        tqLoss = {0,'N*m'}; % tqLoss:left
    end

     nodes
         I = foundation.mechanical.rotational.rotational; % I:left
         O = foundation.mechanical.rotational.rotational; % O:right
     end

    parameters

    end

    variables
        t_in = { 0, 'N*m' };
        t_out = { 0, 'N*m' };
    end

    function setup
        through( t_in, I.t, [] );
        through( t_out, [], O.t );
        % Parameter range checking
        if i == 0
            pm_error('simscape:NotZero','Gear ratio')
        end
    end

    equations
        t_out == i * (t_in - tqLoss);
        I.w == i * O.w;
    end

end
```

Simscape




```
equations
    t_out == i * (t_in - tqLoss);
    I.w == i * O.w;
end
```

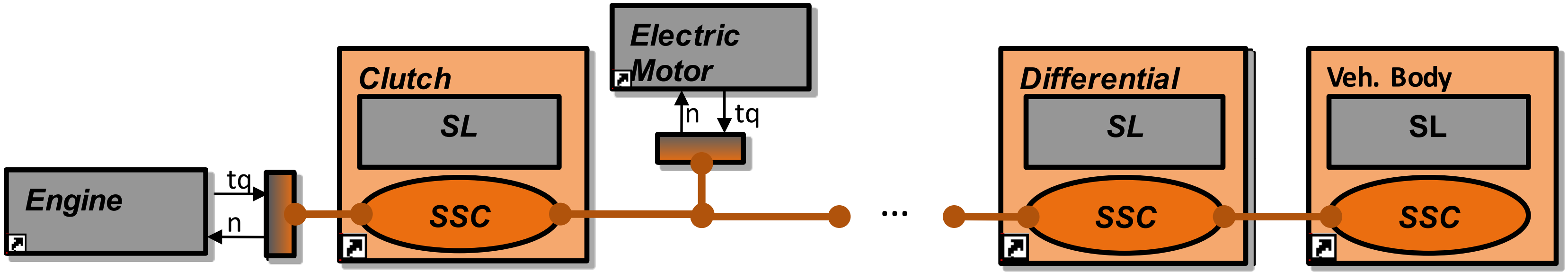

Equations

Results and Conclusion

Powertrain in Simscape

Powertrain in Simscape (schematic)

- Physical model parts in Simscape
- One physical network
- Engines as torque sources
- Torque losses calculated in Simulink
- Control parts in Simulink



Powertrain in Simscape – library structure

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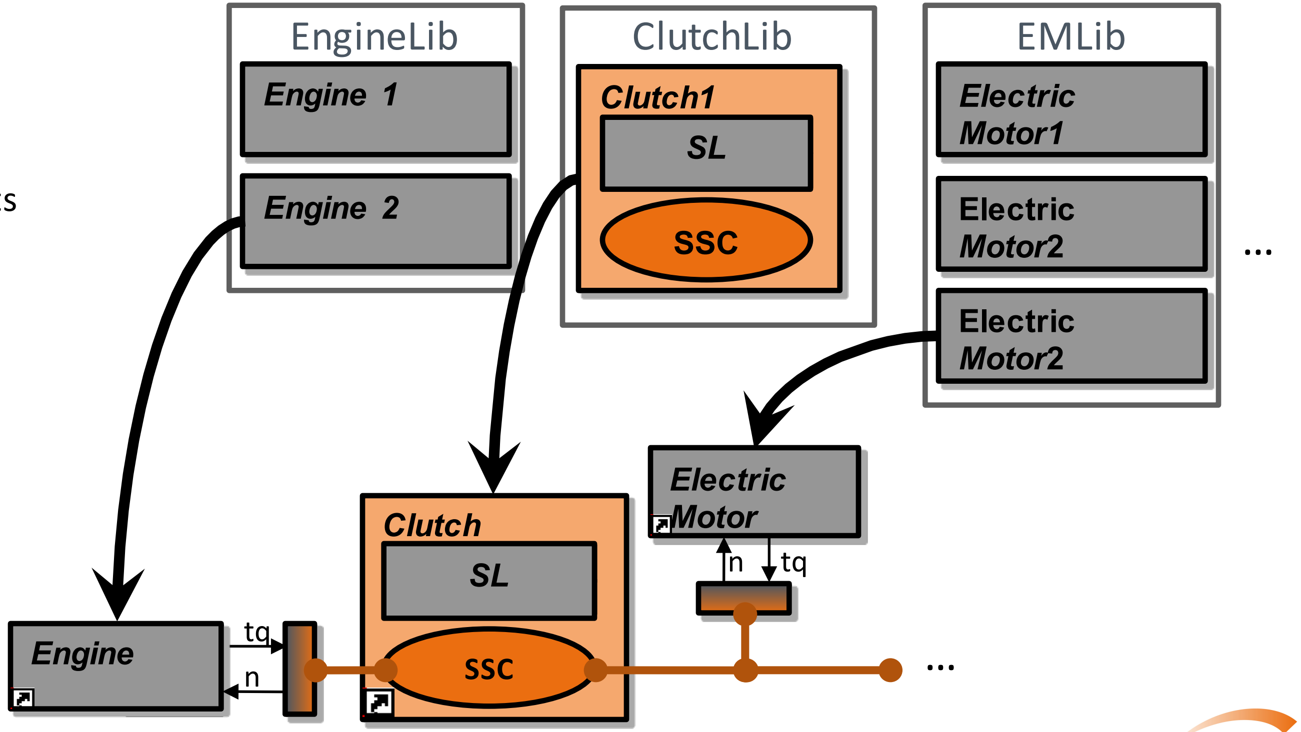


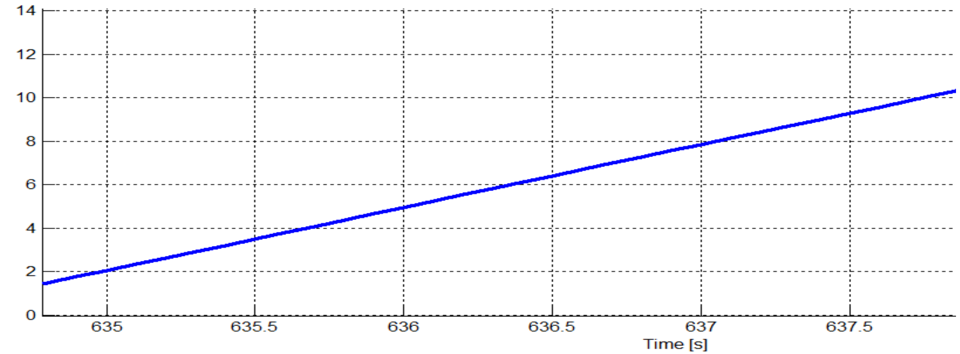
Results and Conclusion

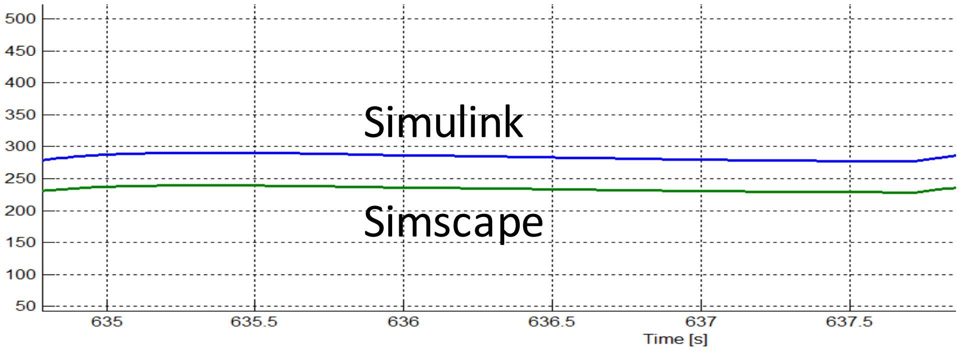
Simulation results and further work

Correct calculation of dynamic torque

- Vehicle acceleration
- Torque at gearbox output
- Total torque in Simscape

  including dynamic torque ✓





Results achieved with Simscape

Improved model structure and streamlined modeling process

- Physically more correct powertrain model ✓
- Simple component interface
  - Less problems with signal names ✓
  - Easier reuse of components ✓

Improved accuracy and numerical stability

- Calculation of dynamic torque throughout the whole powertrain ✓
- Numerically more stable calculation of dynamic torque ✓

Conclusion and further work

- Further redesign of the existing model library in Simscape
- Building of new models in Simscape
- Rollout of the Simscape library for all active users
- Backward calculations in Simscape

Thank you