The Imagine Railway Noise Source Model – technical approach to sources, default data and measurement methods

TNO Science and Industry

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IMAGINE - Improved Methods for the Assessment of the Generic Impact of Noise in the Environment

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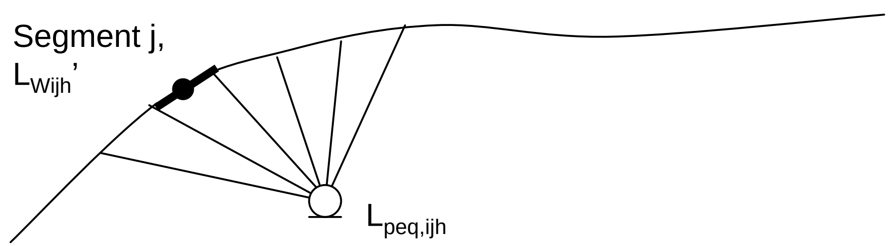
Overview

- Traffic noise model
- Physical models and default data for all source types
- Emission measurement methods

- See report IMA6TR-050912-TNO01

Typical situations with specific operating conditions

Rail traffic noise model based on physical sources and operating conditions combined at each track segment



$$L_{peq,ijh} = L_{W,ijh}{}' + 10\ lg\ l_{seg} - A_{total,i}$$

Summation over:

- segments (j)
- source heights (h)
- frequency bands (i)
- vehicle types and speeds (m)
- physical sources (p)
- operating conditions (k)

$$L_{pAeq,rec} = \sum_{i=1}^{B}\sum_{j=1}^{J}\sum_{h=1}^{Nh} \oplus L_{peq,ijh} + L_{FA,i}$$

→ Total receiver level from each segment and source height

$$L_{W}{}'_{kmih} = L_{peq,Tp,kmih} + 10lg(2\pi r) - A_{excess,i} - 10lg(atan(\frac{l_{test}}{2r}))$$

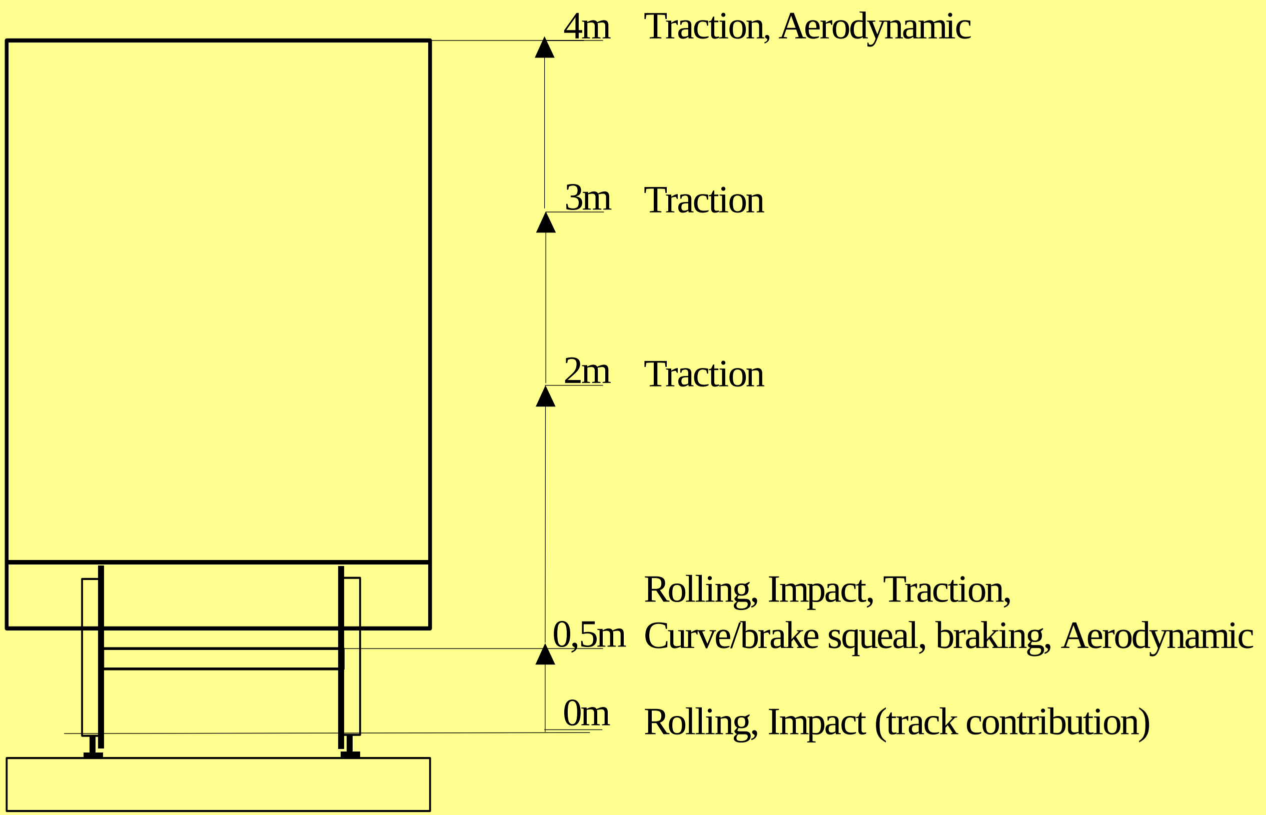
→ Sound power per unit length from measured pass-by sound pressure of test vehicle

$$L'_{W,ijh} = \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{p=1}^{P} \oplus \left(L_{W}{}'_{kmpijh} + 10lg\left(\frac{N_{u,mk}\, l_{u,m}}{1000 v_{mk}}\right) + C_{dir,pih} \right)$$

→ Sound power per unit length at each height and segment for summated over operating conditions, physical sources and vehicle types and speeds

L_{FA} = A-weighting; $A_{excess,i}$ = excess attenuation; N = number of vehicles/hr; l = length; v = speed;
L_W'= sound power level per unit length; N_u = number of units/hour; $C_{dir,pih}$ = directivity index;
$\Sigma\oplus$ = energy sum : $\Sigma\oplus x_i = 10\ lg\ (10^{x1/10} + 10^{x2/10} + \ldots)$

Typical source heights

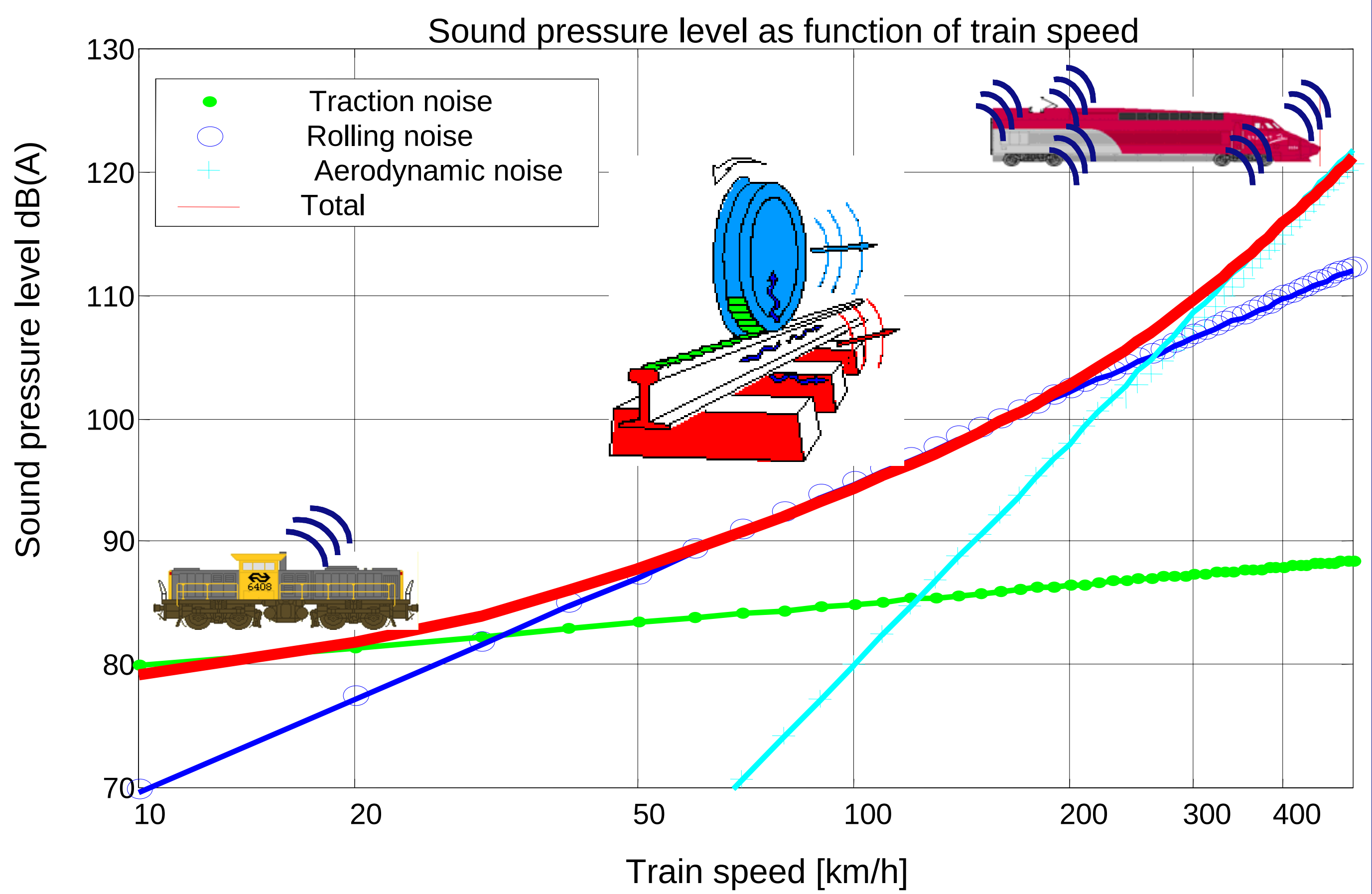


Operating conditions (k) and physical sources (p)

Physical source Operating condition	Rolling and impact noise	Traction noise	Aerodynamic noise	Braking noise	Curve squeal
Constant speed	x	x	x		x
Braking	x	x	x	x	x
Accelerating	x	x	x		x
Curving	x	x		x	x
Idling		x			

- Rolling noise, impact noise and curve squeal also include influence of the track
- Curve squeal, impact noise, bridge noise, braking and acceleration are more localised

Speed dependency of rolling, traction and aerodynamic noise



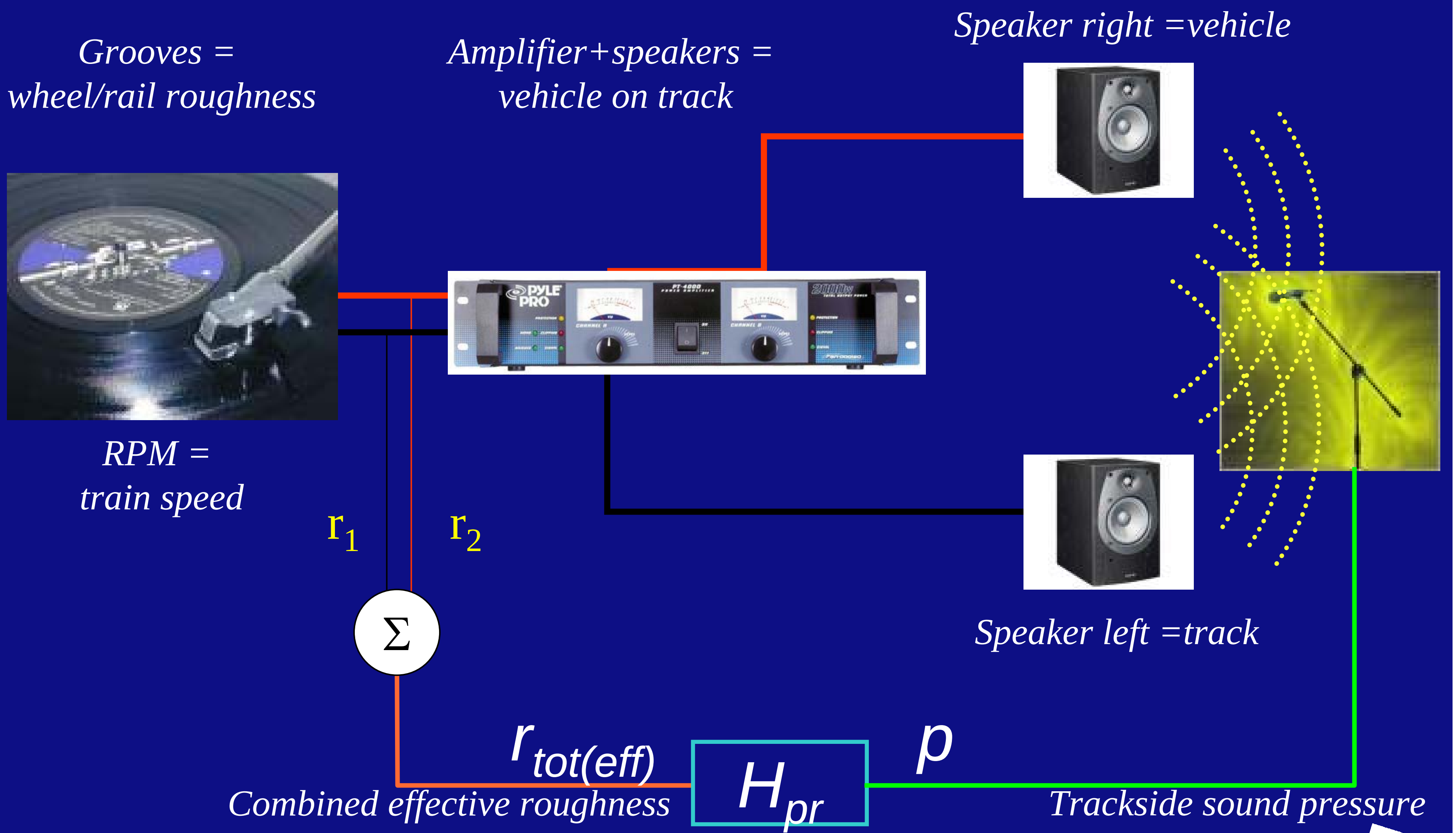
Summary table of source models

Source type	Typical source heights	Formula (refer to text for further details)
Rolling noise See 2.3.1	0m 0.5m	$L_{peqi,roll}(h=0m)=L_{rtot,net,i}(v) + L_{Hpr,nl,tr,i} + 10\ lg\ (N_{ax}/l_{veh})$ $L_{peqi,roll}(h=0{,}5m)=L_{rtot,net,I}(v) + L_{Hpr,nl,veh,i} + 10\ lg\ (N_{ax}/l_{veh})$
Impact noise See 2.3.1	0m, 0.5m	$L_{rtot}(\lambda) = L_{rveh}(\lambda) \oplus L_{rtr}(\lambda) \oplus L_{rimpact}(\lambda)$ further as rolling noise
Traction noise, total, see 2.3.2	0.5m, 2m, 3m, 4m	$L_{peq,i,traction,idle}$,$L_{peq,i,traction,acc}$, $L_{peq,i,\ traction,cs}$, *and* $L_{peq,i,\ traction,dec}$ *or:* $L_{ptraction,i}(n_{drive}, n_{fan}) = L_{pdrive,i}(n_{drive}) \oplus L_{pfan,i}(n_{fan}) \oplus L_{pdj,i}$
Traction noise, drive, see 2.3.2	0.5m, 2m, 3m, 4m	$L_{pdrive,i}(n_{drive}) =$ $L_{pdrive,nmax,i}(f_i\ .(n_{drive,max}/n_{drive})\ ) + C_{drive}\ \lg\ (n_{drive}/n_{drive,max})$
Traction noise, fan, see 2.3.2	0.5m, 2m, 3m, 4m	$L_{pfan,i}(n_{fan}) =$ $L_{pfan,nmax,i}(f_i\ .(n_{fan,max}/n_{fan}\ )\ ) + C_{fan}\ \lg\ (n_{fan}/n_{fan,max})$
Traction noise, other, see 2.3.2	0.5m, 2m, 3m, 4m	$L_{pdj,i} = L_{pi}(f) + 10\ \lg\ (d_j)$
Deceleration noise, total See 2.3.3	0.5m	$L_{pdeceleration,i}(v) = L_{pbrake,i}(v) \oplus L_{pdsqueal,i}$
Deceleration noise, braking See 2.3.3	0.5m	$L_{pbrake,i}(v) = L_{pbrake,i}(v_0) + C_{brake}\ \lg\ (v/v_0)$
Deceleration noise, squeal See 2.3.3	0.5m	$L_{pdsqueal,i} = L_{psqueal,i} + 10\ \lg\ (d_{squeal})$ below squeal cut-in speed (when mechanical braking starts)
Curve squeal See 2.3.4	0.5m	$L_{psqueal}$ = constant (average value) in curve with d< 1000m
Aerodynamic noise See 2.3.5	0.5m, 2m, 3m, 4m	$L_{paero,h}(f,v) = L_{paero,h}(f,v_0) + \alpha_h(f) lg\ (v/v_0)$

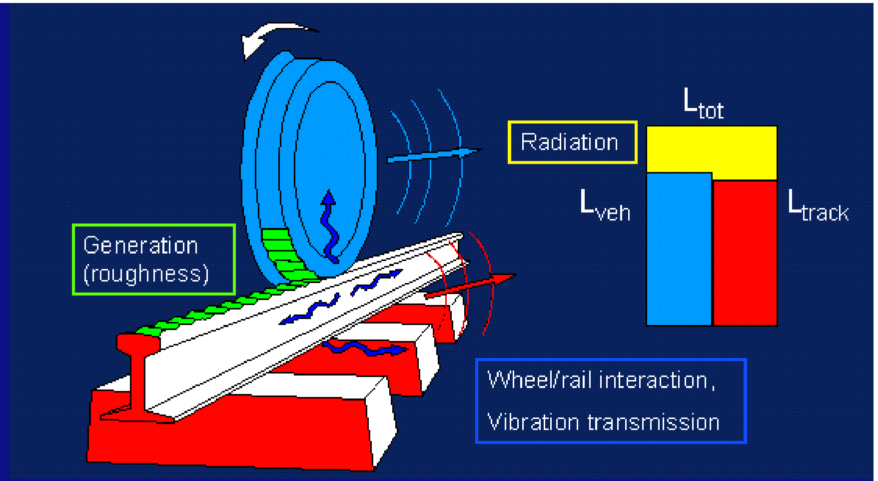
Summary table of default source data

Source type	Default quantities	Vehicle	Track
Rolling noise	N_{ax}/l_{veh} =0.15(passenger coach) $L_{Hpr\ nl,i}$ for track $L_{Hpr\ nl,i}$ for vehicle $L_{r,total,i}(v)$ for vehicle/track combinations	Cast-iron tread K-block Disc	Concrete soft pad Concrete stiff pad Wooden sleeper Rail roughness: ISO, TSI, Network average, Corrugated
Impact noise	$L_{rimpact}(\lambda)$ n_{nl} = 1/100 m		Average joints, points and crossings
Traction noise, drive	$L_{p,drive,i}(n_{drive})$ Diesel: $n_{drive} = n_{25\%}, n_{50\%}, n_{75\%}$ Electric: 1 or 2 speeds accelerating at normal load $C_{drive} = 30$	DMU, Dloco EMU, Eloco	
Traction noise, fan	$L_{p,fan,i}(n_{fan})$ $n_{fan} = n_{50\%}$ or n_{low}, n_{max} or n_{high} d_{fan} = 80% for n_{low}, d_{fan} = 20% for n_{high} $C_{fan} = 50$	EMU, Eloco	
Traction noise, other	L_{pi}, d	Compressor and relief valves	
Deceleration noise, braking	$L_{p,brake,i}(v) = 88 + 30\ lg\ (v/80)$ @800-8000 Hz Only for CI braked vehicles	Cast-iron braked vehicles	
Deceleration noise, squeal	$L_{pbrakesqueal,i}$ = 100 dB @ 1kHz Below 50 km/h	Freight HST, EMU	
Curve squeal	$L_{p,curve\ squeal,\ points,i}$ = 100 dB @ 1kHz, 2kHz $L_{p,curve\ squeal,\ curve,i}$ = 95 dB @ 2kHz , 4kHz	All, unless demon-strated squeal free	Points (when curving) Curve
Aerodynamic noise	$L_{paero,i}(h=0,5m) = 63 + 60\ lg(v/80)$ @20-8000Hz $L_{paero,i}(h=4m) = 65 + 60\ lg(v/80)$ @4000-5000Hz	Unshielded bogies and pantograph recesses	

Approach for Rolling noise - Analogy
Roughness → Amplification → Radiation



Rolling noise



Vehicle

Train speed

Wheel roughness
$L_{reff,veh}$

Rail roughness
$L_{reff,tr}$

L_{reff}

Vehicle Transfer Function
$L_{Hpr,nl,veh}$

Track Transfer Function
$L_{Hpr,nl,tr}$

$L_{eq,veh}$

$L_{eq,tr}$

L_{eq}

Track

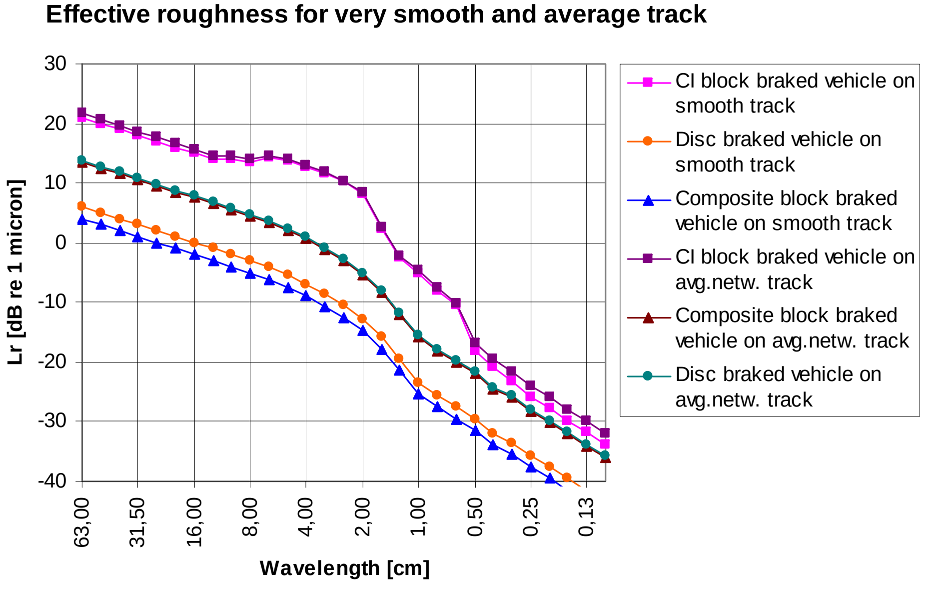
Roughness excitation

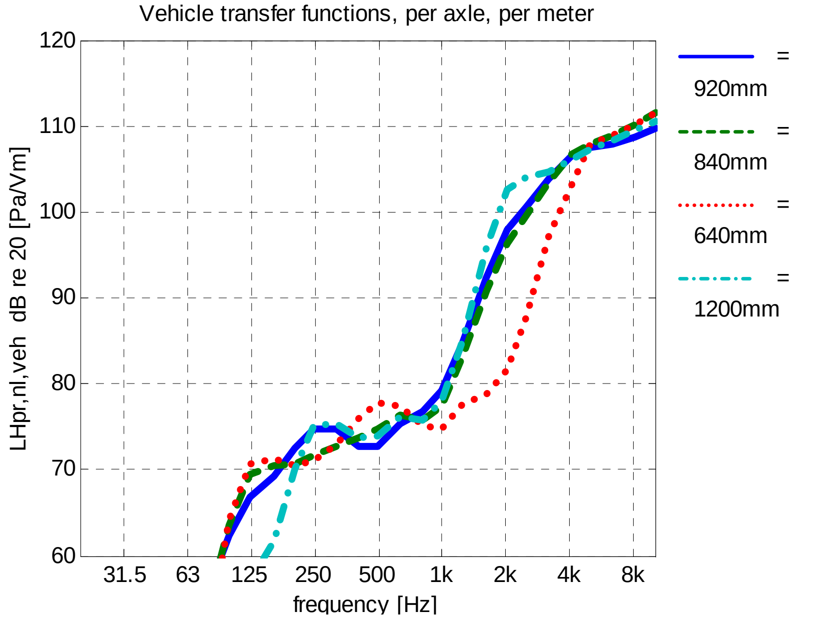
Transfer function from roughness to sound pressure

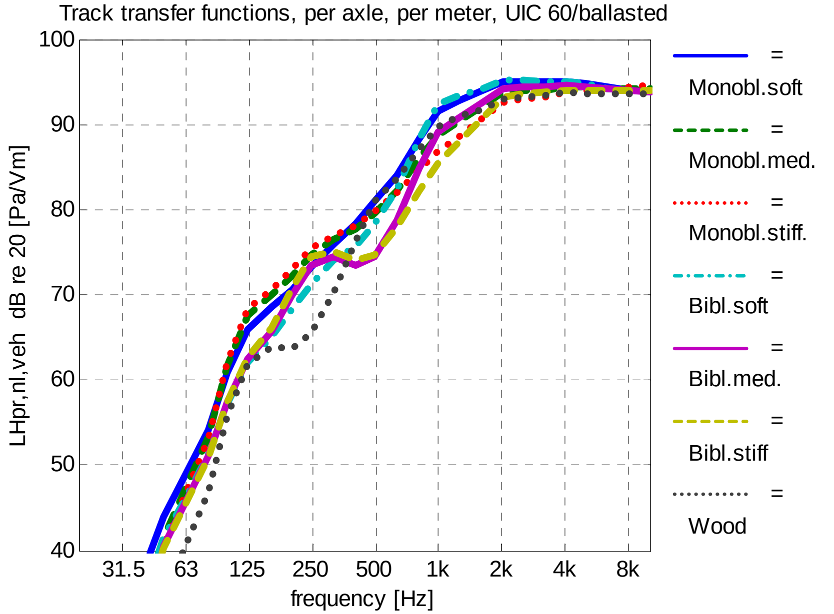
Rolling noise

$$L_{peqi,roll}\ (h=0m)= L_{rtot,i}\ (v) + L_{Hpr,nl,tr,i} + 10\ lg\ (N_{ax}/l_{veh})$$

$$L_{peqi,roll}(h=0,5m)= L_{rtot,i}\ (v) + L_{Hpr,nl,veh,i} + 10\ lg\ (N_{ax}/l_{veh})$$

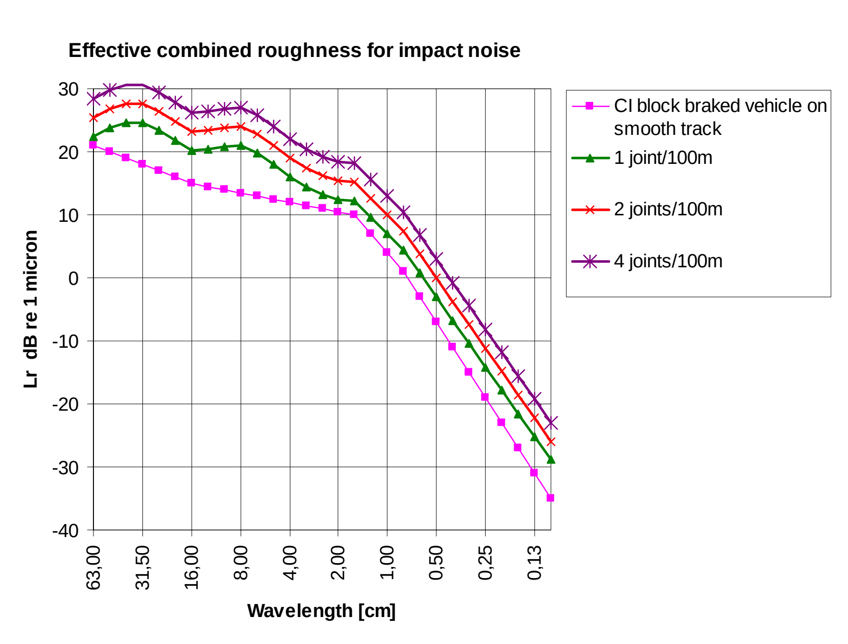






Impact noise

- Same approach as rolling noise, but using an equivalent roughness term representing impact excitation due to joints, points and crossings $L_{r,impact}$
- Note: impact noise is often localised and may require own separate segmentation of track.

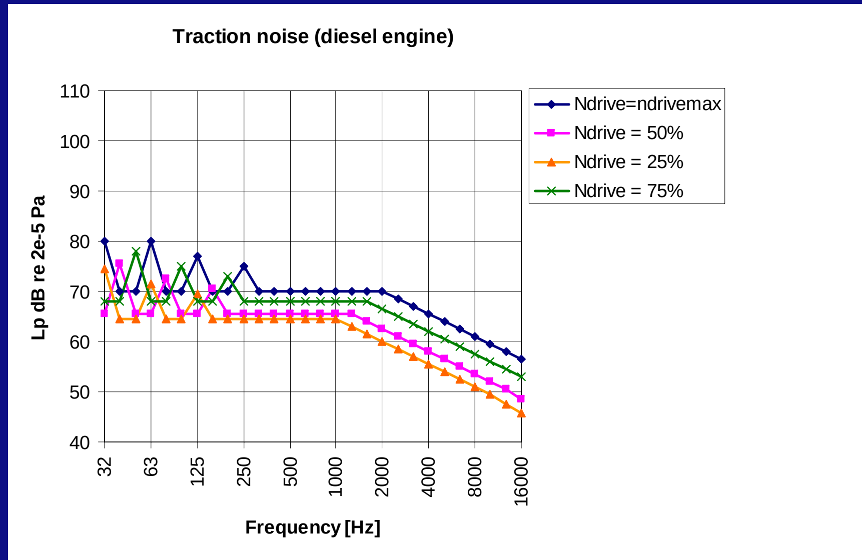


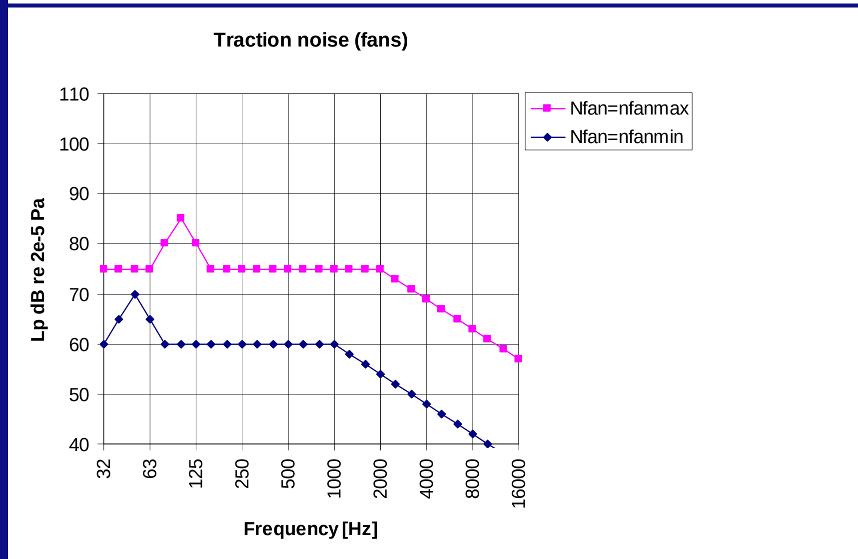
Model for traction noise

- Relevant for powered vehicles in particular operating conditions
- Sound pressure level from traction sources is summation over powertrain noise, fan noise and intermittent sources
- Dependency on driveshaft and fan shaft speeds, electrical power output
- Emission data is best measured for 4 operating conditions:
  - standstill/idling
  - acceleration with load
  - constant speed with normal load
  - if necessary, braking
- Default spectra are available but measurement is recommended

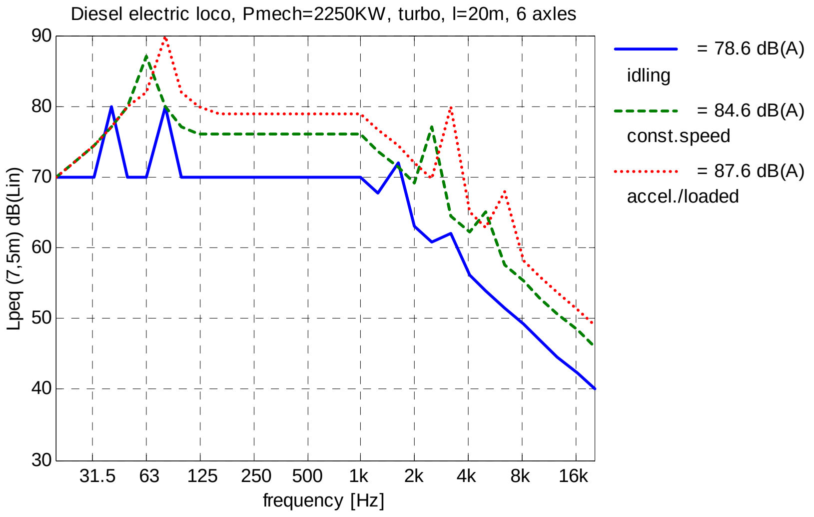
Traction noise –
default shaft speeds, simulated spectra

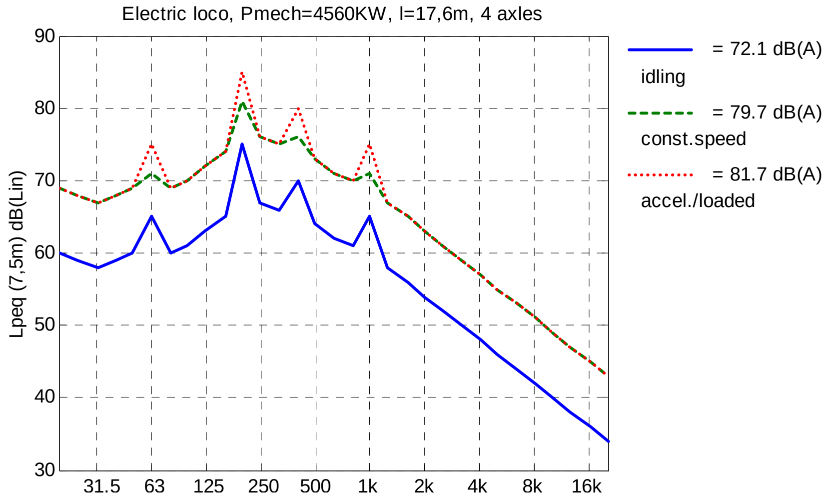
Drive speed n_{drive}	Fan speed n_{fan}
Constant speed	
$n_{driveidle}$ + $0.5(n_{drivemax} - n_{driveidle})$	n_{fanmin} + $0.25(n_{fanmax} - n_{nfanmin})$ or n_{fanLOW}
Acceleration	
$n_{driveidle}$ + $0.75(n_{drivemax} - n_{driveidle})$	n_{fanmin} + $0.75(n_{fanmax} - n_{nfanmin})$ or $n_{fanHIGH}$
Deceleration	
$n_{driveidle}$	n_{fanmin} + $0.75(n_{fanmax} - n_{nfanmin})$ or $n_{fanHIGH}$
Idling	
$n_{driveidle}$	n_{fanmin} or n_{fanLOW}

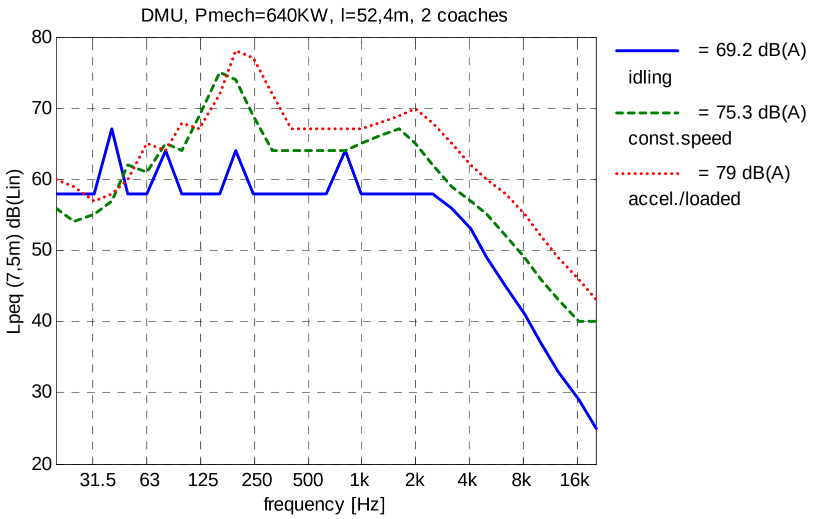


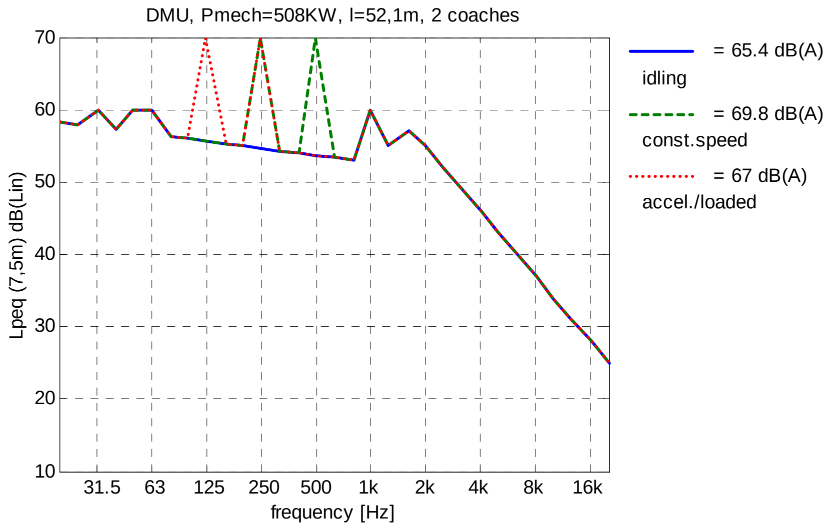


Traction noise examples (total SPL 7.5m)









Deceleration / braking noise

Braking at speed:

$$L_{peq,i,brake} = L_{peq,i,brake}(v_0) + C_{brake}\ lg\ (v/v_0)$$

Default: $88 + 30\ lg(v/80)$ *@800-8k Hz*

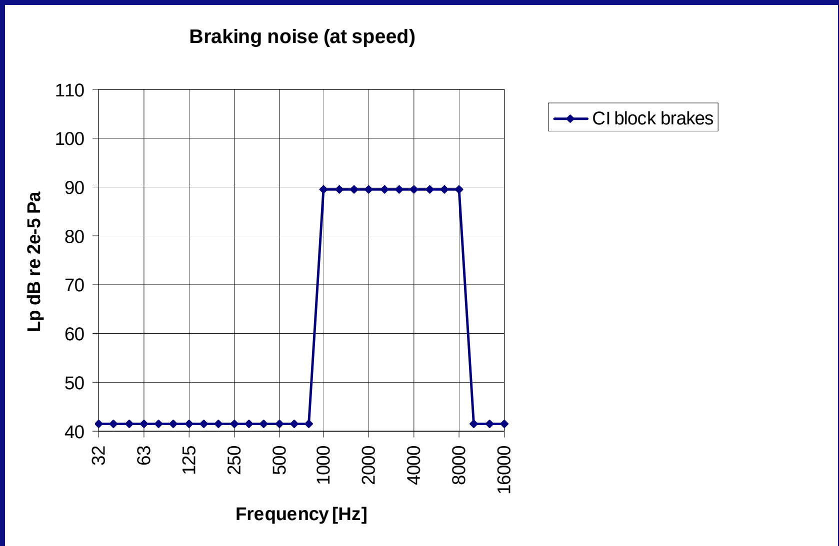
Brake squeal, at low speeds:

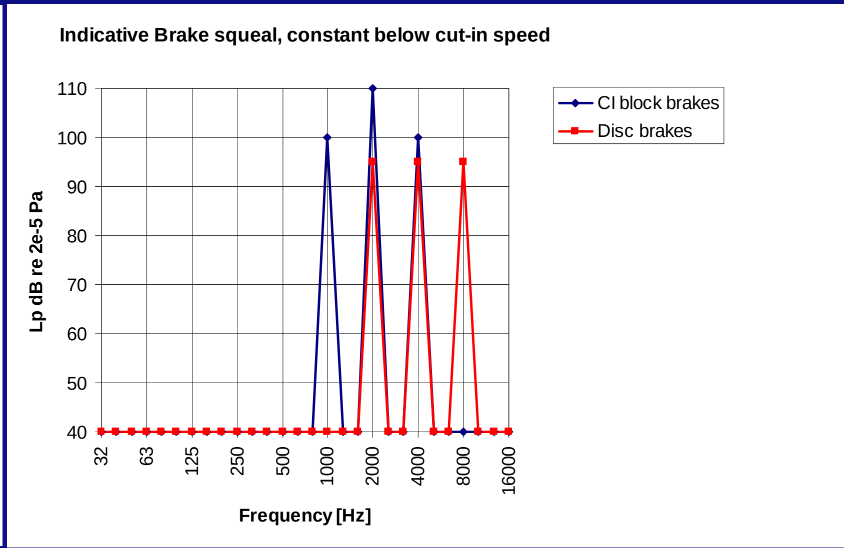
$$L_{peq,i,brake} = L_{peq,i,brakesqueal} \quad \text{for } v<v_{squeal}$$

Default CI brakes: 100 dB @ 1k Hz, 110 dB @ 2kHz, 100 dB @ 4k Hz

Default Disc brakes: 95 dB @ 2kHz, 4kHz, 8 kHz

(constant spectrum)





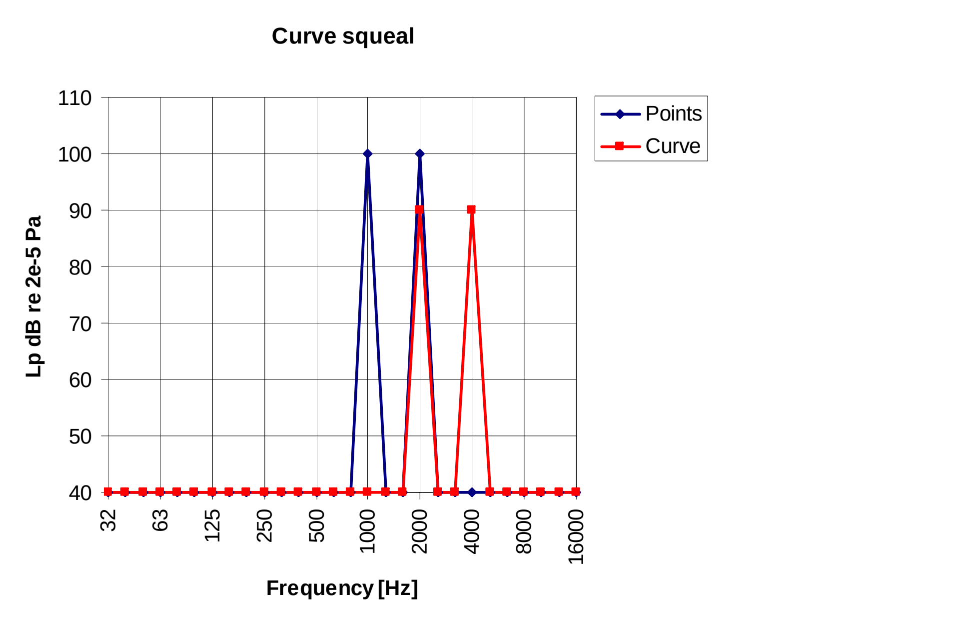
Curve squeal

- Relevant for points (branch-out part) and curves
- Is rolling-stock type dependent
- Speed and curvature are key parameters

$$L_{peq,i,squeal} = L_{peq,i,squeal}(v_0,R_0) + 20\,lg\,(v/v_0) - 20\,lg\,(R/R_0)$$

Default for points: 100 dB @ 1kHz, 2kHz

Default for curves: 90 dB @ 2kHz, 4kHz



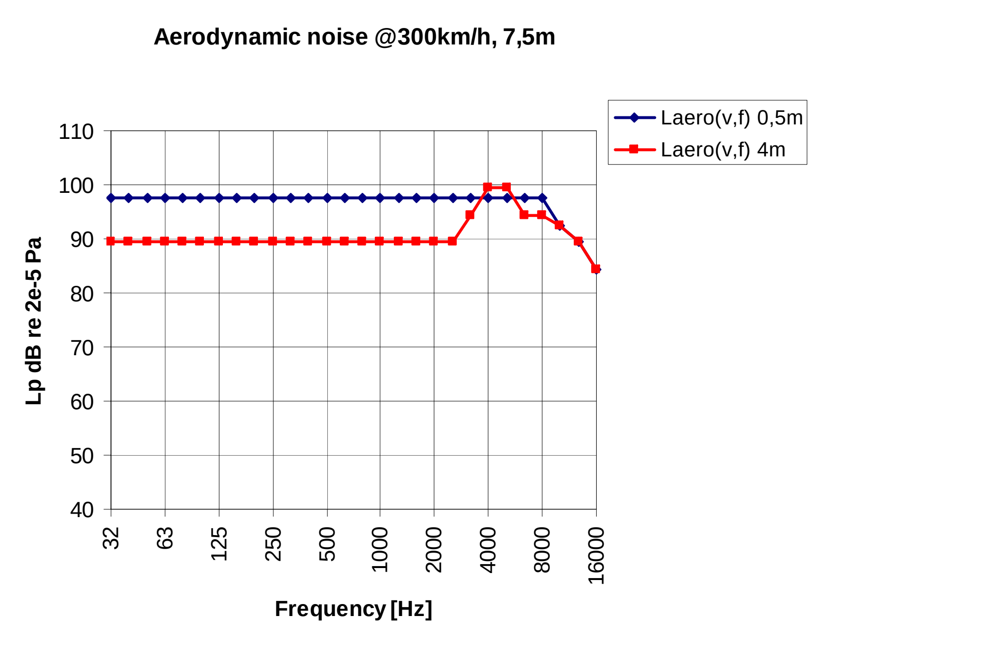
Aerodynamic noise

- Relevant at speeds above 200 km/h
- A function of source height h and speed v, and coefficient α_i:

$$L_{peq,i,\,aero}(h,v) = L_{peq,i,aero}(h,v_0) + \alpha_i(h) lg\,(v/v_0)$$

Default h=0.5m: 63 + 60 lg (v/80) @ 20-8k Hz

Default h=4m: 65 + 60 lg (v/80) @ 4k-5k



Measurement of source data

- Following prEN ISO 3095:2001 standard, but:
- Always use $L_{pAeq,Tp}$:
  Energy is taken over length of whole vehicle for all source types
- Conversion to effective sound power or sound power per meter
- Source height assessment required
  (0 – 0.5 – 2 – 3 – 4 m)
- Rolling noise transfer functions and effective roughness required
- Traction noise measurement requires known drive and fan rpm or characteristic operating points, separate measurement of intermittent sources and duty cycle
- Curve squeal measurement required

Summary table of measurement methods

Source type	Measured quantities	Operating condition	Microphone position	Accelerometer position	Track requirement
Rolling noise	v, L_{peqTp}, L_{veqTp}, D_s, N_{ax}/l_{veh} $L_{r,rail}$ $L_{Hpr\ nl}$ for track (with reference vehicle or other method)	Pass-by at several speeds One or more speeds between 50<v<250kmh Minimum of 3 recommended	D=7.5m, H=1.2m [D=1.75, H=0m]	L1,[L2], V1,[V2],[S1] dependent on method	ISO3095 or TSI compliant
Impact noise	v, N_{ax}/l_{veh} ΔL_{peqTp}, ΔL_r (impact/rolling)	Pass-by(s) with and without rail joint	D=7.5m, H=1.2m At joint	N/A	Joint, crossing or points
Traction noise total	$L_{peqTp,traction,idling}$ $L_{peqTp,traction,acceleration}$ $L_{peqTp,traction,const.\ speed}$ $L_{peqTp,traction,deceleration}$	Stationary Acceleration Constant speed Deceleration	D=7.5m, H=1.2m L=0m, 20 m (20m for acc./dec.)	N/A	ISO3095 compliant
Traction noise, drive (optional)	L_{peqTp}, n_{drive} , v	Pass-by, acceleration or stationary	D=7.5m, H=1.2m L=0+20 m	N/A	ISO3095 compliant
Traction noise, fan (optional)	L_{peqTp}, n_{fan}, d_{fan}	Stationary	D=7.5m, H=1.2m L=Box or L=0m	N/A	ISO3095 compliant
Traction noise, other (optional)	L_{peqTp}, d_i	Stationary	D=7.5m, H=1.2m L=Box or L=0m	N/A	ISO3095 compliant
Deceleration noise, braking	L_{peqTp}, v	Deceleration from maximum and service speeds	D=7.5m, H=1.2m L=0m	N/A	ISO3095 compliant
Deceleration noise, squeal	L_{peqTp}, v	Deceleration from 50 km/h 25 km/h	D=7.5m, H=1.2m L=0m	N/A	[ISO3095 compliant]
Curve squeal	L_{peqTp}, v	Curve pass-bys in points (10,20,40km/h) curve (80,120 km/h)	D=7.5m, H=1.2m L=0m	N/A	In points and/or curve R<1000m
Aerodynamic noise	L_{peqTp}, v	Pass-by at high speeds	D=25m, H=3.5m Convert to 7,5m	N/A	ISO3095 or TSI compliant

Conclusions and Outlook

- Generally applicable railway source model proposed
- Model takes various operating conditions and relevant physical sources into account
- Default data and examples are available
- Measurement methods proposed to obtain specific vehicle data
- More data collection required
- Integration of type testing, source measurement in future standards? (ISO/CEN, TSI)

- Model should enable railways and authorities to
  - make a more reliable assessment of environmental noise,
  - taking all sources into account
  - better accounting for noise control measures