Validation of Sound Model

2018.07.10-12

ASEP IWG #8 meeting

@Brussels

JASIC

Contents

1. Test vehicles and test conditions

Test vehicle		Vehicle-04 (HEV, 7AT)	Vehicle-05 (HEV, CVT)	Vehicle-06 (ICE, 7CVT)
Spec.	Category	M1	M1	M1
	Power unit	ICE (3498 cc) + Motor	ICE (1797 cc) + Motor	ICE (1496 cc)
	Max. power	225 kW / 6800 rpm + 50 kW	73 kW / 5200 rpm + 60 kW	80 kW / 6000 rpm
	mro	1925 kg	1485 kg	1295 kg
	PMR	142.9	89.6	61.8
	Tyre size	225/55RF17	195/65R15	195/65R15
R51-03 Annex 3		4th (Locked) D-range (Non-locked)	D-range (Non-locked)	3rd (Locked) D-range (Non-locked)

Conditions	Gear	Vehicle-04 V, km/h	Vehicle-04 n, rpm	Vehicle-04 a, m/s²	Vehicle-05 V, km/h	Vehicle-05 n, rpm	Vehicle-05 a, m/s²	Vehicle-06 V, km/h	Vehicle-06 n, rpm	Vehicle-06 a, m/s²
Vehicle running (Wot, Partial, Crs)	1st	10-60	1000-6000	1.7-5.5				6-57	800-5800	0.4-2.6
	2nd	22-90	1300-6000	0.3-4.0				15-69	1400-5400	0.7-2.1
	3rd	32-117	1300-5000	0.4-3.3				22-89	1400-5400	0.7-1.5
	4th	43-120	1300-3400	0.3-2.4				26-109	1400-5400	0.5-1.2
	5th	60-119	1300-2500	0.6-1.7				34-120	1400-4700	0.4-0.9
	6th	73-120	1300-2200	0.9-1.3				42-120	1400-3800	0.2-0.6
	7th	73-118	1200-1900	0.7-1.1				50-120	1300-3100	0.1-0.4
	D*	20-121	1100-6100	0.5-3.8	22-120	900-4500	0.1-3.1	6-120	800-4300	0.1-2.6
	D**	20-117	0-6000	0.2-3.6	20-90	0-3700	0.5-2.7			
Tyre rolling	N	29-117			33-116			30-119		
Power train	N		No data			No data			900-5000	

* Engine is "on" between AA' and BB' (wot, partial, crs)

** Engine is "off" at AA' and "on (re-start)" before BB' (wot, partial)

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① Tyre Rolling Sound Model, L_{TR}

$$L_{TR} = Slope_{TR} * \log(v_{test} / 50) + L_{REF,TR}$$

$$L_{REF,TR} = X \% \text{ of } L_{CRS,REP}$$

② Power Train Base Mechanic Sound Model (No Load), $L_{PT,NL}$

$$L_{PT,NL} = Slope_{PT,NL} * \log((n_{test} + n_{shift}) / (n_{CRS,REP} + n_{shift})) + L_{REF,PT,NL}$$

$$L_{REF,PT,NL} = (100 - X \%) \text{ of } L_{CRS,REP}$$

③ Dynamic Model, L_{DYN}

$$L_{DYN} = Slope_{DYN,NL} * \log((n_{test} + n_{shift}) / (n_{WOT,REP} + n_{shift})) + L_{REF,DYN,NL} + \Delta L_{DYN}$$

$$L_{REF,DYN,NL} = L_{REF,PT,NL} - 15$$

$$\Delta L_{DYN} = [L_{WOT,REP} \circleddash L_{TR}(V_{WOT,REP}) \circleddash L_{PT,NL}(n_{WOT,REP})] - L_{REF,DYN,NL}$$

2-1 Tyre Rolling Sound model L_{TR}

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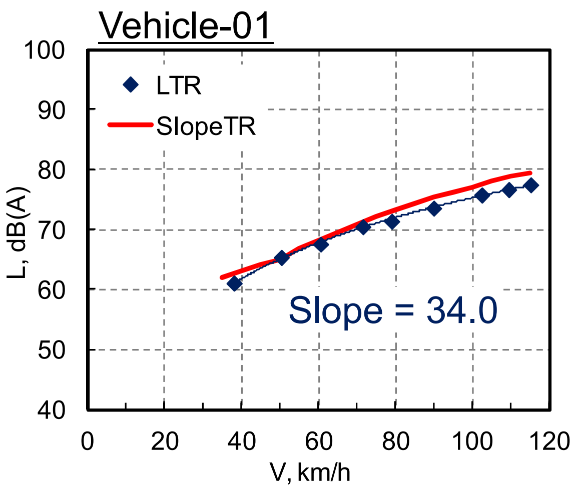
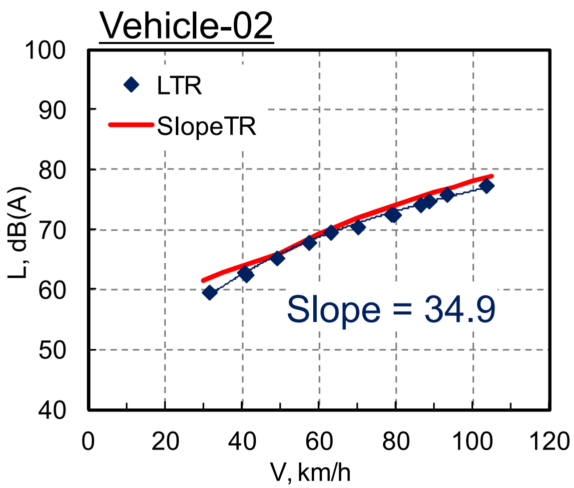
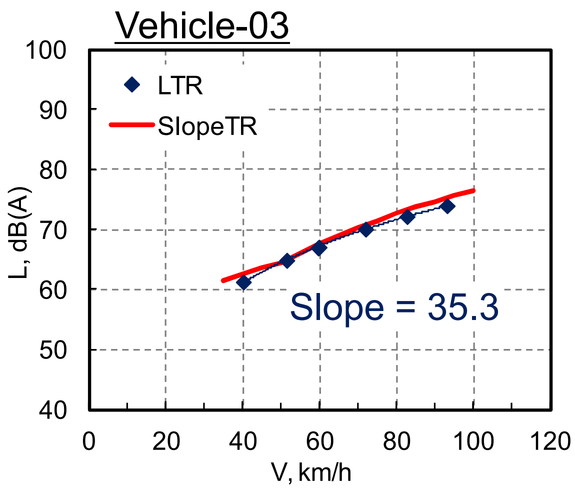
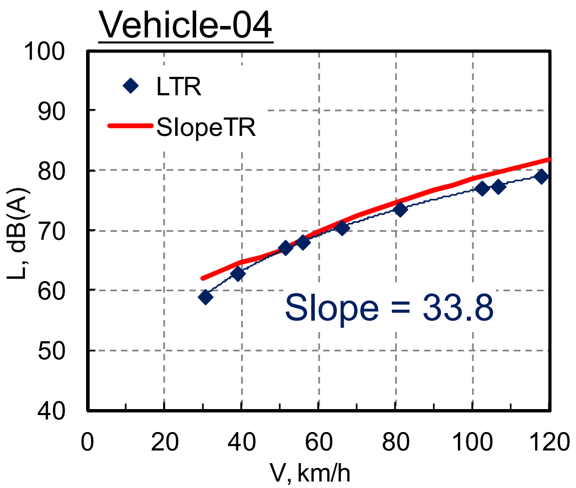
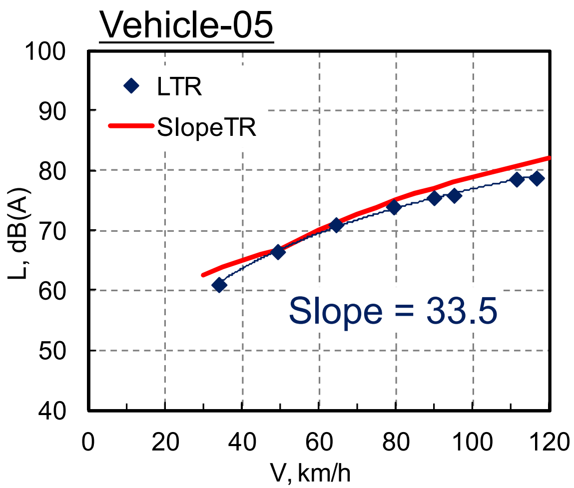
$$L_{TR} = Slope_{TR} * \log(v_{test} / 50) + L_{REF,TR}$$

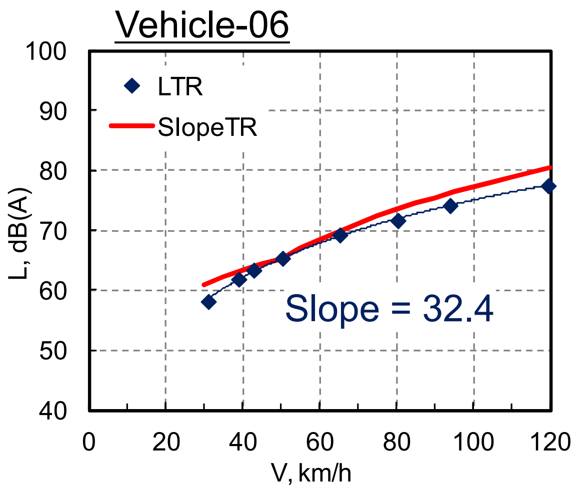












Tyre model L_{TR} can fit in several cars.

(Results of vehicle-01, -02, -03 were reported at #5 IWG)

2-2 Power Train Base Mechanic Sound Model (No Load), $L_{PT,NL}$

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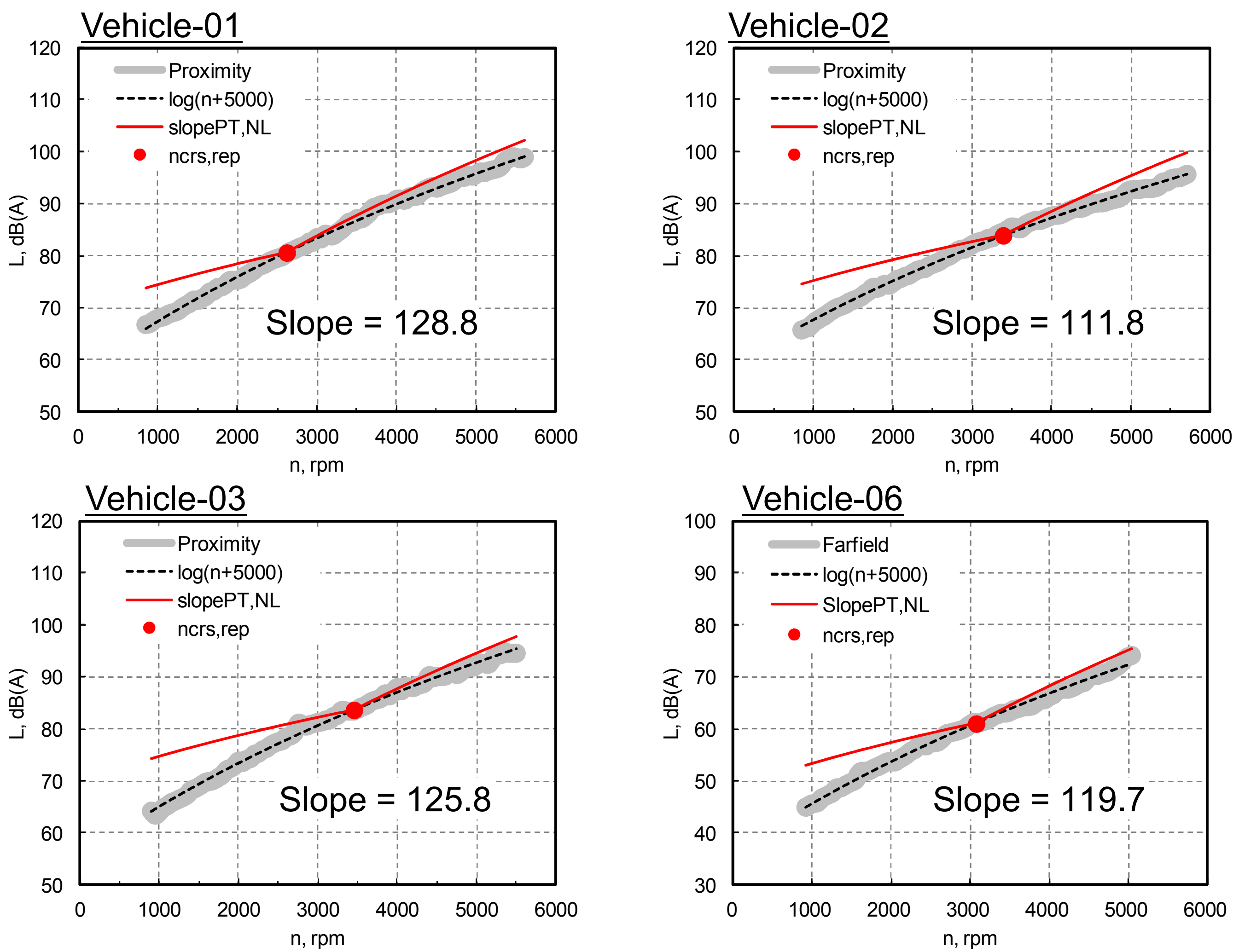
$$L_{PT,NL} = Slope_{PT,NL} * \log((n_{test} + n_{shift}) / (n_{CRS,REP} + n_{shift})) + L_{REF,NL}$$



Mechanical model $L_{PT,NL}$ can fit in several cars.

(Results of vehicle-01, -02, -03 were reported at #5 IWG)

2-3 X% in $L_{REF,TR}$ and $L_{REF,PT,NL}$

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① Tyre Rolling Sound Model, L_{TR}

L_{TR} = $Slope_{TR}$ * log(v_{test} / 50) + $L_{REF,TR}$

$L_{REF,TR}$ = **X %** of $L_{CRS,REP}$

② Power Train Base Mechanic Sound Model (No Load), $L_{PT,NL}$

$L_{PT,NL}$ = $Slope_{PT,NL}$ * log((n_{test} + n_{shift}) / ($n_{CRS,REP}$ + n_{shift})) + $L_{REF,PT,NL}$

$L_{REF,PT,NL}$ = (100 - **X %**) of $L_{CRS,REP}$

$L_{REF,TR}$ and $L_{REF,PT,NL}$ depends on X% of $L_{CRS,REP}$

How influence is X% on sound model?

2-3 X% in $L_{REF,TR}$ and $L_{REF,PT,NL}$

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$L_{REF,TR}$ and $L_{REF,PT,NL}$ are determined by X%, tyre noise contribution of $L_{CRS,REP}$.

X % for test vehicles

Vehicle	PMR	Annex 3	% of $L_{CRS,REP}$	
			X %	100 - X %
		Gear	**Tyre Rolling $L_{REF,TR}$**	Power Train (No Load) $L_{REF,PT,NL}$
-04	142.9	4th (i)	> 99	< 1
		D	> 99	< 1
-05	89.6	D	> 99	< 1
-06	61.8	3rd (i)	65	35
		D	> 99	< 1

X% are different depending on the vehicle.

Compared with L_{test} and L_{exp} (Veh.04 Locked gear)

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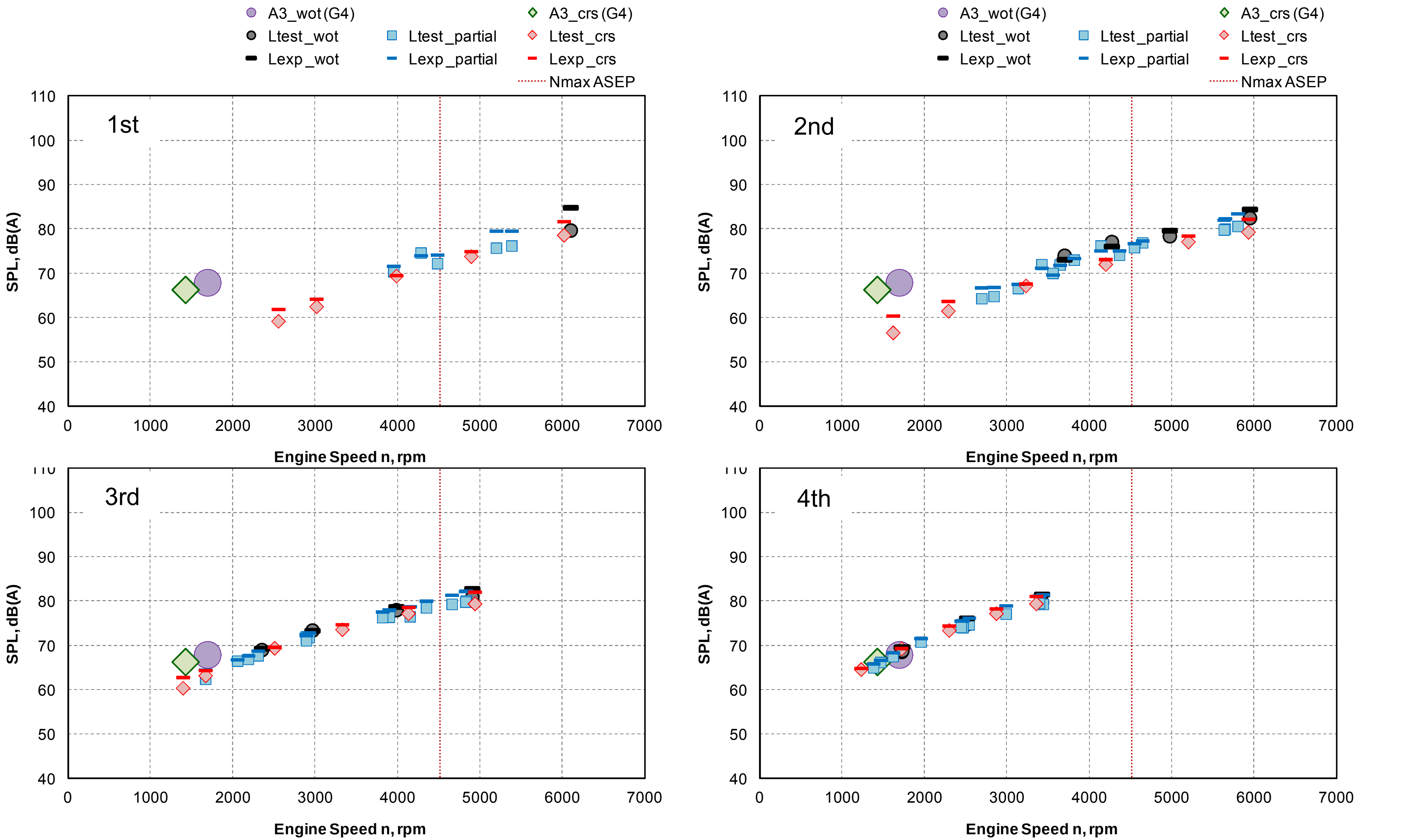
Vehicle-04, Locked, 1st-4th, X=99 %



Compared with L_{test} and L_{exp} (Veh.04 Locked gear)

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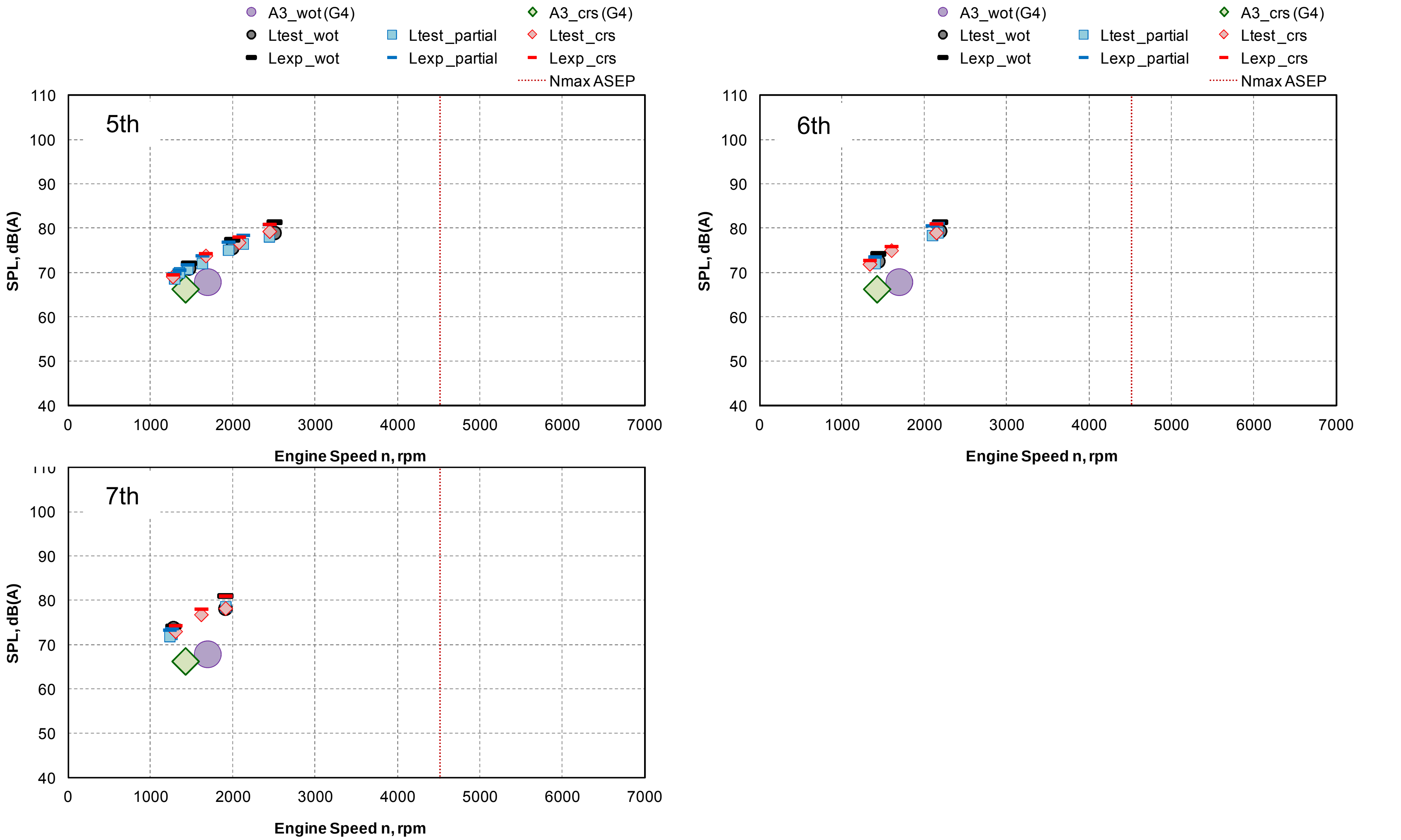
Vehicle-04, Locked, 5th-7th, X=99 %



Compared with L_{test} and L_{exp} (Veh.06 Locked gear)

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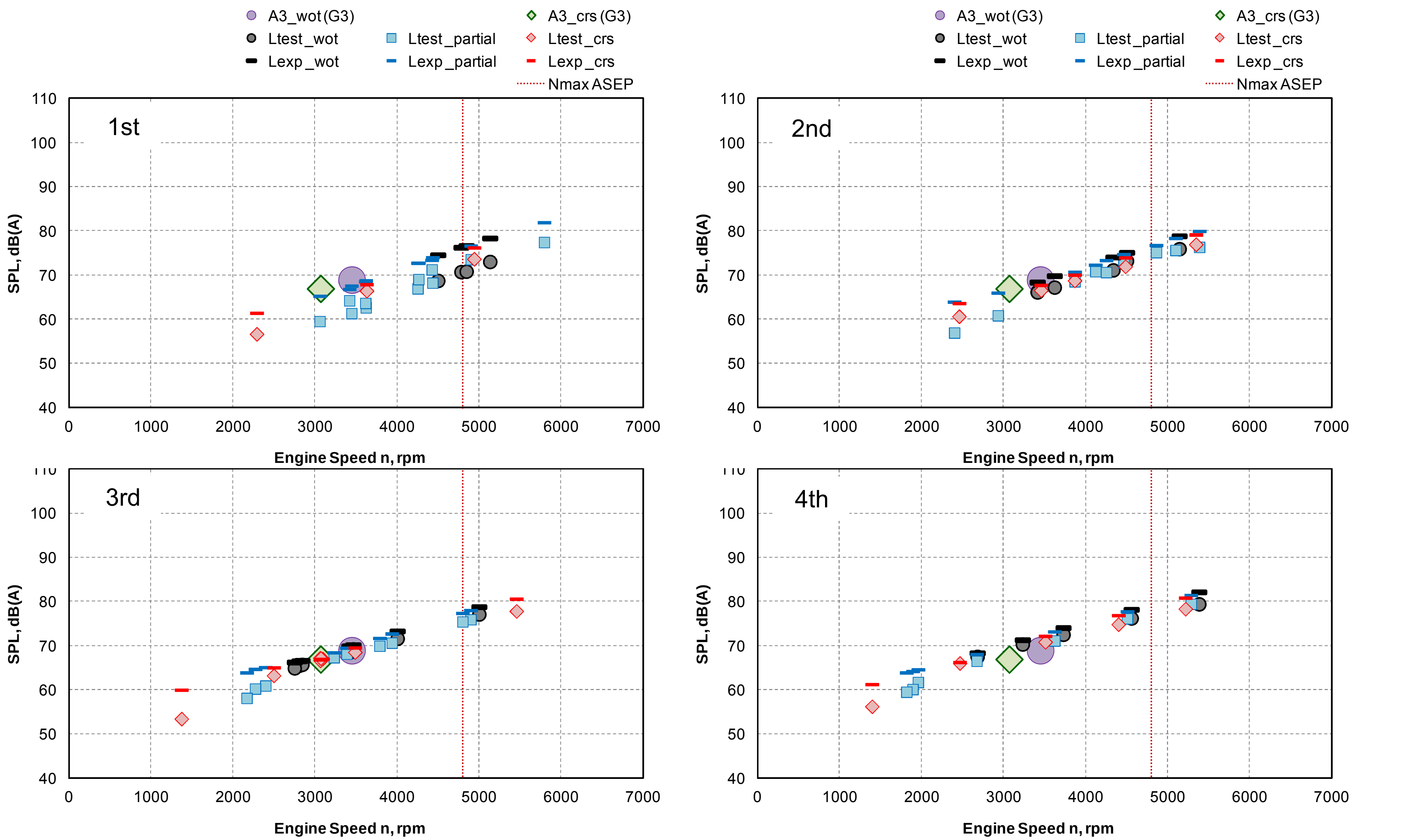
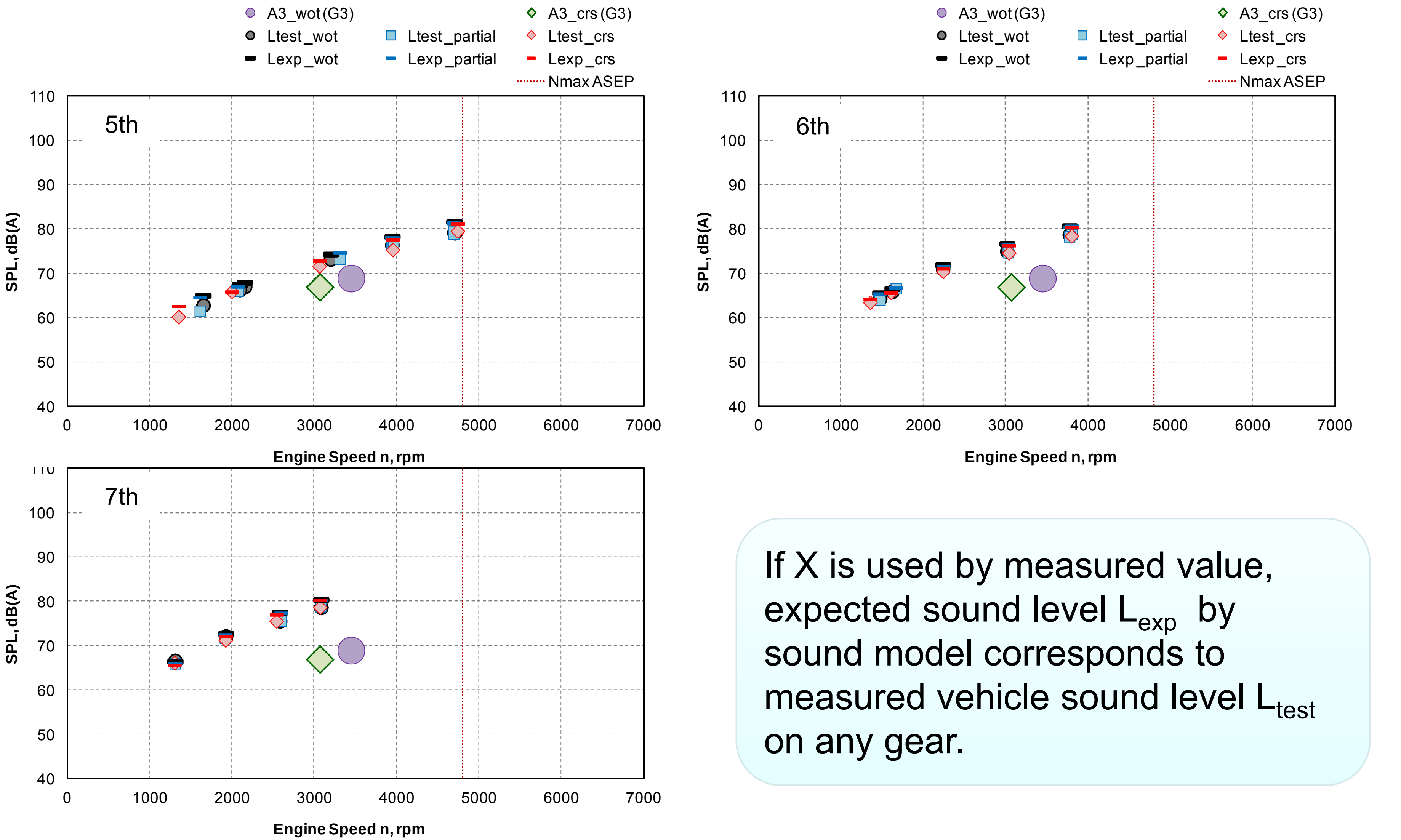
Vehicle-06, Locked, 1st-4th, X=65 %



Compared with L_{test} and L_{exp} (Veh.06 Locked gear)

Vehicle-06, Locked, 5th-7th, X=65 %



If X is used by measured value, expected sound level L_{exp} by sound model corresponds to measured vehicle sound level L_{test} on any gear.

Compared with L_{test} and L_{exp} (Non-locked gear)

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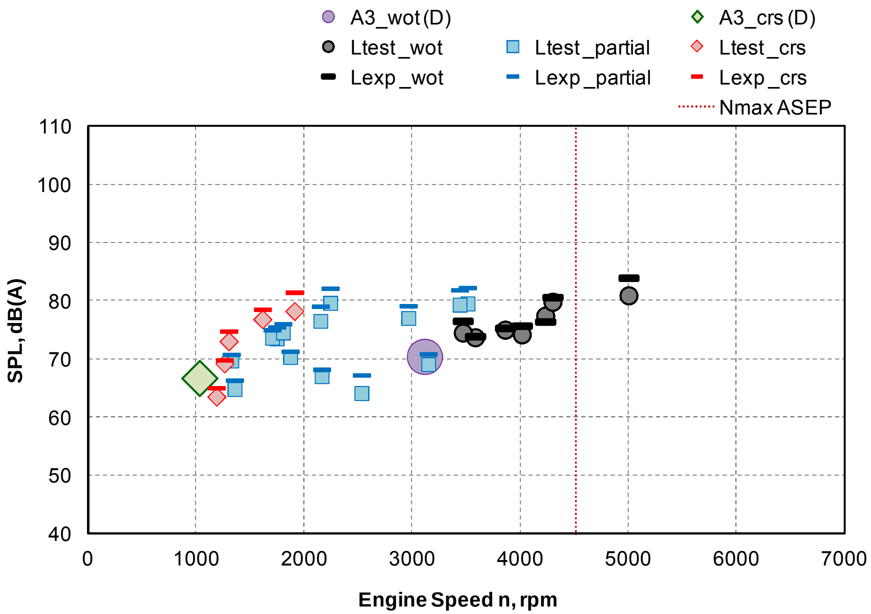
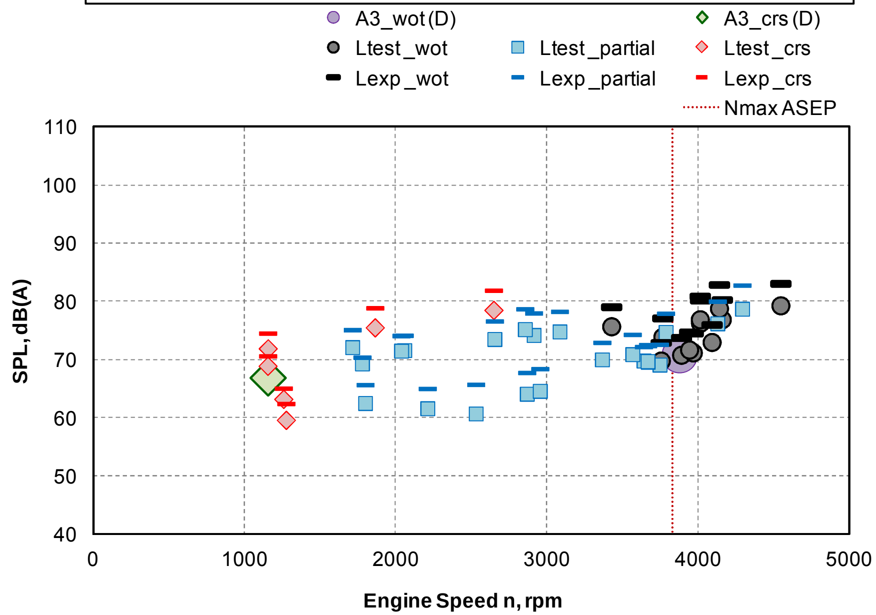
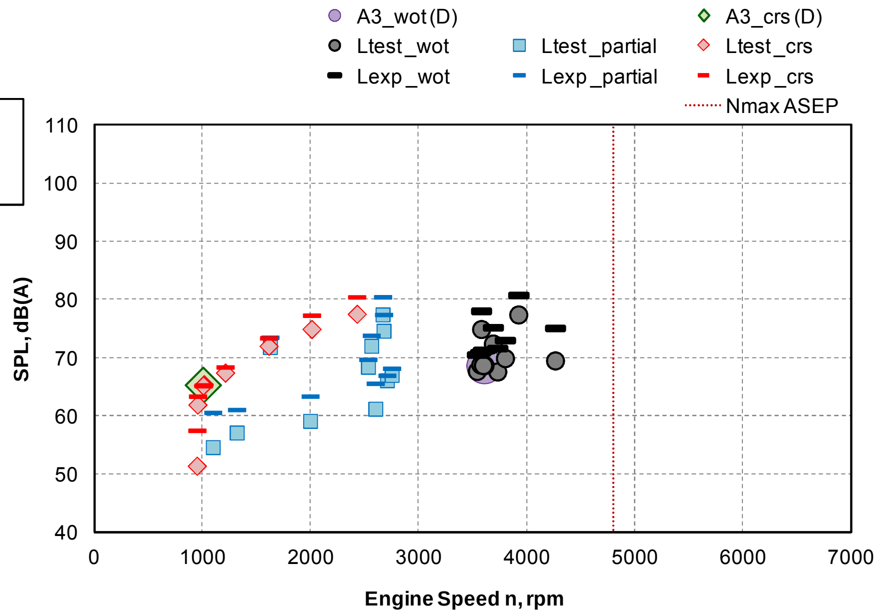
Vehicle-04, Non-locked, D-range, X=99%



Vehicle-05, Non-locked, D-range, X=99%



Vehicle-06, Non-locked, D-range, X=99 %



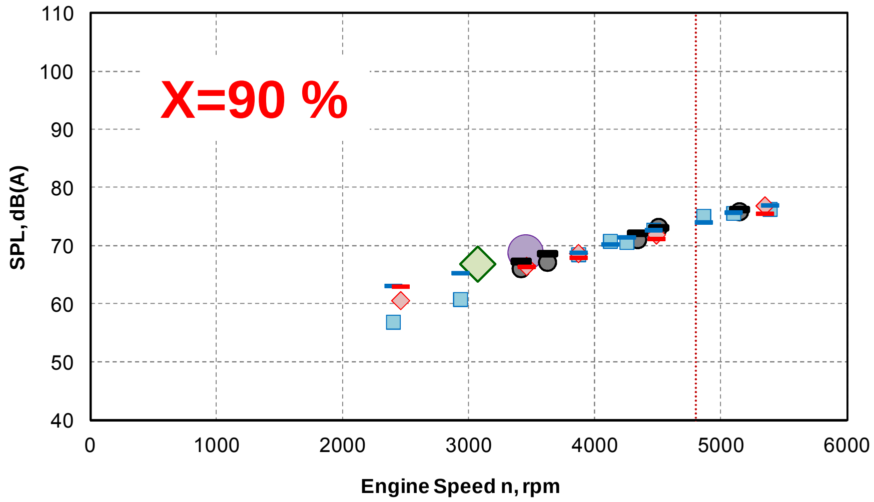
If X is used by measured value, expected sound level L_{exp} by sound model corresponds to measured vehicle sound level L_{test} on D range.

Compared with L_{test} and L_{exp} (Fixed X=90%)

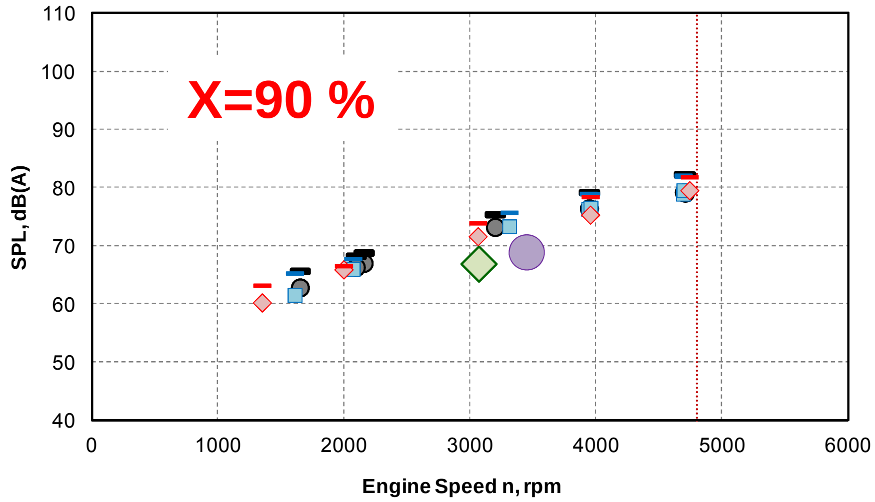
If fixed X=90% is used, how does the model work?

In case of measured X<90%;

Vehicle-06 Locked 2nd



Vehicle-06 Locked 5th



In case of lower X and engine speed of L_{CRS} is middle of the range, calculation error of the sound model is small. Therefore, fixed 90% can be used for simplification.

Compared with L_{test} and L_{exp} (Fixed X=90%)

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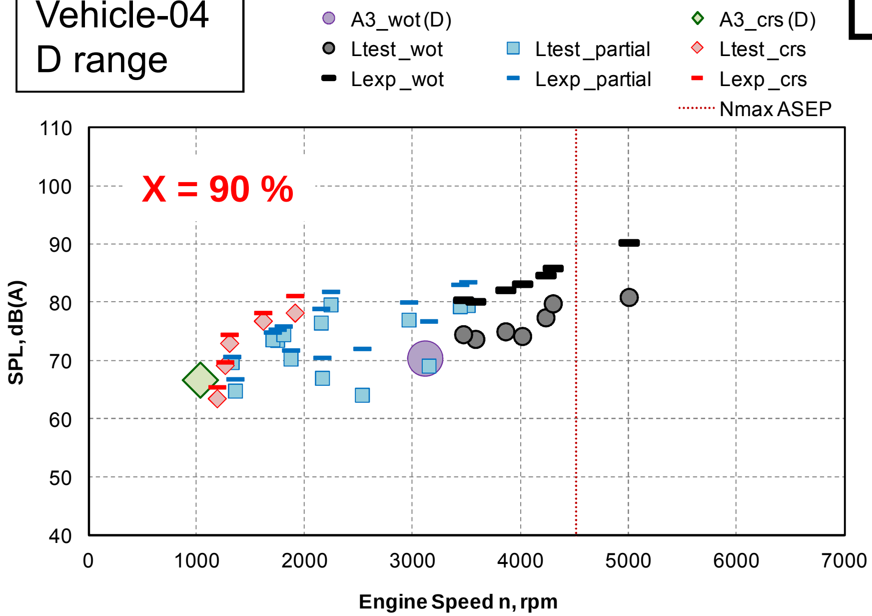
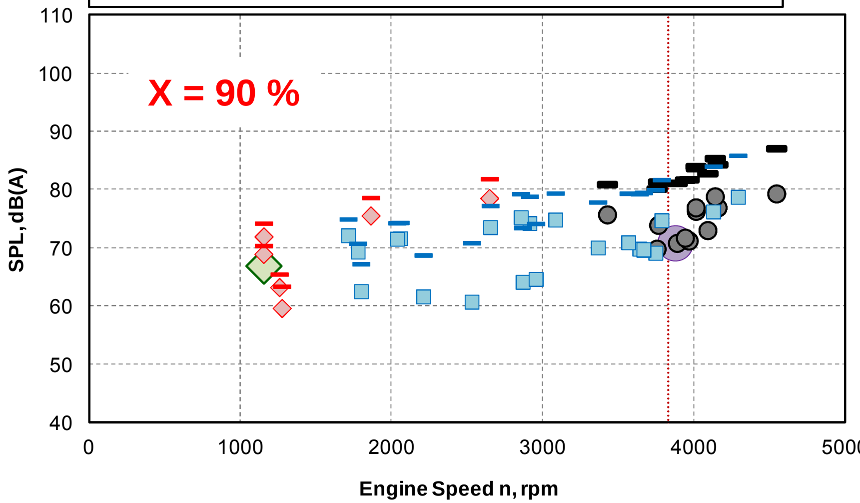
In case of measured X>90%;

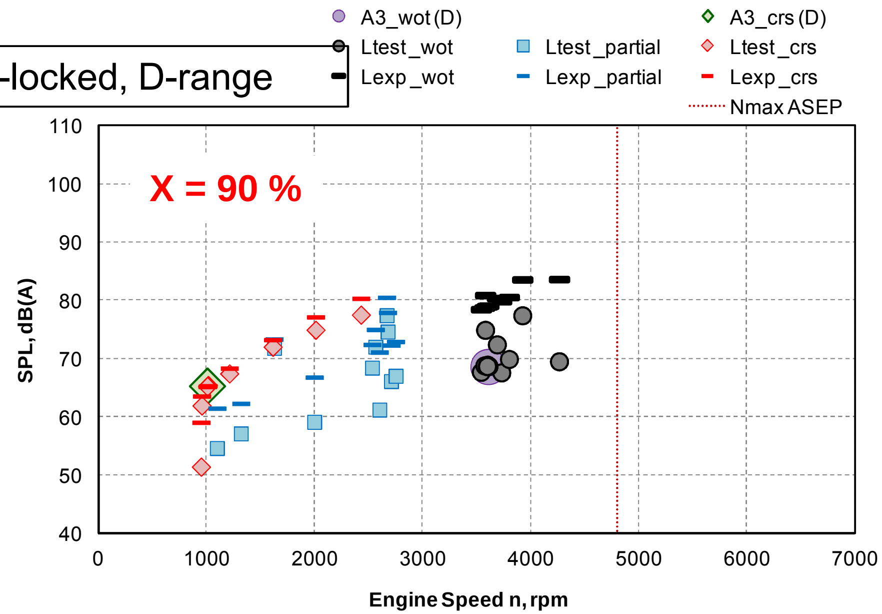
Vehicle-04
D range



Vehicle-05 Non-locked D-range



Vehicle-06, Non-locked, D-range



In case of higher X and engine speed of L_{CRS} is lower, difference between L_{test} and L_{exp} looks large, but within tolerance of sound slope.

2-4 Dynamic model L_{DYN}

$L_{DYN} = L_{WOT} \ominus L_{CRS}$

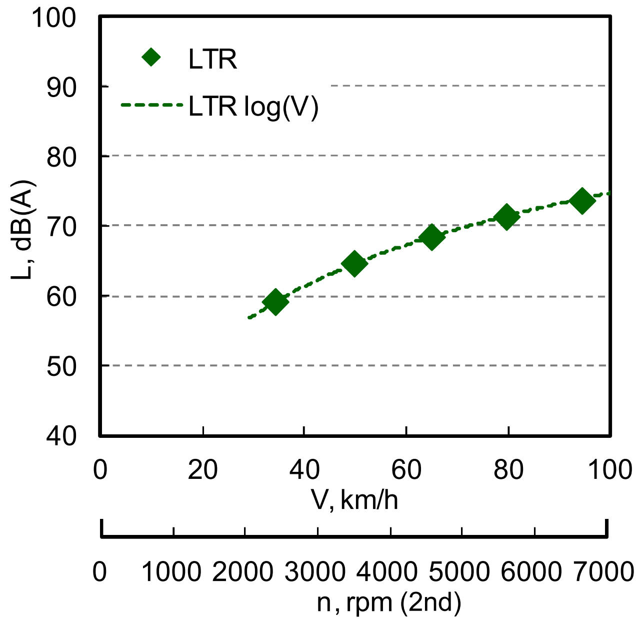
$L_{DYN} = L_{WOT} \ominus (L_{TR} \oplus L_{PT,NL})$

No data with same running conditions in L_{WOT} and L_{CRS}.

Difference between L_{WOT} and L_{CRS} is small for Veh. No.1 to 6.

For the analysis of L_{DYN}, another car was used (PMR=157).

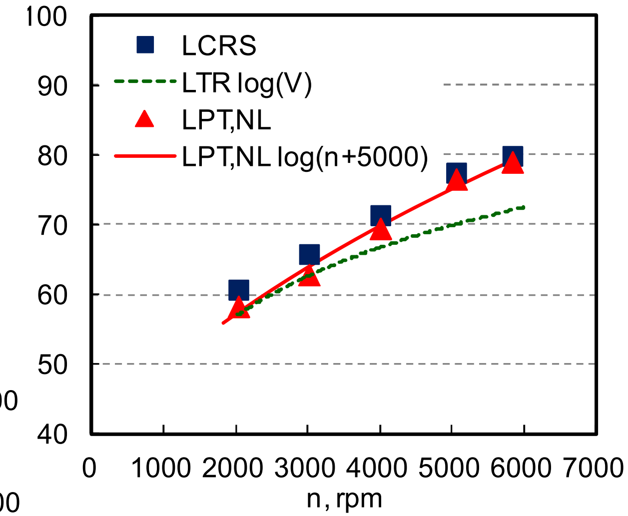
(1) L_{TR}



(V*gear ratio) n vs L_{TR}

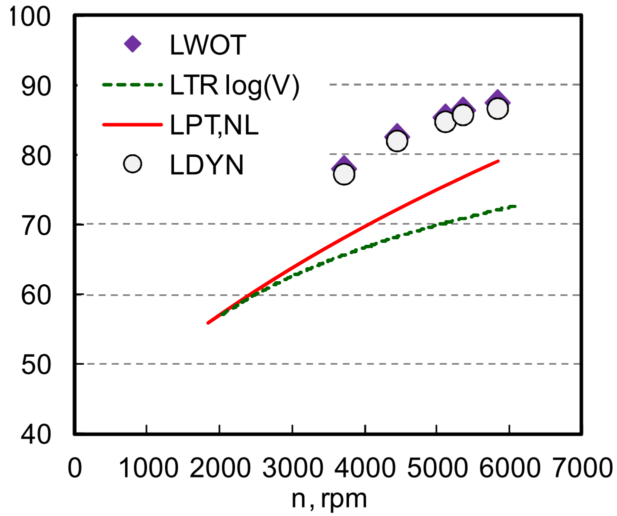
(2) $L_{PT,NL}$

$L_{PT,NL} = L_{CRS} \ominus L_{TR}$



(3) L_{DYN}

$L_{DYN} = L_{WOT} \ominus (L_{TR} \oplus L_{PT,NL})$



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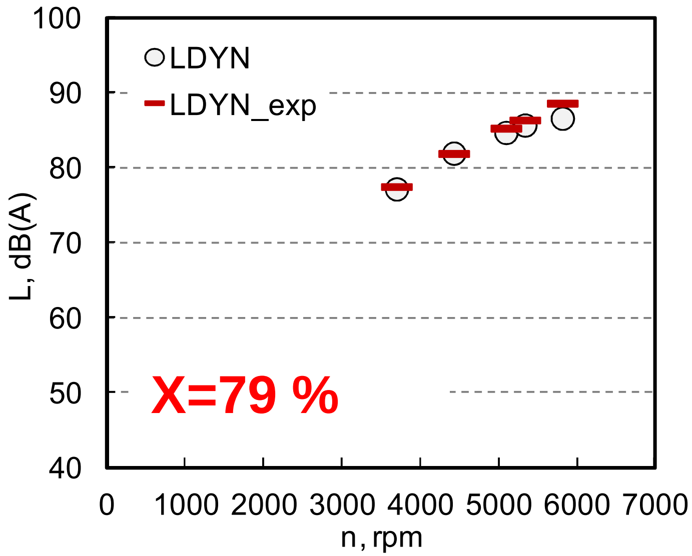
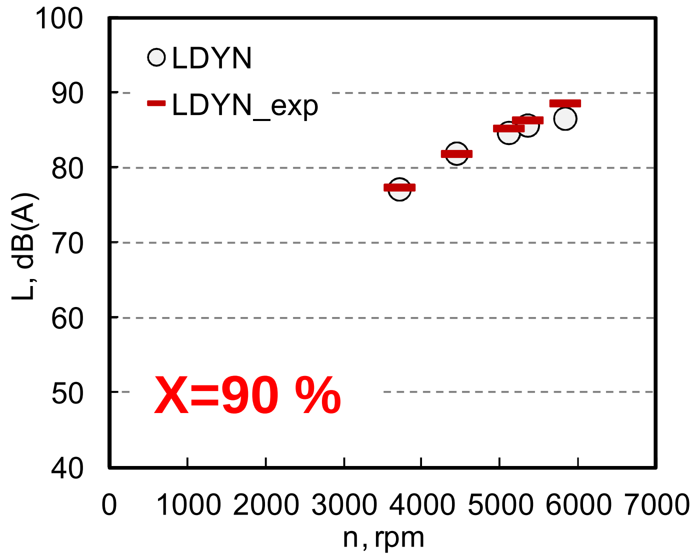
(4) Comparison of L_{DYN} and L_{DYN_exp}

- X% was verified as 79% and additionally used as 90%.
- L_{DYN} obtained in (3) and L_{DYN_exp} are almost same
- Dynamic model also fits.





Summary of Sound model

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All of tyre, mechanical, and dynamic model work well.

Tyre model : already have enough data

Mechanical model: Default value works in our investigation

Dynamic model: Although one car at the moment, the model works.

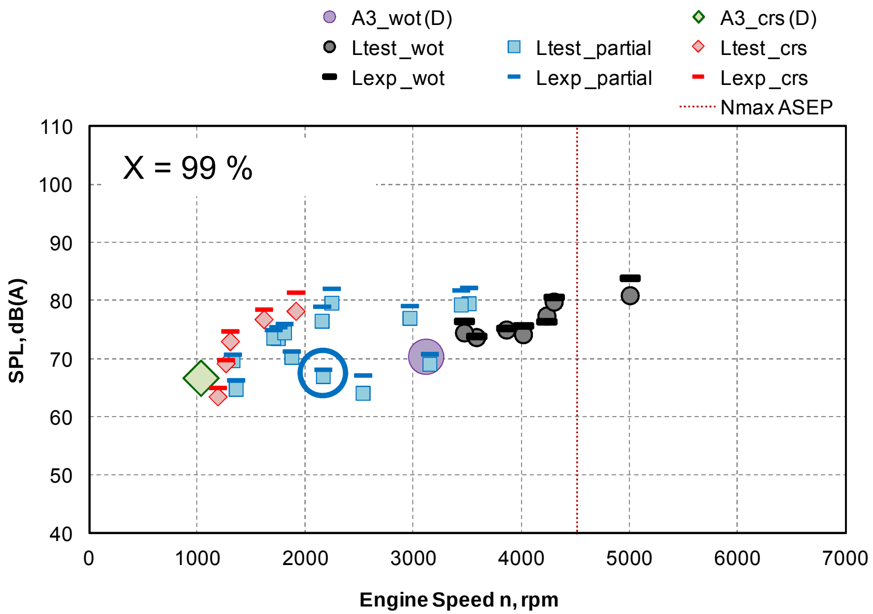
Tyre noise contribution on L_{crs} ,X%, may be considered fixed value 90%.

In case of lower than X=90, calculation error of the sound model is small.
Therefore, fixed 90% can be used for simplification.
In case of higher than X=90, some difference between L_{test} and L_{exp} could be possible. But fixed 90% may be considered because of still within tolerance of sound slope.

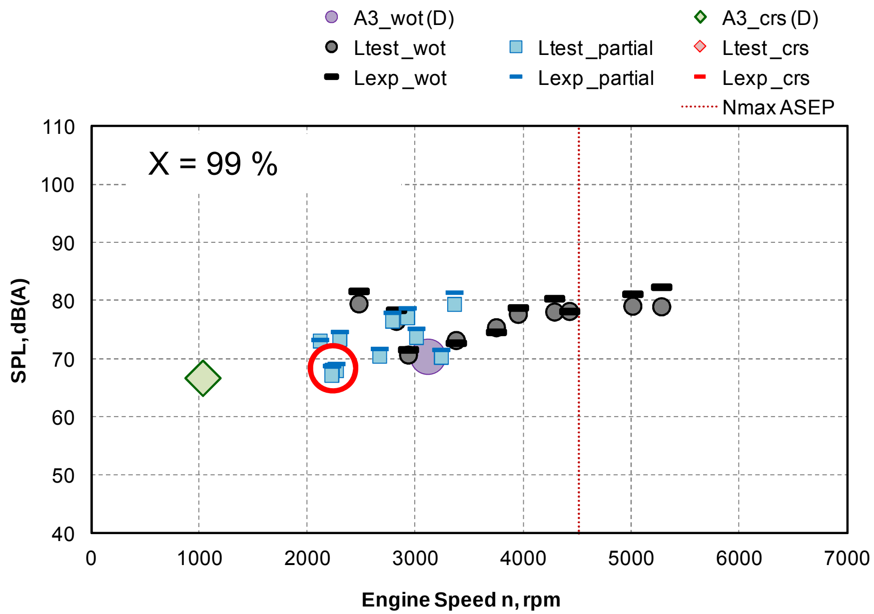
3. Applying to hybrid vehicles

Confirm the sound model to apply hybrid vehicle with ICE on/off during measurement

Vehicle-04, Non-locked, Engine on



Vehicle-04, Non-locked, Engine off→on

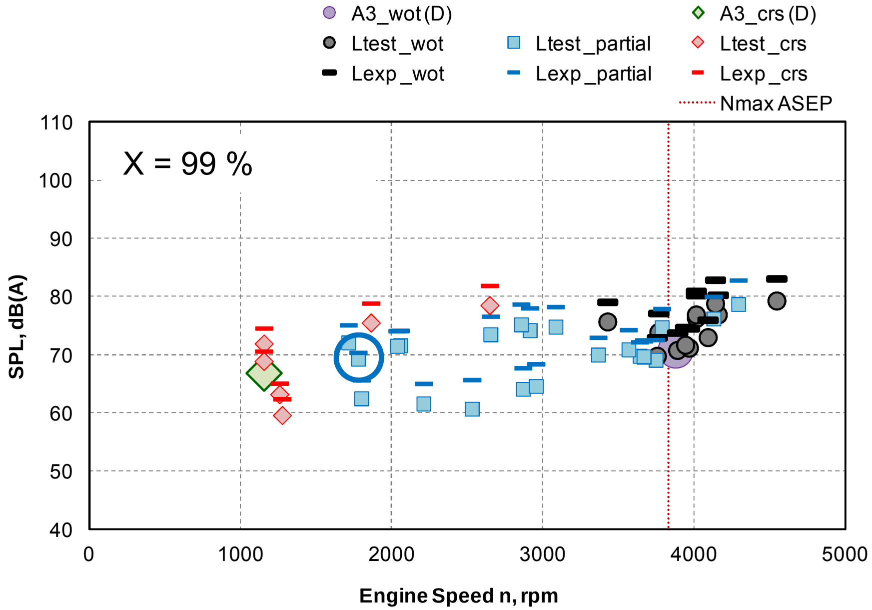


Engine		V, km/h			partial a, m/s^2		n, rpm			SPL, dB(A)	
		AA	PP	BB	AA-BB	PP-BB	AA	PP	BB	Test	Exp
○ (blue)	on	40.1	42.1	51.5	1.63	2.30	1024	1841	2159	67.1	68.0
○ (red)	off→on	40.8	43.0	54.0	1.95	2.78	-	1916	2264	68.1	68.9

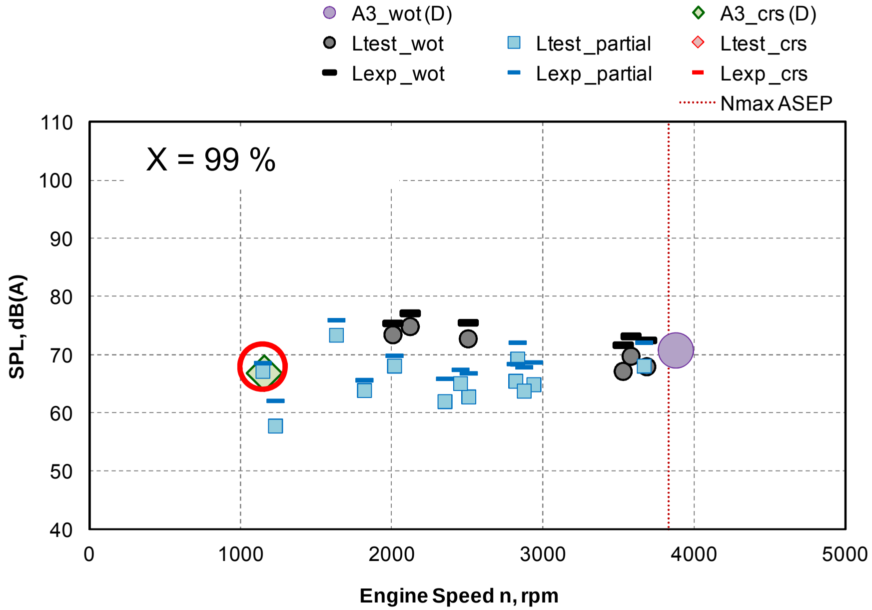
The model can be applied to HEV (Engine off → on)

Confirm the sound model to apply hybrid vehicle with ICE on/off during measurement

Vehicle-05, Non-locked, Engine on



Vehicle-05, Non-locked, Engine off→on



Engine		V, km/h			partial a, m/s^2		n, rpm			SPL, dB(A)	
		AA	PP	BB	AA-BB	PP-BB	AA	PP	BB	Test	Exp
○	on	59.2	60.1	61.2	0.38	0.36	1050	1704	1776	69.4	70.5
○	off→on	52.5	53.7	55.4	0.49	0.49	-	-	1143	67.3	68.7

The model can also be applied to HEV (Engine off → on)

4. Remaining issues

Applying to EV and Series-HEV is needed consideration.

Tyre rolling noise and mechanical model should be used without change.
Dynamic model is include torque influence of tyre noise and should be modified.

Vehicle type	Tyre Rolling	Base mechanic	Dynamic
EV	✔	—	Driven torque influence of tyre noise
Series-HEV	✔	✔	Driven torque influence of tyre noise Load impact of ICE

An idea for EV;

③ Dynamic Model, L_{DYN}

$$L_{DYN} = \cancel{Slope_{DYN,NL} * \log((n_{test} + n_{shift}) / (n_{WOT,REP} + n_{shift})) +} L_{REF,DYN,NL} + \Delta L_{DYN}$$

$$L_{REF,DYN,NL} = \cancel{L_{REF,PT,NL}}\ L_{REF,TR} - 15$$

$$\Delta L_{DYN} = [\, L_{WOT,REP} \ominus L_{TR}(V_{WOT,REP}) \ominus \cancel{L_{PT,NL}(n_{WOT,REP})}\,] - L_{REF,DYN,NL}$$

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Thank you for your attention.