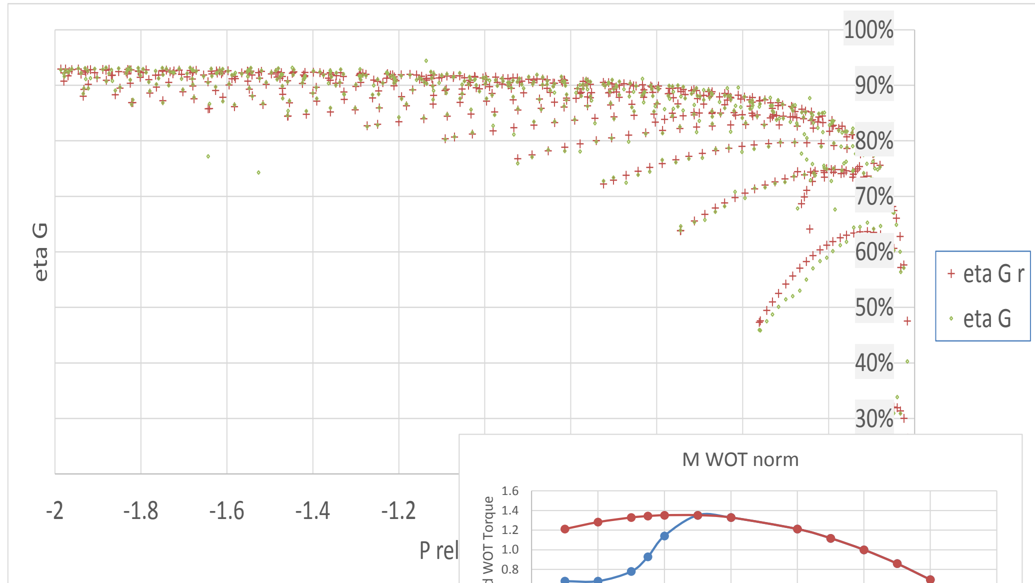
ICE Driving Simulation

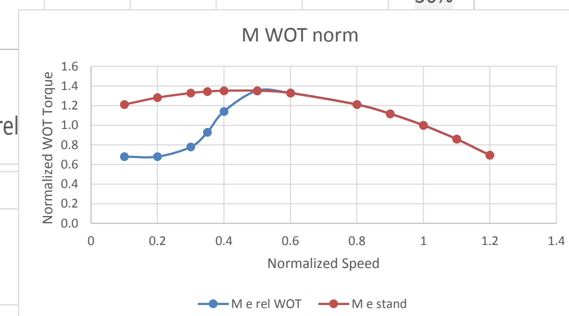
Description

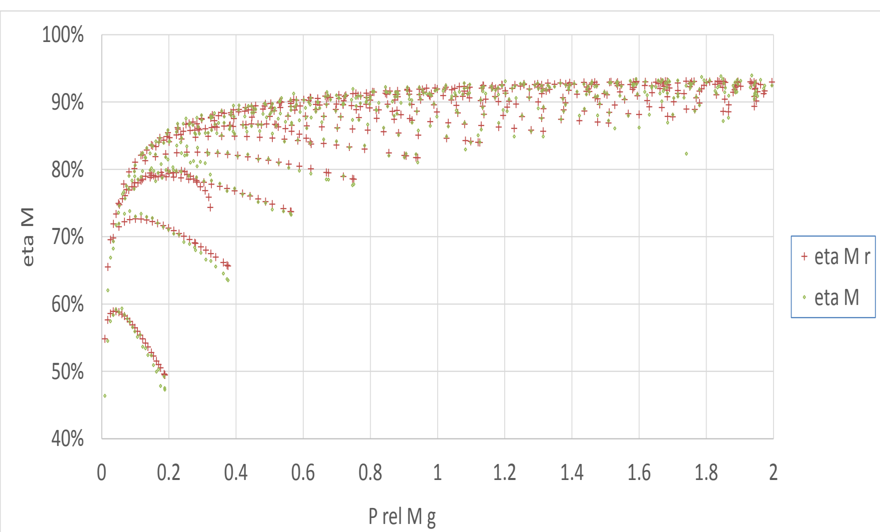
The code is focused on simulation of vehicle longitudinal dynamics for the route defined by sections including velocity, weather, adhesion and traffic constraints. The route is prepared before the trip starts. The code can be used for re-optimizing it according to up-dated situation during a trip. The engine map is substituted by regression model of ICE efficiency and torque WOT curve with accuracy of 2%. Powertrain is defined by transmission ratios and mechanical efficiency. All driving resistances are involved. Load can be changed between route sections. Constraints of available power or torque, speed limit use, braking deceleration and use of adhesion limit including gears used for different sections are subjected to optimization, done by external code and using genetic algorithm.

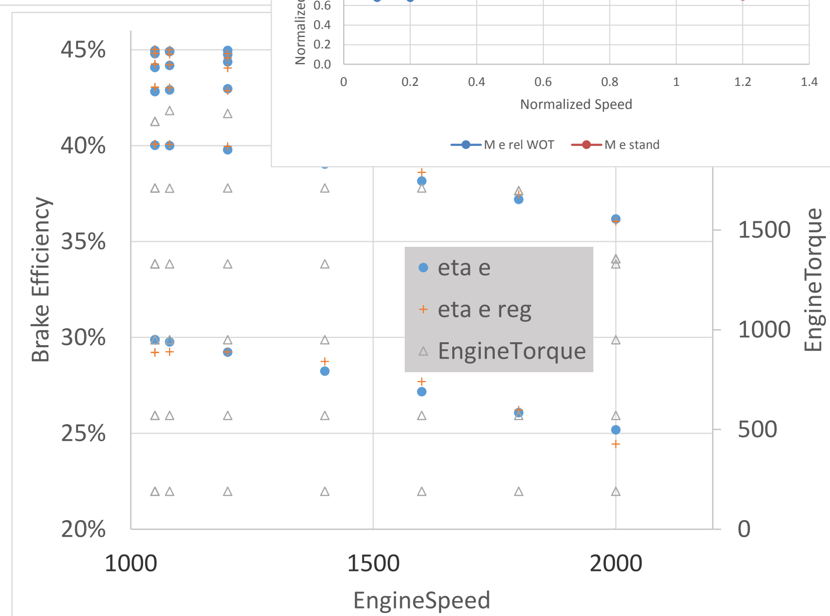
ICE Driving Simulation

- Simulation with an ICE – up to now WLTC
- Single general regression formula for both electric machines and ICE – prepared for hybrid use
- WOT for ICE prepared for correction of power limit used in optimization in dependence on ICE speed









Inputs

- **In-house Vehicle Model (for optimization)**
- Engine - quasi steady estimates as a first approximation, simple dynamic estimates of turbo-lag may follow if more data are available
  - **bsfc map (torque-speed dependence) including WOT torque curve,**
  - **engine moment of inertia including cranktrain (masses and moments of inertia of cranktrain components),**
  - engine cooling system details –
- thermal flux map without intercooling
- estimates of engine block&cylinder head and radiator mass and material data,
- engine cooling liquid contents (thermal capacity) in different parts of system (block&head, pipes, radiator)
  - Should WHR be modelled
- exhaust gas temperature map downstream of a TC turbine,
- exhaust gas mass flow rate map
- WHR thermal efficiency map (dependence on input temperature),
- estimated thermal inertia of WHR circuits.
  - Should pollutants potential be assessed, pollutant emission maps as a first approximation.

Inputs

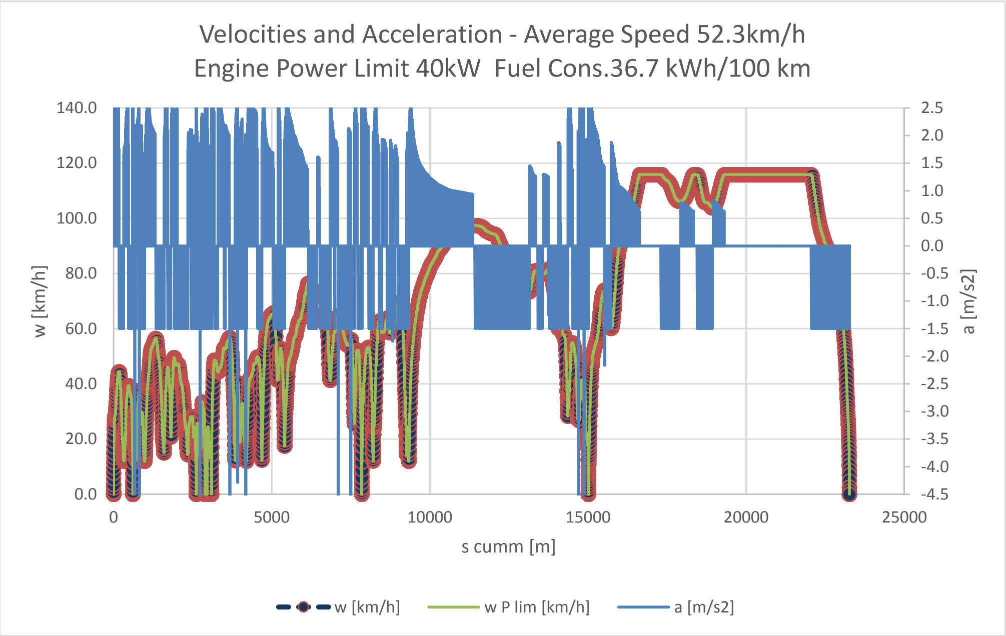
- Powertrain
  - **gear ratios of a gearbox** or shifting schedule**,**
  - **other transmission ratios, wheel diameter, rated speeds**
  - **reduced moment of inertia or moments of inertia of parts and their speed**
  - **battery capacity - upper and lower SOC,**
  - **motor/generator efficiency – speed - torque map,**
  - motor/generator and cooling circuit heat transfer surfaces and heat transfer coefficients, thermal capacities, motor temperature upper limit
  - other hybrid system data – e.g., for pressurized gas,
  - mechanical efficiency of powertrain (estimates),
  - brake force capacity.

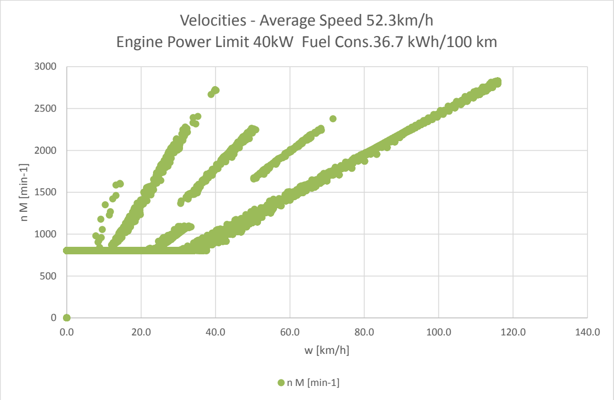
Inputs

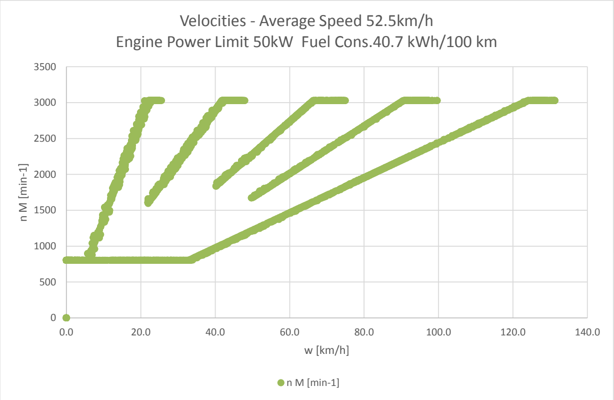
- vehicle
  - **reduced mass and moment of inertia of rotating components not included into powertrain,**
  - **rolling resistance,**
  - **air drag,**
  - **typical cargo loads (in details they are fixed during a trip),**
  - mass, surface and window surface of a cabin and cargo space – if relevant
  - thermal conductivity and thermal capacities of a cabin and cargo space – if relevant
  - HVAC upper power and efficiency and thermal capacities of a HVAC system
  - temperature range in cabin
  - temperature range in cargo space including cargo thermal conditioning requirements

Examples of WLTC Optimization

- Simulation with an ICE (up to now WLTC)
- **Example for limited torque (higher energy comsumption) or optimum ICE efficiency**
- Shifting strategy – either gear (up to 16 gears) found from vehicle speed ranges (and gear ratio increased if torque demand too high) or optimum transmission ratio found from ICE efficiency

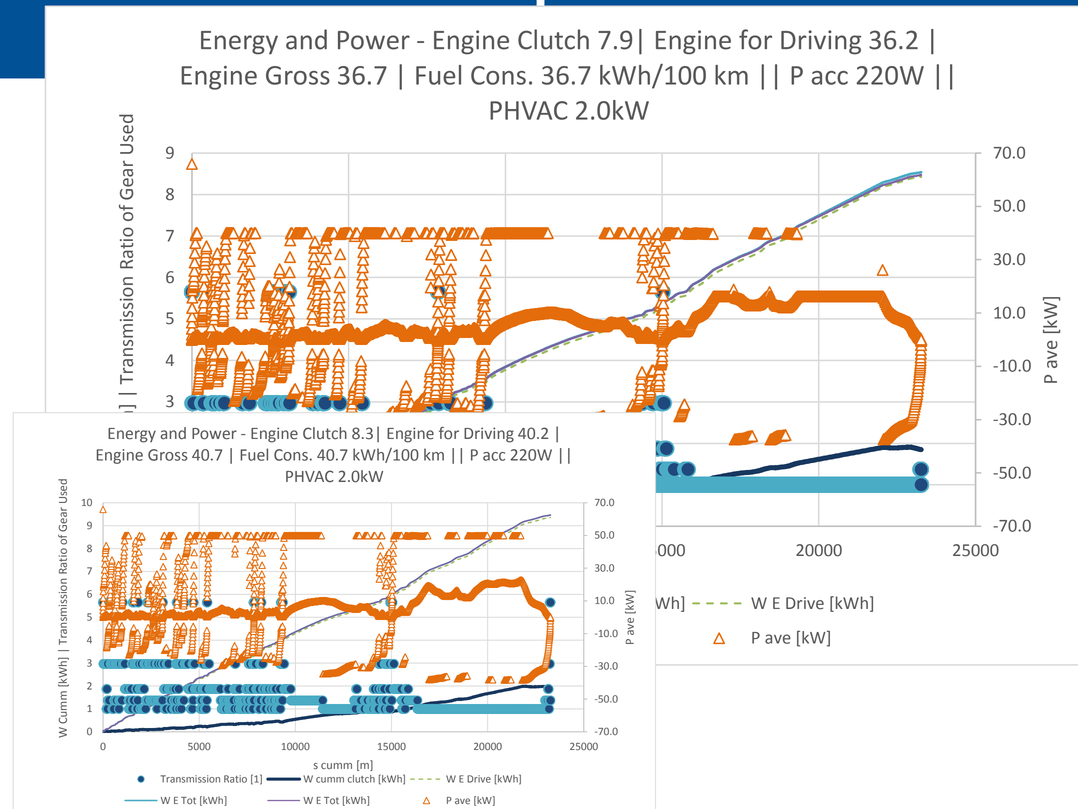


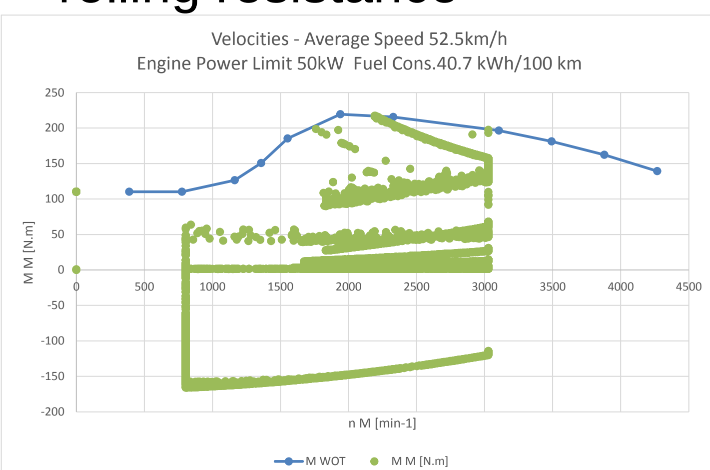


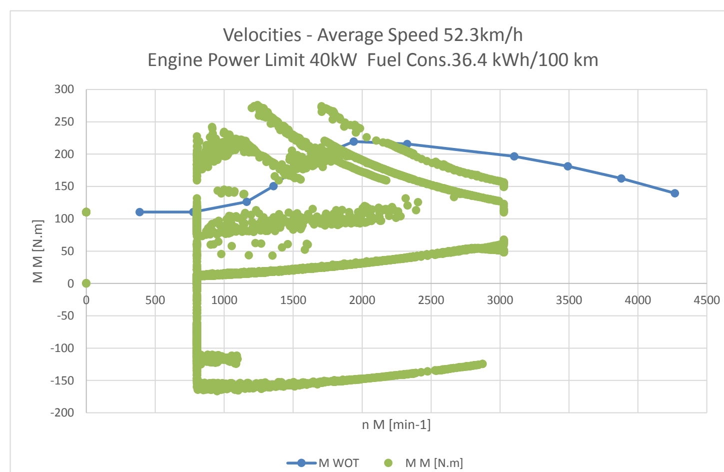


Examples of WLTC Optimization

- Simulation with an ICE (WLTC)
- **Example for optimum efficiency**
- Extra torque at low speed covered by hybrid electric motor – extreme optimum case – and limited torque
- 10 kWh = 1 dm^3 of diesel oil
- PC with extremely low rolling resistance

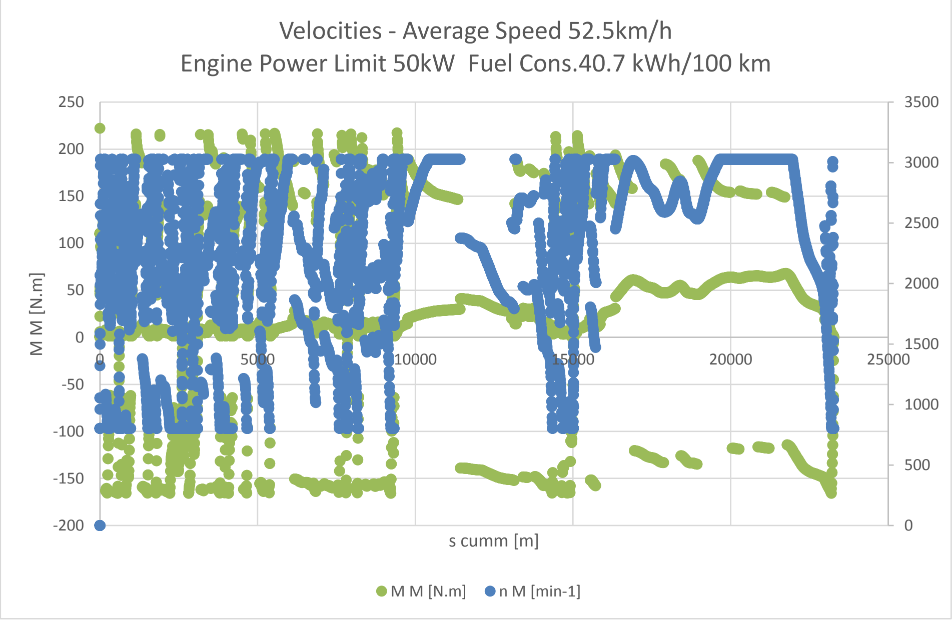


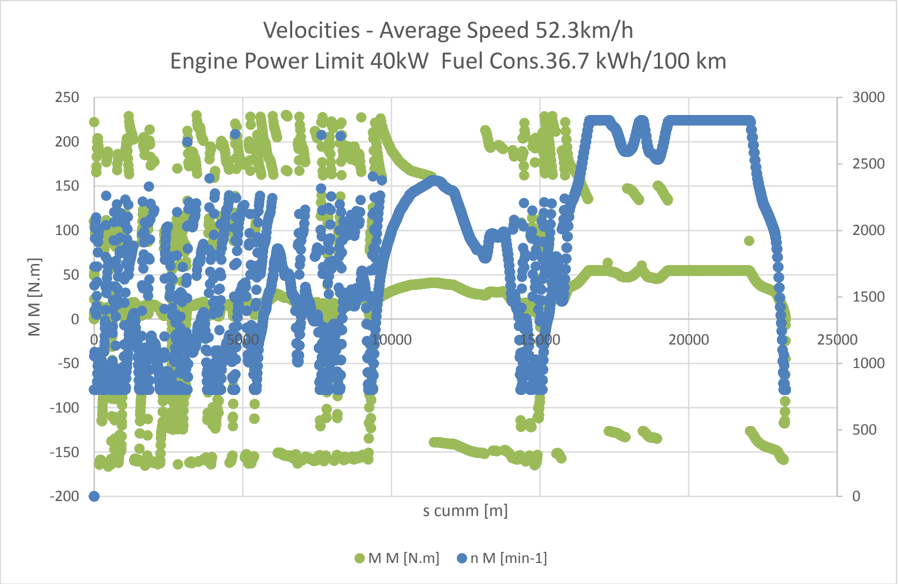


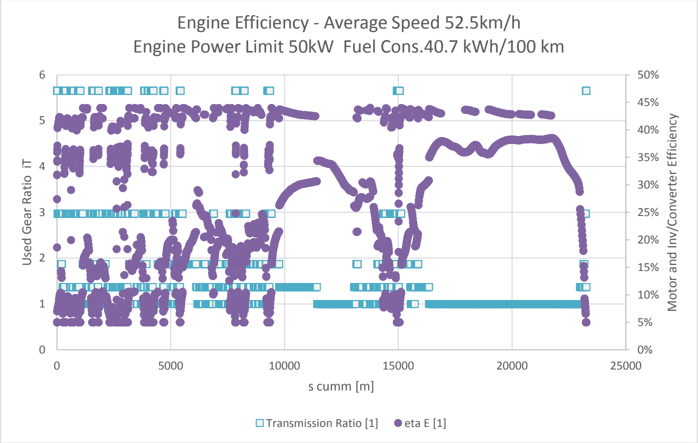


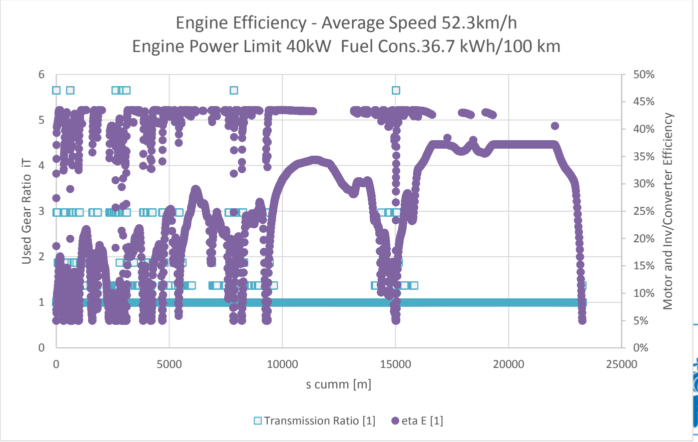
Examples of WLTC Optimization

- Simulation with an ICE (WLTC)









Local Optimum Vehicle Speed

Route fuel consumption [dm^3/100 km] for steady speed can be found using engine brake efficiency representation (function of vehicle speed only) and optimum transmission ratio from a set of ratios of a gearbox.

Formulas deduced and programmed

$$E_{road} = \frac{F_e w}{\eta_e} \frac{s}{w} \frac{1}{s} = \frac{K_1 + K_2 w^2}{\eta_e} = \frac{K_1 + K_2'' \omega_{rel}^2}{\eta_e} =$$

$$= \left(K_1 + K_2'' \omega_{rel}^2\right) \cdot \left\{ 1 + \left[\begin{array}{l} A_O + A_5 \left(K_1' \omega_{rel} + K_2' \omega_{rel}^3\right)^{z_1} + \\ + A_1 \left(K_1' + K_2' \omega_{rel}^2\right)^{y_1} + A_2 \left(K_1' + K_2' \omega_{rel}^2\right)^{y} + \\ + A_3 \left(\omega_{rel}\right)^{x_1} + A_4 \left(\omega_{rel}\right)^{x} + A_6 \left(K_1' \omega_{rel} + K_2' \omega_{rel}^3\right)^{z} \end{array} \right] \frac{\omega_{rel}^{x_g}}{K_1' \omega_{rel} + K_2' \omega_{rel}^3} \right\}$$

Locally steady optimum speed for a section with constant slope and rolling resistance is being found from a derivative of algebraic formulas (solving condition for minimum fuel consumption numerically)

$$y = 2K_2''\omega_{rel}\left(1 + \frac{J\omega_{rel}^{x_g}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3}\right) + \left(K_1 + K_2''\omega_{rel}^2\right)\frac{x_g\omega_{rel}^{x_g-1}J + \omega_{rel}^{x_g}\frac{dJ}{d\omega_{rel}}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3} + $$
$$- \frac{\left(K_1 + K_2''\omega_{rel}^2\right)J\omega_{rel}^{x_g}}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2}\left(K_1' + 3K_2'\omega_{rel}^2\right)$$

$$\frac{dy}{d\omega_{rel}} = 2K_2''\left(1 + \frac{J\omega_{rel}^{x_g}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3}\right) + 2K_2''\omega_{rel}\frac{x_g J\omega_{rel}^{x_g-1} + \omega_{rel}^{x_g}\frac{dJ}{d\omega_{rel}}}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)} - 2K_2''\omega_{rel}\frac{J\omega_{rel}^{x_g}\left(K_1' + 3K_2'\omega_{rel}^2\right)}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2} +$$
$$+ 2K_2''\omega_{rel}\frac{x_g\omega_{rel}^{x_g-1}J + \omega_{rel}^{x_g}\frac{dJ}{d\omega_{rel}}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3} + \left(K_1 + K_2''\omega_{rel}^2\right)\frac{x_g\left(x_g - 1\right)\omega_{rel}^{x_g-2}J + x_g\omega_{rel}^{x_g-1}\frac{dJ}{d\omega_{rel}}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3} +$$
$$+ \left(K_1 + K_2''\omega_{rel}^2\right)\frac{x_g\omega_{rel}^{x_g-1}\frac{dJ}{d\omega_{rel}} + \omega_{rel}^{x_g}\frac{d^2J}{d\omega_{rel}^2}}{K_1'\omega_{rel} + K_2'\omega_{rel}^3} - \frac{\left(K_1 + K_2''\omega_{rel}^2\right)\left(x_g\omega_{rel}^{x_g-1}J + \omega_{rel}^{x_g}\frac{dJ}{d\omega_{rel}}\right)}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2}\left(K_1' + 3K_2'\omega_{rel}^2\right) +$$
$$- \frac{d}{d\omega_{rel}}\left[\frac{\left(K_1 + K_2''\omega_{rel}^2\right)J\omega_{rel}^{x_g}}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2}\left(K_1' + 3K_2'\omega_{rel}^2\right)\right]$$

$$\omega_{rel\,i+1} = \omega_{rel\,i} - \frac{y\left(\omega_{rel\,i}\right)}{\left(\frac{dy}{d\omega_{rel}}\right)_{\omega_{rel} = \omega_{rel\,i}}}$$

$$\frac{d}{d\omega_{rel}}\left[\frac{\left(K_1 + K_2''\omega_{rel}^2\right)\left(K_1' + 3K_2'\omega_{rel}^2\right)J\omega_{rel}^{x_g}}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2}\right] = \frac{2K_2''\left(K_1' + 3K_2'\omega_{rel}^2\right)J\omega_{rel}^{x_g+1} + 6K_2'\left(K_1 + K_2''\omega_{rel}^2\right)J\omega_{rel}^{x_g+1}}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2} +$$
$$+ \frac{\left(K_1 + K_2''\omega_{rel}^2\right)\left(K_1' + 3K_2'\omega_{rel}^2\right)\left(x_g\omega_{rel}^{x_g-1}J + \omega_{rel}^{x_g}\frac{dJ}{d\omega_{rel}}\right)}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^2} +$$
$$- 2\frac{\left(K_1 + K_2''\omega_{rel}^2\right)\left(K_1' + 3K_2'\omega_{rel}^2\right)^2 J\omega_{rel}^{x_g}\left(K_1' + 3K_2'\omega_{rel}^2\right)}{\left(K_1'\omega_{rel} + K_2'\omega_{rel}^3\right)^3}$$