15^{th} Heavy Duty Hybrid (HDH) Meeting
24 to 25 October 2013, San Francisco, USA

Consideration on Vehicle Parameters for HILS Simulation

Background and motivation

- Vehicle parameters need to be defined for the HILS simulation model (e.g. weight, air resistance, axle ratio)
- In Japan standard vehicle values are defined for 7 truck (T1-T7) and 5 bus (B1-B5) categories.

truck/tructor category			bus category		standard vehicle specification by MLIT for exhaust gas																
category	vehicle mass range	pay load range	category	vehicle mass range		empty vehicle mass	maximum payload	number of persons	test vehicle mass	tire dynamic radius	overall hight	overall width	transmission gear ratio							diff gear ratio
NO	GVW/GCW(kg)		NO	GVW(kg)	fuel	(kg)	(kg)		(kg)	(m)	(m)	(m)	1st	2nd	3rd	4th	5th	6th	7th	
T1	3.5t<&≦7.5t	≦1.5t	-	—	D・LPG・CNG	1957	1490	3	2757,0	0,313	1,982	1,695	5,076	2,713	1,529	1,000	0,795			4,615
					G・LPG・CNG	1659	1458	3	2443,0	0,303	1,975	1,695	4,942	2,908	1,568	1,000	0,834			4,477
T2		1.5t<	B1	3.5t<&≦6t	D・LPG・CNG	2482	2396	3	3735,0	0,343	2,106	1,780	5,080	2,816	1,587	1,000	0,741			5,275
					G・LPG・CNG	2259	2016	3	3322,0	0,327	2,052	1,722	5,089	2,773	1,577	1,000	0,777			6,051
T3	7.5t<&≦8t	—	B2	6t<&≦8t	G・D・LP G・CNG	3543	4275	2	5735,5	0,388	2,454	2,235	6,350	3,876	2,301	1,423	1,000	0,762		4,771
T4	8t<&≦16t	—	B3	8t<&≦16t	G・D・LP G・CNG	4527	7737	2	8450,5	0,469	2,617	2,374	6,416	4,096	2,385	1,475	1,000	0,760		5,208
T5	16t<&≦20t	—	B4	16t<&≦20t	G・D・LP G・CNG	8688	11089	2	14287,5	0,502	3,049	2,490	6,331	4,224	2,410	1,486	1,000	0,763	0,612	6,309
T6	20t<&≦25t	—	B5	20t<	G・D・LP G・CNG	8765	15530	2	16585,0	0,473	2,934	2,490	6,304	4,170	2,393	1,456	1,000	0,752	0,604	5,102
T7	25t＜	—	-	—	G・D・LP G・CNG	12120	24974	2	24662,0	0,507	2,961	2,490	6,147	4,000	2,281	1,434	1,000	0,760	0,597	6,061

- Due to different vehicle categories in each region (EU/ US / Japan) harmonization of vehicle categories is very challenging and would probably lead to different categories for each region and an increase of certification effort and complexity

Objectives

Overall objective:

- No need of vehicle categories
- As much as possible independent of OEM specific vehicle specification
- Suitable for global harmonization
- As simple as possible but suitable for certification

Driving resistance related vehicle parameters:

- Since reference positive cycle work of WHVC is derived from WHTC work, the influence of driving resistance related vehicle parameters (test vehicle mass, air resistance, rolling resistance, etc.) is very low
- Proposal:
  - Definition of vehicle resistance related parameters by calculation based <u>only on rated power</u> of hybrid system
  - Independent of OEM specific vehicle configuration and no vehicle categories needed

Ratio related vehicle parameters (engine to wheel):

- For ratio related vehicle parameters some OEM specific vehicle parameters are needed

Overview of proposed vehicle parameter

Vehicle parameter	Proposal for Parallel Hybrid	Proposal for Serial Hybrid	Current Japanese HILS
Test vehicle weight	Calculation by formula	Calculation by formula	vehicle category specific standard values
Curb weight	Calculation by formula	Calculation by formula	vehicle category specific standard values
Rolling resistance	Calculation by formula	Calculation by formula	Formula based in veh. weight (vehicle category specific std. values)
Air resistance	Calculation by formula	Calculation by formula	vehicle category specific standard values
Transmission gear ratio	OEM specific	OEM specific	vehicle category specific standard values
Rear axle ratio	Calculation by formula or OEM specific	OEM specific (if needed)	vehicle category specific standard values
Tire radius	Standard tire radius or OEM specific	Standard tire radius or OEM specific	vehicle category specific standard values
Losses in transmission	Standard value: gear efficiency 98% or 95%	OEM specific value	Standard value: gear efficiency 98% or 95%
Inertia moments of engine/clutch	OEM specific (from engine to drive gear of TM)	OEM specific (from engine to drive gear of TM)	OEM specific (from engine to drive gear of TM)
Inertia moments of transmission, tire, etc	7% of the vehicle curb mass for drive gear of transmission to tire	OEM specific value	7% of the vehicle curb mass for drive gear of transmission to tire

Driving resistance related parameters (Test vehicle weight, Curb weight, Rolling resistance, Air resistance)

Ratio related parameters (Transmission gear ratio, Rear axle ratio, Tire radius)

Losses (Losses in transmission)

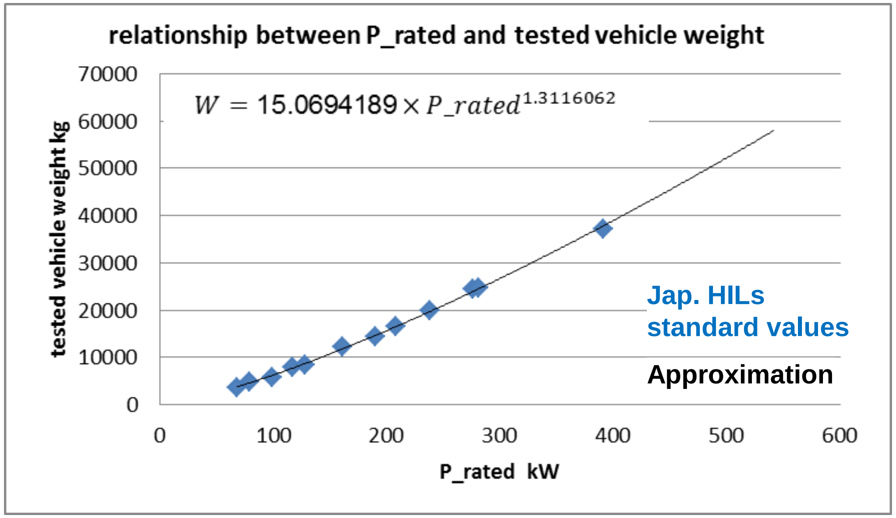
Inertia moments (Inertia moments of engine/clutch; Inertia moments of transmission, tire, etc)

Test Vehicle Weight

Calculation of test vehicle weight

- Test vehicle weight calculated as function of rated system power

$$W[kg] = 15.0694189 \times P\_rated[kW]^{1.3116062}$$

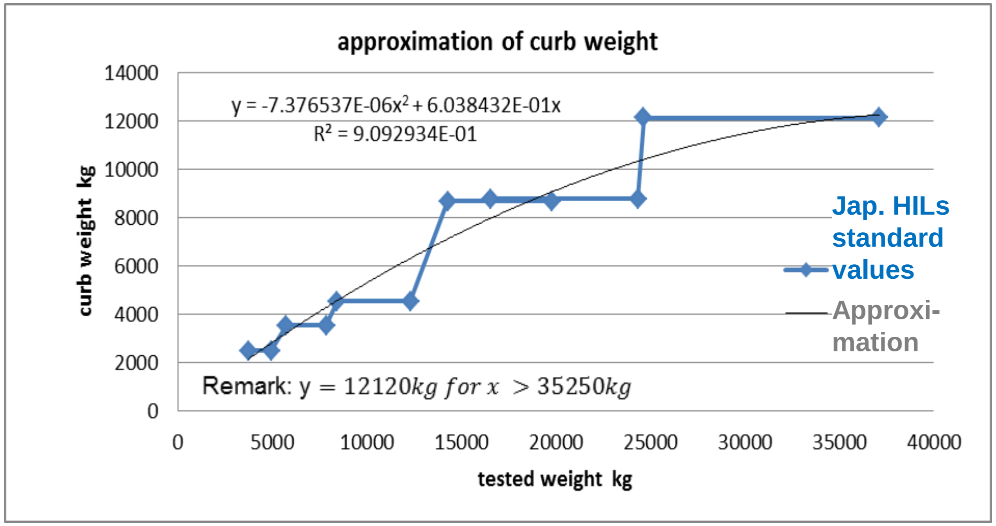


Curb Weight

Calculation of curb weight

- Formula based on test vehicle weight which was empirical evaluated by using the Japanese HILS vehicle categories
- Needed for calculation of inertias

$$W0[kg] = -0{,}000007376537 \times W[kg]^2 + 0.6038432 \times W[kg]$$



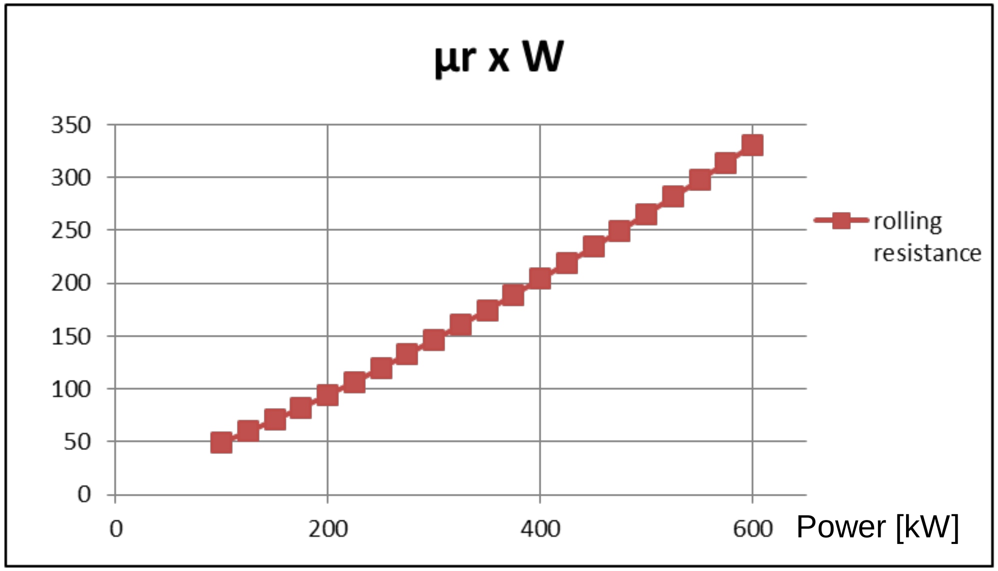
Rolling Resistance

Calculation of rolling resistance

- Rolling resistance $\mu r \times W$ calculated based on vehicle test weight (as defined in Jap. HILS):

$$\mu r \times W = 0{,}00513 \times W[kg] + 17{,}6$$

$$F_{roll}[N] = \mu r \times W[kg] \times g[\frac{m}{s^2}]$$

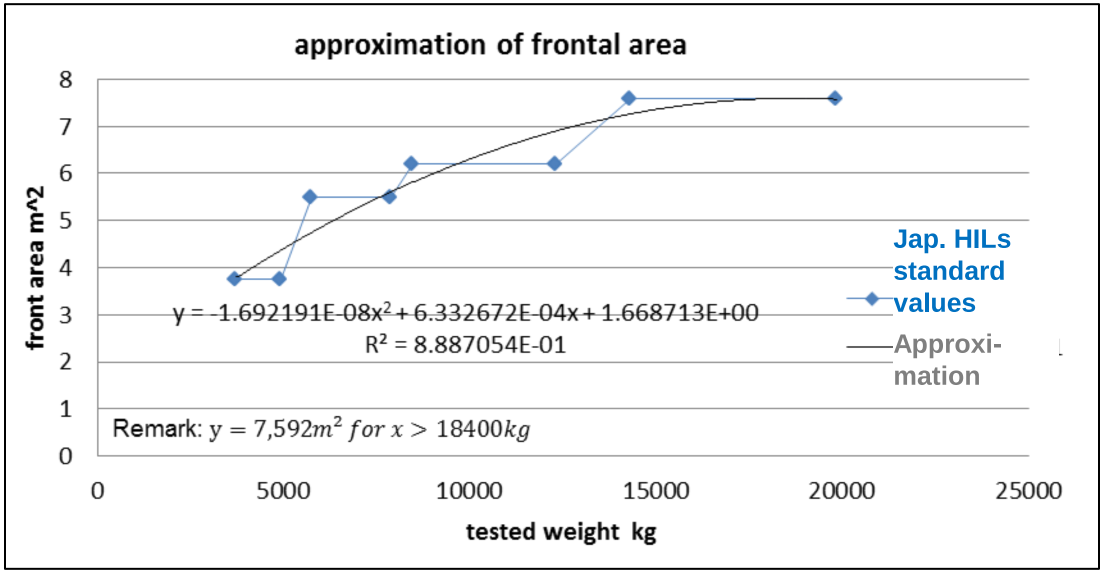


Air Resistance

Calculation of air resistance

- Front area A_{front} as function of the test vehicle weight is derived from the approximation of standard vehicle parameters as defined in Jap. HILS (see graph)
- Simplified formula for air resistance based on Japanese HiLS
- Cw*A values based on Japanese HiLS show a typical and realistic characteristic

$$F_{air}[N] = (0{,}00299 \times A_{Front}[m^2] - 0{,}000832) \times v^2[\frac{km}{h}] \times g[\frac{m}{s^2}]$$



Transmission

Transmission

- Use of OEM specific transmission is recommended because…
  - Standard transmission does not reduce certification effort
  - Global harmonization of standard transmission (fixed number of gears, gear ratios) is difficult due to large number of variants
  - OEM specific transmission needed for OEM specific shifting strategy (if hybrid master ECU includes shifting strategy)

Axle Ratio & Tire Radius (parallel HEV)

Rear axle ratio and tire radius (for parallel HEVs)

- Two alternatives for rear axle ratio and tire radius are proposed
  - Calculation of rear axle ratio based on formula
    - Standard tire radius
    - Rear axle ratio based on calculation (derived from engine speed at 87 km/h)
  - OEM specific ratio between rear axle and wheel
    - OEM specific tire radius
    - OEM specific rear axle ratio
    - Only worst case of overall powertrain ratio (regarding exhaust emission) should be considered

Rear Axle Ratio (parallel HEV)

Rear axle ratio (for parallel HEV)

- Definition of the total powertrain ratio based on the maximum vehicle speed at WHVC (87km/h) and preferred engine speed according to WHTC procedure
- The engine speed at maximal vehicle speed at WHVC is derived from the preferred engine speed and can be calculated based on full load curve of the engine according to WHTC formula:

$$n_{engine_{87km/h}} = n\_norm_{87km/h} \times \left(0{,}45 \times n_{lo} + 0{,}45 \times n_{pref} + 0{,}1 \times n_{hi} - n_{idle}\right) \times 2{,}0327 + n_{idle}$$

n_pref: is defined as that engine speed, where the max. torque integral is 51% of the whole integral (from n_idle to n_95).

n_pref has to be higher than 1.25 x n_low

$n\_norm_{87km/h}$ is the average WHTC speed during max. vehicle speed (87km/h) = 0,566

n_hi is the highest speed where the power is 70% of maximum power.

n_lo is the lowest speed where the power is 55% of maximum power

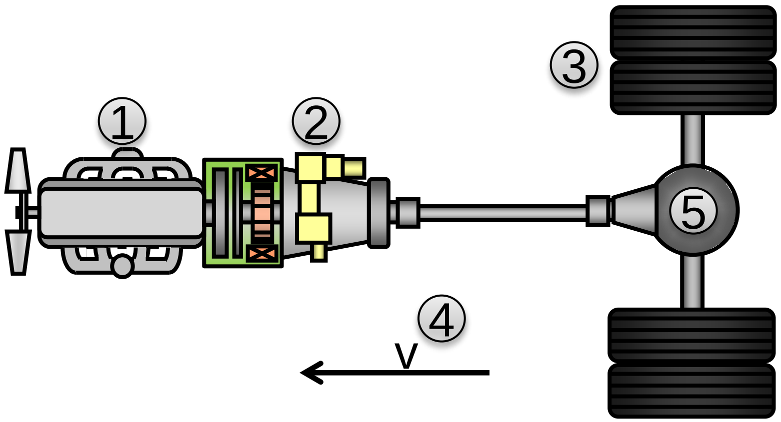
$N_{engine87km/h}$ is the typical / characteristic engine speed at the designed v_max (87km/h)

- Assumption: For the definition of the total powertrain ratio consideration of full load curve of combustion engine without hybrid system seems to be sufficient because additional hybrid system power is available only temporary

Rear Axle Ratio (parallel HEV), cont'd

Rear axle ratio (for parallel HEV)

- Knowing following parameters
  - ① engine speed $n_{87km/h}$ by formula
  - ② ratio of the highest gear of TM (OEM specific)
  - ③ standard tire radius
  - ④ assumed max. vehicle speed of 87km/h



- the axle ratio ⑤ can be calculated as follows:

$$ratio_{axle} = \frac{60 \times 2\pi}{1000 \times v_{max}[\frac{km}{h}]} \times \frac{n_{engine_{87km/h}}[min^{-1}]}{ratio_{gear\_high}}$$

with v_{max} = 87 km/h

Rear Axle Ratio (parallel HEV), cont'd

Rear axle ratio (for parallel HEV) - alternative proposal

WHTC deformalized data from 1536sec to 1746sec

rated power kW	rated speed rpm	avr.WHDHC speed km/h	① Average engine speed @ 87km/h	② Approximated avr.engine speed @ 87km/h	deviation %
115	2200	86,9	1519,2	1516,2	-0,2
130	2200	86,9	1520,2	1516,2	-0,3
155	2200	86,9	1525,8	1516,2	-0,6
170	2200	86,9	1537,3	1516,2	-1,4
175	2200	86,9	1501,0	1516,2	1,0
200	2200	86,9	1537,4	1516,2	-1,4
220	2200	86,9	1544,6	1516,2	-1,9
235	2200	86,9	1530,1	1516,2	-0,9
260	2200	86,9	1523,4	1516,2	-0,5
240	1800	86,9	1211,1	1266,6	4,4
265	1800	86,9	1233,3	1266,6	2,6
290	1800	86,9	1249,0	1266,6	1,4
315	1800	86,9	1247,6	1266,6	1,5
310	1800	86,9	1272,7	1266,6	-0,5
330	1800	86,9	1274,8	1266,6	-0,6
350	1800	86,9	1276,9	1266,6	-0,8
375	1800	86,9	1278,5	1266,6	-0,9
380	1700	86,9	1179,8	1204,2	2,0
425	1700	86,9	1212,9	1204,2	-0,7
460	1700	86,9	1235,2	1204,2	-2,6
81	3500	86,9	2306,7	2327,6	0,9
96	3500	86,9	2346,0	2327,6	-0,8
110	3500	86,9	2298,8	2327,6	1,2
129	3500	86,9	2337,0	2327,6	-0,4

Engine specific values

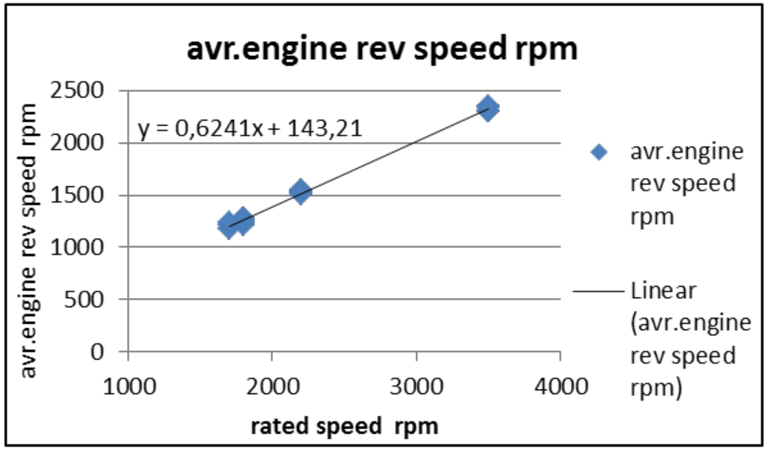
① Average engine speed of several Daimler engines has been calculated with WHDHC simulation tool at 87km/h (based on the engine full load curve)

② An approximation of "*average engine speed*" as function of "*rated speed*" was developed (see graph)

$$avr.engine\ speed = 0{,}6241 \times rated\ speed + 143{,}21$$

③ $ratio_{axle}$ can be calculated by approx. engine speed at 87km/h and ratio of the highest gear (TM)

$$ratio_{axle} = \frac{60 \times 2\pi}{1000 \times v_{max}[\frac{km}{h}]} \times \frac{n_{engine_{87km/h}}[min^{-1}]}{ratio_{gear\_high}}$$



*Further OEM specific engines needed for validation of the function!

Tire Radius

Tire radius

- Standard tire radius or OEM specific
  - Proposed standard tire radius: 0,40m
  - Standard tire radius calculated as average from Japanese vehicle categories

Powertrain ratio (serial HEV)

Powertrain ratio for serial HEV

- Premises for serial hybrids:
  - Transmissions and rear axles vary strongly between different serial hybrid concepts
  - Depending on concept transmissions and rear axles don’t exist for serial hybrids
  - Combustion engine speed is not related to the wheel speed
- Proposal:
  - Therefore for serial HEV ratios between engine and wheel (if existing) should be OEM specific
  - It should be possible to adjust the following parameters:
    - axle ratio, number of gears and gear ratios (e.g. to “1” for a serial HEV with a real hub engine)
    - transmission between e-motors and tire
  - For certification of serial hybrid only worst case of overall powertrain ratio (regarding exhaust emission) should be considered

Transmission Losses

Losses in transmission

- Japanese HILS regulation defines standard values:
  - gear efficiency of 98% for direct drive gear or
  - gear efficiency of 95% for indirect drive gears.
- The values seems to be sufficient for parallel Hybrid in the GTR HILS model and should be taken over
- OEM specific value shall be allowed for a fix-transmission or 2-gear transmission for serial Hybrids

Losses in drive axle

Losses in drive axle

- Japanese HILS regulation defines a standard value for the driven axle efficiency of 95%
- The values seems to be sufficient for parallel Hybrid in the GTR HILS model and should be taken over
- OEM specific value shall be allowed for a special axles for serial Hybrids

Inertia Moments

Inertia moments

- Most important rotating parts regarding inertia:
- Wheels (esp. at high gears)
  - Japanese HILS regulation defines a standard inertia value for the section from driven gear of transmission to wheel of 7% of the vehicle curb weight
  - The curb weight can be calculated based on the test vehicle weight according to the formula mentioned before
  - This simple approach seems to be sufficient for the GTR HILS model and should be taken over
- Engine, Clutch plate (to the driven gear of transmission)
  - Japanese HILS regulation uses OEM specific values
  - This approach should be taken over since it seems to be hard to define common values
  - OEM specific values shall be allowed especially for the inertias of a generators, wheel hub e-motors or central e-motors which can be used serial hybrid and which are not harmonized.

Further Steps

The following steps are suggested:

- Suitable definition of rated power (p_rated) of hybrid system needs to be further investigated