January 2018

PRESENTATION OF

OICA

INTERNATIONAL ORGANIZATION OF MOTOR VEHICLE MANUFACTURERS

Additional Sound Emission Provisions

Revision 2.0

ASEP Assessment based on a Prediction Model

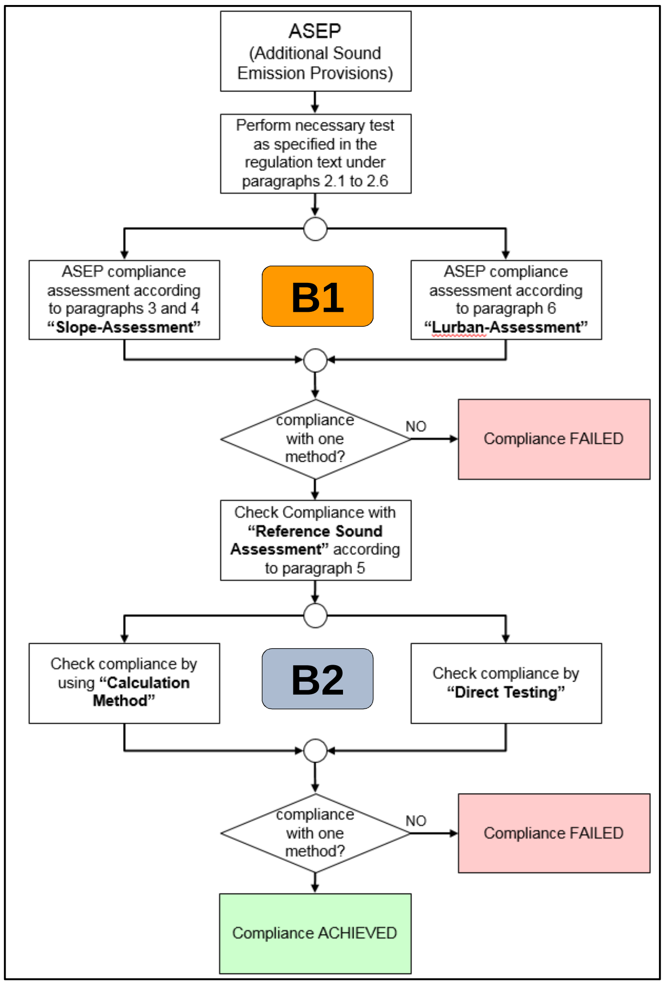
ASEP Revision 2.0 - Expectations

Contracting Parties	Automotive Industry

➢ Improve efficiency of ASEP
➢ ASEP shall become mandatory during Type Approval
➢ Broaden the boundary conditions
➢ Check need for
    ➢ Defeat device provisions
    ➢ Not to Exceed Concepts (NTE)
	➢ Simplify ASEP
	➢ Reduce work load
	➢ Safe qualification about ASEP compliance, especially with “normal” products
	➢ ASEP shall follow physics

- It is a challenge find a test concept, that is capable to integrate all these aspects.
- Some aspects need a careful discussion (defeat devices, NTE)

Actual ASEP Concept



ASEP Flowchart, UN R51.03 Supplement 2

- The actual ASEP concepts consists of several modules.
- For compliance, the manufacturer can select from each block (**B1** and **B2**) one way of compliance.
- Testing in Block **B1** is very time consuming.
- The requirements of Block **B2** are design restrictive especially for products that are designed to meet ultimate emission standards.
- The manufacturer is not obliged to carry out these tests, but will have to provide a statement of compliance.
- This makes ASEP non-transparent.

Test Burden of UN R51.03

Estimated Work Load for Testing Annex 3 and Annex 7

	Annex 3		Annex 7 (Today)		Annex 7 (Extended ASEP)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Gears	1	2	1	3	5	10
Modes	1	1	1	**10**	1	**10**
Test Points	1	1	4	4	4	**6**
Conditions	2	2	1	1	1	**4**
Repetition	4	4	1	1	1	1
Total Runs	**8**	**16**	**4**	**120**	**20**	**2400**

- The necessary time per test run varies very much with the test track length an geometry.
- A run requires 2 minutes at minimum, not including validity checks.
- Annex 3 tests are typically performed within 30 min, while today’s ASEP tests require easily up to 2 hours. The driving distance can be more than 10 km.
- An extended ASEP with a broadened control range at any gear and mode can end in more than a day testing at more than a 100 km/h. This is unrealistic for CoP tests.

ASEP Concept Based on a Physical Expectation Model

- A compromise between an extended test area and a reduced test burden is feasible, when tests are selected randomly and when after each individual test run a direct compliance assessment is available.
- Already existing elements of the today's ASEP assessment are integrated into a new approach:

Physical Behavior
(Origin: „Slope Method“)

Direct Assessment
(Origin: „L_{urban} Method“)

Based on Annex 3 Results
(Origin: „Slope & L_{urban} Method“)

Engine Speed Based
(Origin: „Slope Method“)

Direct assessment based on a physical expectation model, referenced to the type approval result of Annex 3

To be Solved: How to treat BEV, HEV

Sound Prediction Model - Basic Considerations

1 Tyre

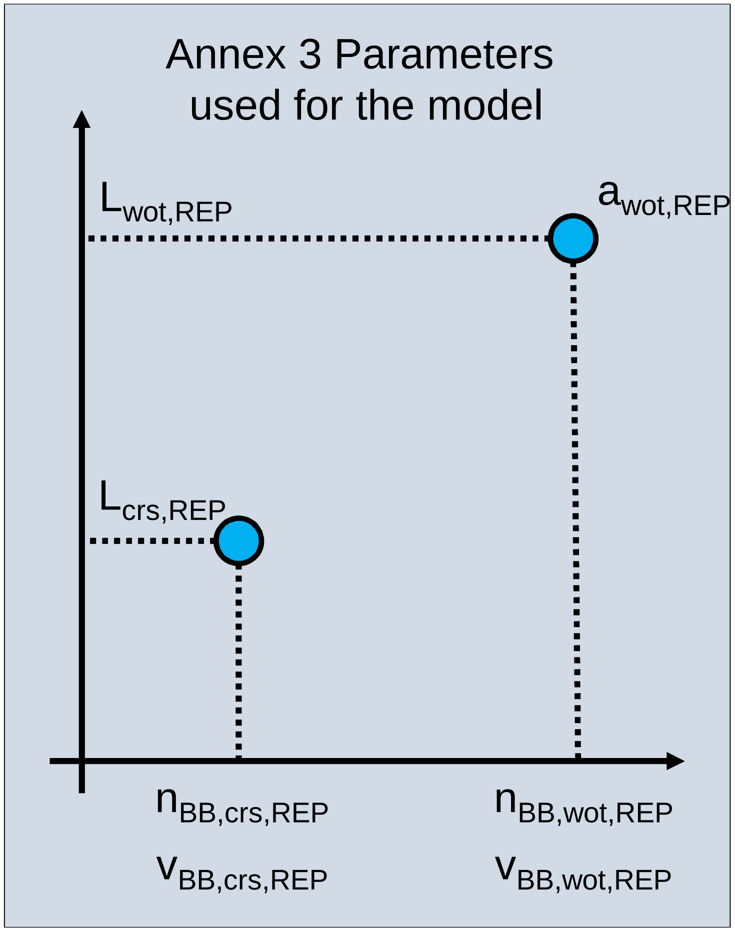
2 Base Mechanic

- The two elements together create the “physical” base model for a behavior of any internal combustion engine vehicle.
- These two models will form the minimum sound emission of a vehicle.
- This sound emission is given by physics an qualified / justified by the type approval test according to Annex 3 and controlled by the limit values.

3 Dynamic

- The dynamic model covers all sound behavior, that is linked to acceleration (load) conditions
- It covers tyre torque effects, powertrain dynamics and gas flow dynamics.

Model Construction



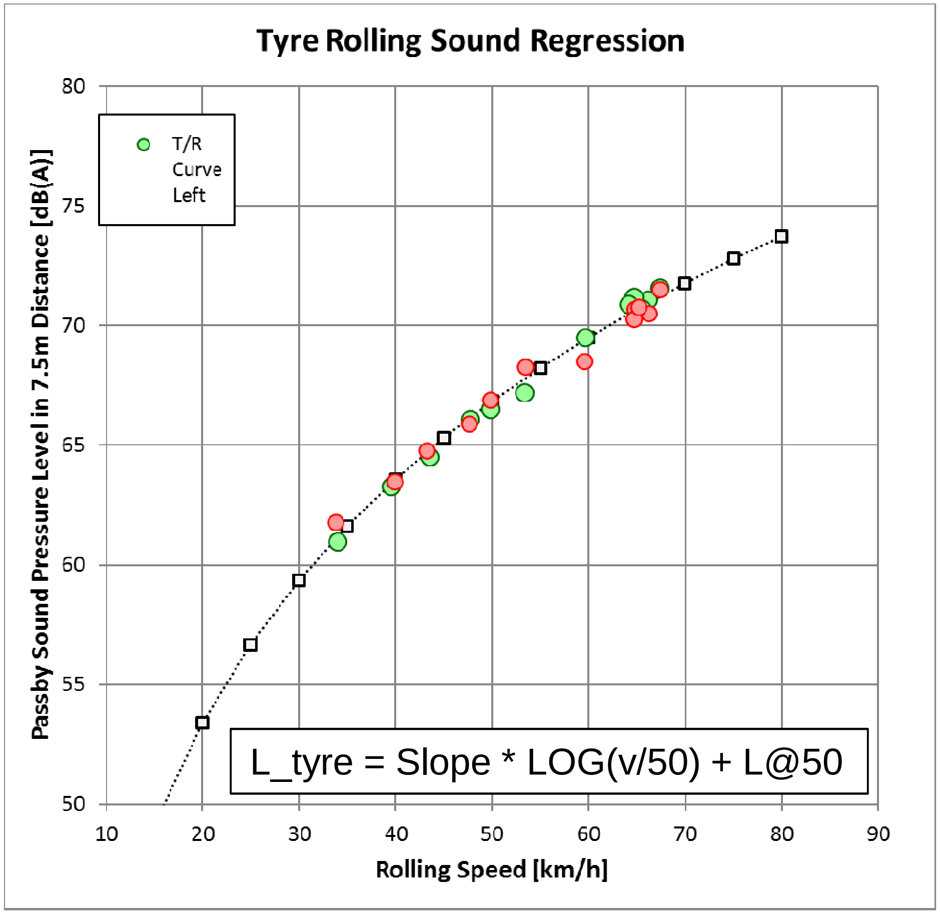
The index REP or R indicates the lower reported gear during type approval according to Annex 3

	1 Tyre	2 Mechanic	3 Dynamic
Acceleration	$L_{TR}(v_{BB,wot,R})$	$L_{PT}(n_{BB,wot,R})$	$L_{DYN} = L_{DYN,NL}(n_{BB,wot,R}) + \Delta L_{DYN}$
Cruise	$L_{TR}(v_{BB,crs,R})$	$L_{PT}(n_{BB,crs,R})$	$L_{DYN,NL} = L_{PT}(n_{BB,crs,R}) - \Delta L$
	one model	**one** model	**two** models

➢ The following slides will guide you through the model details

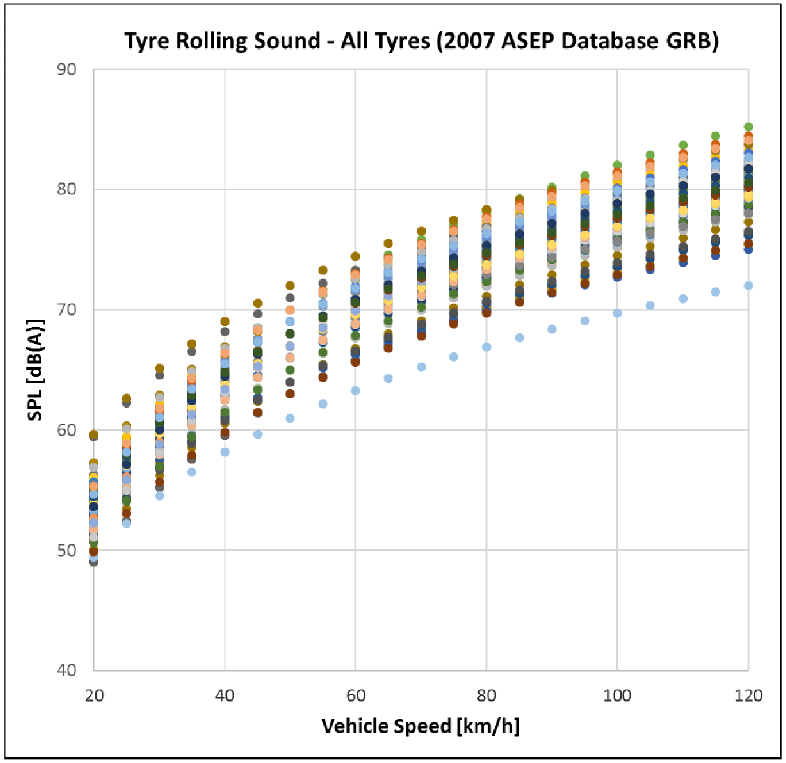
1 Tyre Rolling Sound Modelling

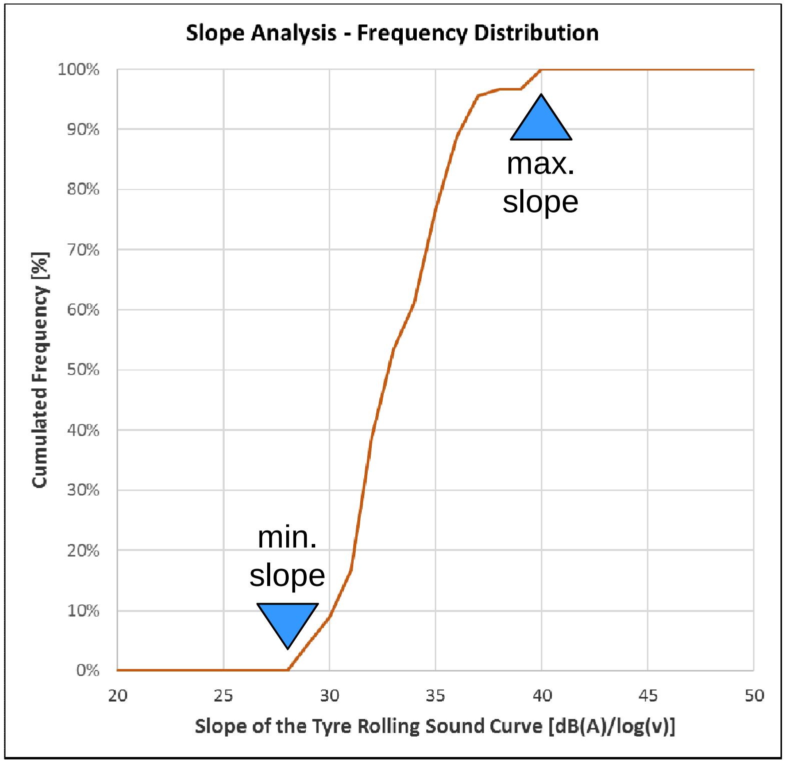
1 Tyre Rolling Sound - Modelling



- Tyre rolling sound can be described with good accuracy by a logarithmic regression.
- Tyres may as well have smaller resonances, by the typical deviation from the regression is rather small.
- Typical regression qualities are $R^2 > 0.98$

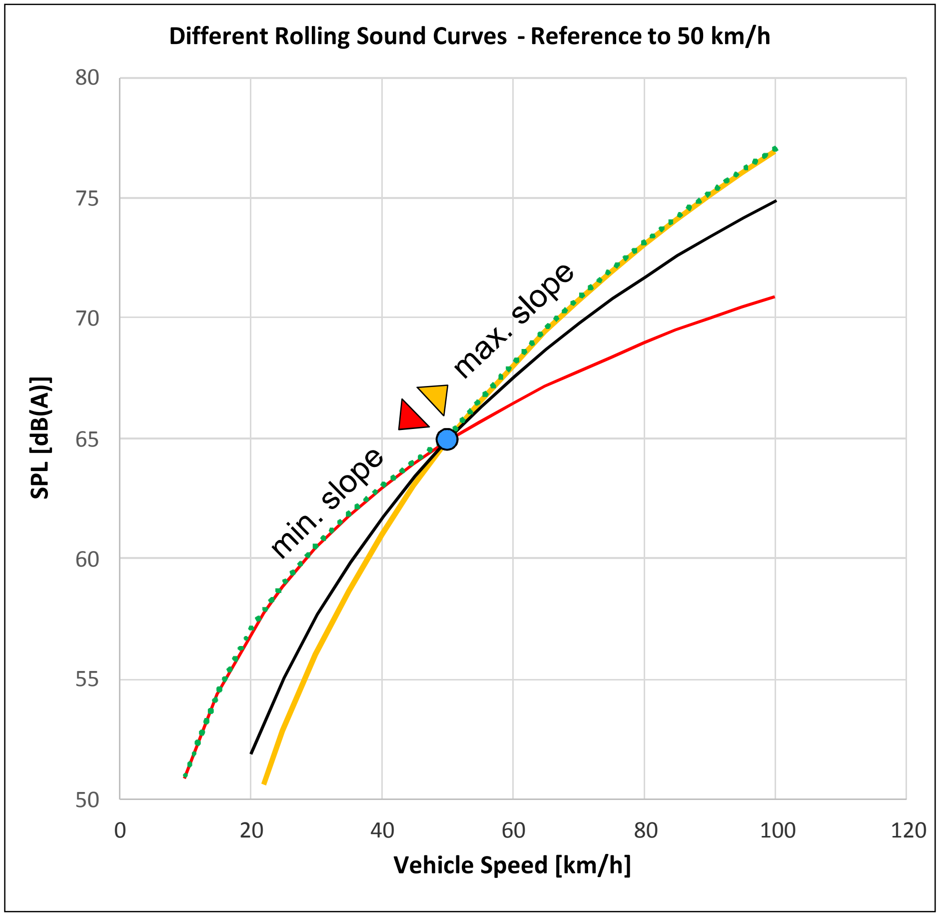
1 Tyre Rolling Sound





- A vehicle OEM can only select tyres with an approval according UN R117.
- Thus, any sound behavior of the tyre versus vehicle speed is acceptable.
- The model will acknowledge two different slopes

1 Tyre Rolling Sound



- Any tyre has only **one** slope (sound variation with speed).
- If, for example, a particular tyre has a high slope,
  - it will become proportionally louder at higher vehicle speeds, but
  - will as well become proportionally quieter at lower vehicle speeds

1 The "Prediction Model" for the Tyre Rolling Sound

- The mathematical function is:

$$L_{TR,NL} = slope_{TR} * LOG_{10}(v_{test} / 50) + L_{REF,TR}$$

There will be a **$slope_{TR,min}$** for test speeds below 50 km/h and a **$slope_{TR,max}$** for speeds above 50 km/h.

The differentiation accounts for the unknown behaviour of the tyre rolling sound.

The **$L_{REF,TR}$** is a fraction of the steady speed test result of Annex 3 **$L_{CRS,i}$**.

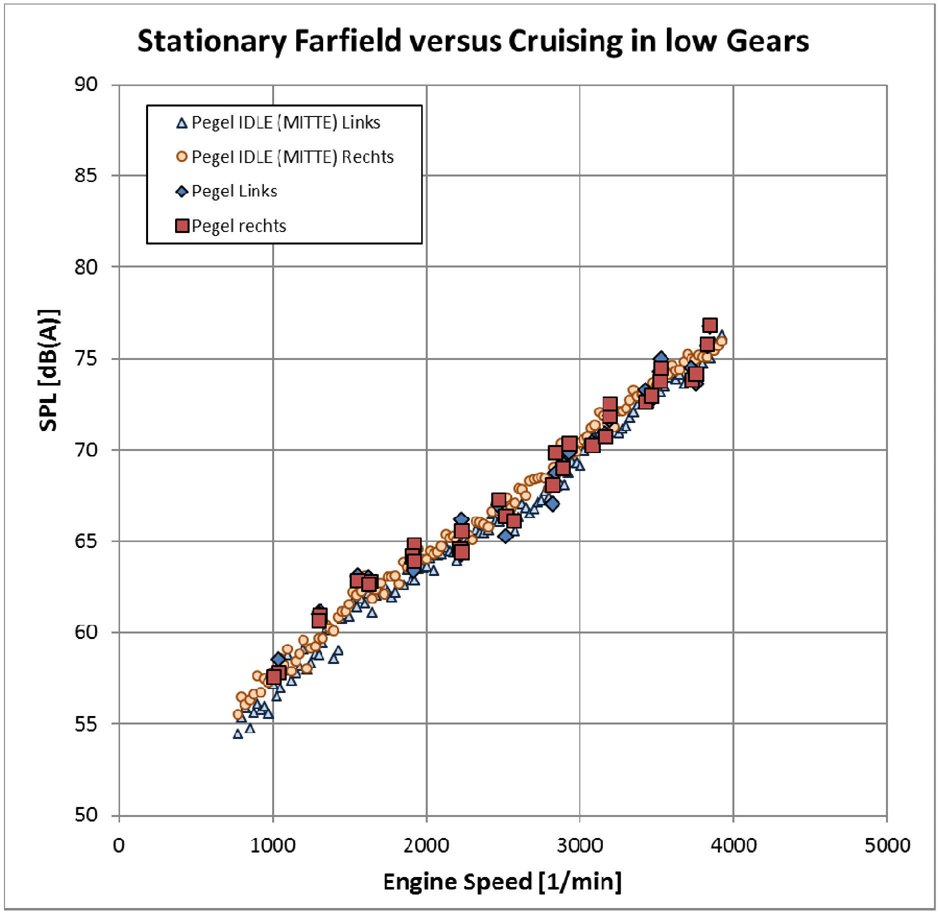
$$L_{REF,TR} = 10 * LOG_{10}(x\% * 10^{(L_{crs,i}/10)})$$

How much percent (**x%**) of the steady speed result is used, needs further investigation and might be defined differently for the vehicle categories.

The tyre rolling sound's load dependency is covered under the dynamic model 3 .

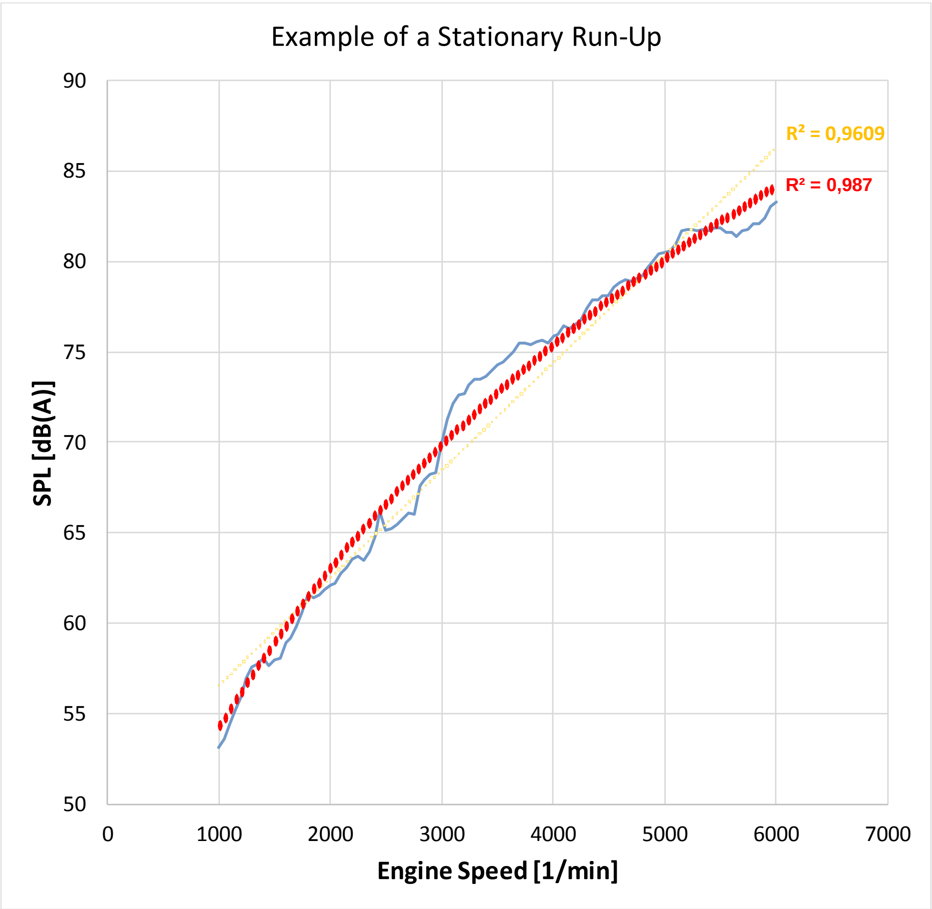
2 Power Train Base Sound Modelling

2 Base Mechanic - Modelling



- For determination of the power train base mechanic, there are two possibilities:
  - stationary run-up in far field
  - cruise-by measurements at low gears, e.g. 1st gear
- It is important to eliminate the influence of the tyre rolling sound and to suppress any gas flow dynamics.
- Both methods provide almost the same result and can be used to elaborate the powertrain base mechanic model.

2 The Base Mechanic Model for the Power Train



- The power train sound behavior over engine speed is neither a linear nor a logarithmic model.
- The best way to describe the behavior is a shifted logarithm.
- model is described as a logarithmic function, over engine speed.
- However, the power train does not follow
- The sound level from the stationary run-up are not important. The model is later linked to the type approval data from UN R51.03 Annex 3.
- The important information is the slope characteristic over engine speed.

2 The "Prediction Model" for the Power Train (No Load)

- The mathematical function is:

$$L_{PT,NL} = slope_{PT,NL} * LOG_{10}(\, n_{test} + n_{shift}) / (n_{wot,ref} + n_{shift})) + L_{REF,NL}$$

A **$slope_{PT,min}$** for test engine speeds below $n_{BB',REF}$ and a **$slope_{PT,max}$** for speeds above $n_{BB',REF}$ is introduced.

The differentiation accounts for the unknown behaviour of the power train.

An engine speed shift component **n_{shift}** is introduced for an optimized curve fitting for the power train model

The parameter **$L_{REF,NL}$** is the remaining part of the steady speed test of Annex 3 **$L_{CRS,i}$** that was not used in the tyre model before.

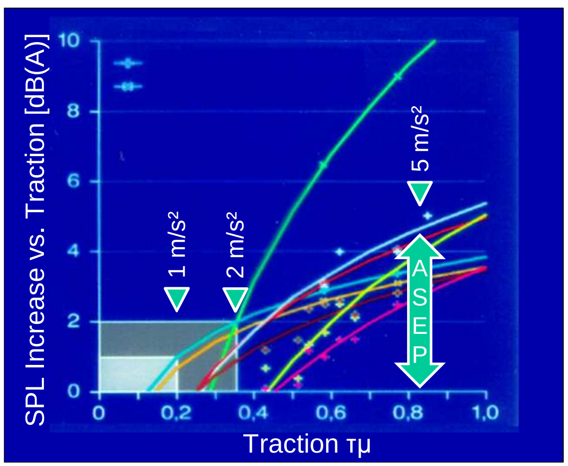
$$L_{REF,NL} = 10*LOG((100\%-X\%)*10^{(L_{CRS,i}/10)})$$

The power train base mechanic's load dependency is covered under the dynamic model 3 .

3 Power Train Dynamic Modelling

3 The Dynamic Model

- The dynamic model covers all energy generated under load, respectively acceleration:
  a) All gas flow components (intake and exhaust), no load and load
  b) Change of the power train mechanic sound with the load
  c) Tyre torque effects
- The load response from the power train and the torque effect are relatively small compared to the gas flow components from intake and exhaust.



Tyre Rolling Sound Level Increase
under Acceleration
Example on Various Tyres

3 The Dynamic Model

- The dynamic model consists engine speed dependent model, a no load basis and a dynamic that is dependent on the load.

  a) A “no load” basis $\mathbf{L_{DYN,NL}}$

  There must be a basis for the dynamic model, otherwise the dynamic would be undefined. One could chose the base mechanic model for simplicity, but practical experience suggests a separate approach with a different “slope over the engine speed, as the mechanical energy increases more over engine speed compared to the gas flow dynamics.

  a) A transient behavior between “no load” and “maximum load” $\mathbf{\Delta L_{DYN}}$

- The dynamic model is always subject to greater uncertainties, as the dynamic behavior depends on several factors that are difficult to control
  - The gas flow temperature
  - The dynamic is not constant over engine speed, but for simplicity of the model a uniform $\mathbf{\Delta L_{DYN}}$ was choosen.

3 The Dynamic Model

- The mathematical function is:

$$L_{DYN} = slope_{DYN,NL} * LOG_{10}(n_{test} + n_{shift})/(n_{wot,ref} + n_{shift})) + L_{REF,DYN,NL} + \Delta L_{DYN}$$

A **$slope_{DYN,min}$** for test engine speeds below **$n_{BB',REF}$** and a **$slope_{DYN,max}$** for speeds above **$n_{BB',REF}$** is introduced.

The differentiation accounts for the unknown behaviour of the power train.

$$n_{BB',REF} = n_{BB',WOT,i}$$

An engine speed shift component **n_{shift}** is introduced for an optimized curve fitting for the dynamic model

See next slide

See next slide

3 The Dynamic Model – The Reference for Calculation

- The “no load” condition of the dynamic model covers the gas flow under no load condition. Even under cruise condition, there is still a gas flow, but its sound output is typically very low.
- The dynamic no load reference of the model is calculated by:

$$L_{REF,DYN,NL} = L_{PT,NL} - L_{DYN,NL}$$

- By setting **$L_{DYN,NL}$ = 15 dB(A)**, the dynamic components do not contribute to the cruise test result $L_{CRS,i}$.
- For values lower than 15 dB(A), the dynamic component would contribute as well to cruise conditions and the model would have an increased uncertainty.
- One could select value greater than 15 dB(A), but this would not change the model behavior. The reference would become lower and the dynamic would increase accordingly.

3 The Dynamic Model – The Dynamic Part ΔL_{DYN}

- The Dynamic Part ΔL_{DYN}
- Decribes the variation of load, between cruising (no load) and maximum acceleration (full load).
- As already mentioned, the dynamic is set in this model to a constant value over engine speed, so that at any engine speed the difference between no load and maximum load is the same.
- This enables to calculate the dynamic $L_{DYN,FL}$ from the type approval test results:

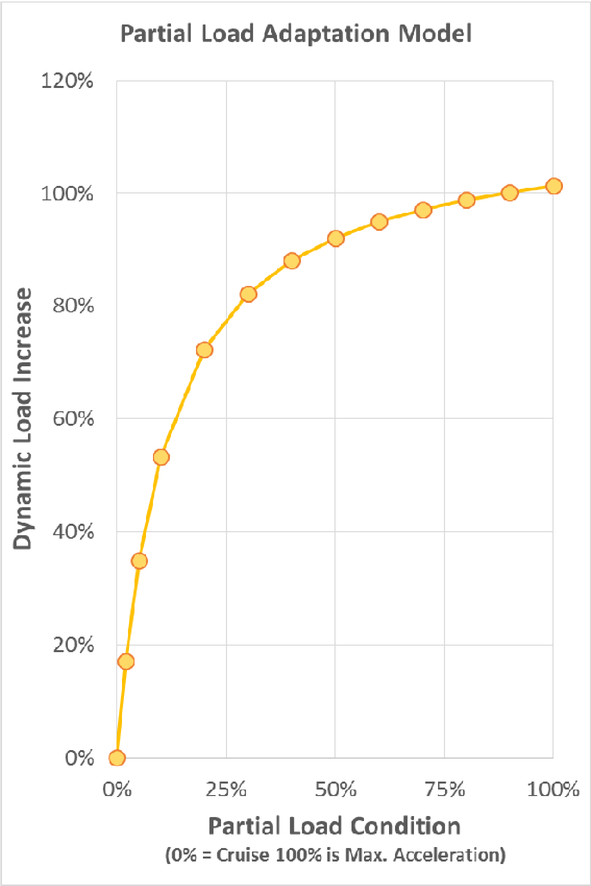
$$L_{DYN,FL} = [\, L_{wot,i} \ominus L_{crs,i} \,]$$

- However, cruise and acceleration during type approval do not happen at the same speed and engine speed. By using the already existing model components $L_{TR,NL}$ and $L_{PT,NL}$, one can adjust the cruise test results to match with the acceleration test condition:

$$\Delta L_{DYN} = \underbrace{[\, L_{wot,i} \ominus L_{TR,NL}(V_{BB',WOT,i}) \ominus L_{PT,NL}(N_{BB',WOT,i}) \,]}_{\text{This is the dynamic part under full load } L_{DYN,FL} \text{ at the type approval acceleration test condition}} - L_{REF,DYN,NL}$$

The Partial Throttle Model

- For a full dynamic model it is necessary to consider a partial throttle model.
- One difficulty is, that for many situations an already partially opened throttle means already full throttle.
- While we consider in Annex 3 that the link between the constant speed test and the acceleration test is linear, we need for ASEP a different model with a high increment from low throttle positions and a 90% load saturation at 50% throttle condition.
- Another difficulty is the question, how to determine the partial throttle condition.
  - This is most correctly done, by the determination of the position of the accelerator. His is design neutral and more accurate compared to the control of the throttle opening
  - Alternatively, this might be determined by the determined acceleration relative to the maximum acceleration of a given gear or gear ratio.
- Here is more research needed.
- As a simplification, one might apply the full throttle curve as well to any partial throttle conditions.



$\Delta L_{partial}$ = (1-0,111/(0,111+Load%/100)/(1-0,111)

 June 2017

Integration of all Modules

- Before the ASEP evaluation, it is necessary to carry out the Annex 3 type approval test
  - The parameter to be reported are: L_{wot} and L_{crs} from the lower or single gear, the acceleration (actually PP-BB), the vehicle speed v_{BB}, the engine speed n_{BB}.
  - For the gear ratio, the maximum acceleration must be known to determine the load condition.

- The expectation level is then calculated

$$L_{exp} = 10 * LOG\,(10^{0,1*L_{TR,NL}} + 10^{0,1*L_{PT,NL}} + 10^{0,1*(L_{DYN,NL} + \Delta L_{DYN}})\ + \Delta L_{MARGIN}$$

- Compliance is achieved when

$$L_{test}\,(v_{test}, a_{test}, n_{test}) \leq L_{exp}\,(v_{test}, a_{test}, n_{test})$$