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Considerations on adapting the new WLTC test cycle for a conventional powertrain to a computerized simulation using AVL Cruise software

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Abstract. Vehicle simulation is a very important part in the design and development of powertrains groups. To precisely simulate the powertrain running status, many commercial software products are applied into the development of control strategy. AVL Cruise software allows the simulation of the vehicle driving performance, fuel consumption and emissions. In 2017 the European Union intends to adopt a unique normalized cycle World Harmonized Light vehicles Testing Cycle – WLTC, more representative for the real traffic, with more aggressive acceleration and patchy, with higher maximum speed, with a greater length of time. A conventional powertrain will be created in the AVL Cruise software and simulate vehicle driving performance, fuel consumption and emissions over the new WLTC test cycle. In order to achieve this, the WLTC test cycle will be written and adapted to the Cruise simulation software for the proposed powertrain. A conventional powertrain, with a unique power source represented by an internal combustion engine will be considered for the sake of simplicity. The results will be useful for the automotive specialists and car manufacturers.

1. Introduction

Road transport contributes about one- fifth of the European Union's (EU) total emissions of carbon dioxide (CO2), the main Greenhouse Gas (GHG), 75% of which originates from passenger cars. Despite the fact that these emissions fell by 3.3% in 2012, they are still 20.5% higher than in 1990.

A fleet average mass-dependent CO_2 limit of 130g/km by 2015 was adopted. Another10 g of CO_2 were expected to be gained from supplementary measures not covered by the type approval test (i.e. bio-fuels, gearshift indicators, improved air-conditioning systems, driver education etc.), in order to reach overall emission levels of 120g CO_2/km. Since then the EU implemented a strategy for reducing fur-ther CO2 emissions and fuel consumption from passenger cars foreseeing compulsory, fleet average and mass dependent targets of 95g/km by 2021. Failure of a manufacturer to comply with mandatory limits results in fines ranging from €5 to €95per gram of excess CO_2 per vehicle sold.
This policy has caused significant changes in the average official CO_2 emissions and a shift in the major characteristics of European passenger vehicles over the past decade (Figure 1).
This has been accompanied by a reduction in average engine capacity despite the apparent increase in engine power and is a direct result of engine downsizing for both diesel and gasoline engines.
However, the WLTP is not expected to change the established CO_2 targets or the way policy is being assessed, and a translation of the WLTC into the NEDC- based system will take place until year 2020.To what extent, and how, the new procedure will be used in Europe for policy making and vehicle labelling with regards to vehicle fuel consumption and CO2 emissions, remains (as of 2017) unclear.

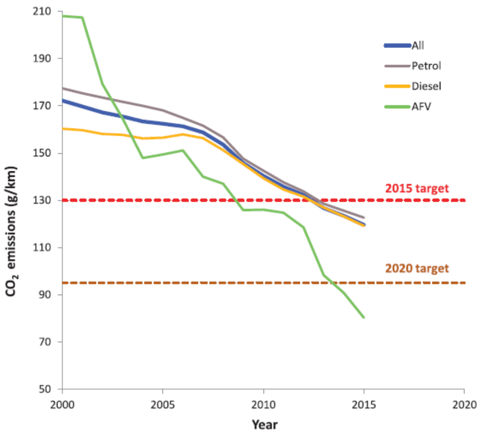

Figure 1. Evolution of CO2 emissions from new passenger cars by fuel type.

Therefore, this paper treats software simulation as an important part of all this process of adapting the new WLTC test cycle using AVL Cruise software and can significantly reduce the time required for developing new technologies and control strategies in the automotive field. In order to achieve this, the WLTC test cycle will be written and adapted to the Cruise simulation software for the proposed powertrain.

2. Adapting the new WLTC test cycle in AVL Cruise simulation software

In the following paragraphs the most influential differences between the NEDC and WLTP are described and how to adapt and introduce the new WLTC test cycle parameters to simulate a conventional vehicle in the AVL Cruise software.

2.1. Description of the main differences between NEDC and WLTC test cycle

WLTP substantially differs from NEDC in the preparation and preconditioning of the vehicle for testing and the post-test management. The latter mainly concerns the corrections applied in the CO2 values to account for the different contribution of each vehicle's electrical system, a correction which is of crucial importance given the high penetration of micro and mild hybridization systems to modern cars.
The kinematic characteristics of NEDC and WLTC, speed and acceleration related rebound effects, as well as their potential effect on pollutant formation and CO2 emissions have been sufficiently

covered by the scientific community so far. The basic characteristics of NEDC and WLTC, are described in Table 1.

Table 1. Basic characteristics of NEDC and WLTC.

	NEDC	WLTC
Distance [km]	11.023	23.262
Duration [s]	1180	1800
Idle time [s]	280	235
Phases [#]	2	4
Average speed/w idle (w/o idle) [km/h]	33.6 (44.7)	46.5 (53.5)
Max speed [km/h]	120.0	131.3
Max acceleration [m/s2]	~ 1.0	~ 1.7

Compared to WLTC, NEDC is characterized by shorter duration and distance, longer idling and cruising time and lower speed and acceleration (Figure 2).

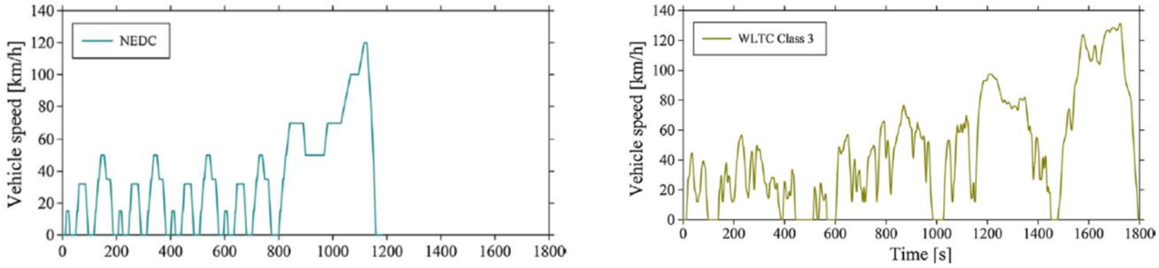

Figure 2. NEDC and WLTC driving profiles over time.

It can be seen that the NEDC have stabilized speed zones with slow acceleration while the WLTC they are more aggressive due to the operation in the transitional phases.

Table 2 presents the main improvements of the WLTP with respect to the NEDC. The changes are divided in four categories, namely: (i) road-load determination; (ii) laboratory test; (iii) processing test results; and (iv) Certificate of Conformity (CoC).

With regards to (i) a series of changes take place. In WLTP for example the definition of the mass has changed (to be more realistic by e.g. including the effect of optional equipment). In addition, the mass is allowed to vary in a continuous way (inertia classes have been removed). A new more detailed protocol regarding the calculation of resistance forces is introduced; tyre characteristics are strictly defined as are the boundary conditions for tyre pressure and pressure during the test.

For example, the WLTP prescribes that the type-approval test is carried out with the tyre pressure set at the minimum of its range, resulting in an approximate 0.3% increase in CO2emissions. The WLTP standard for the minimum tyre tread depth is more stringent (80%-100%) than under NEDC (50% - 90%). In category (ii) the new speed profile and gears shifting calculation algorithm are the main changes where as more strict definitions regarding the test temperature boundaries and the vehicle preconditioning are introduced.

The world harmonized driving cycle (WLTC) is expected to address the issue of a non-realistic speed profile or traffic conditions. The WLTC cycle was produced from around 1 million km of real-world vehicle activities and is subdivided in four different phases reflecting traffic conditions at different average speeds.

With regards to the processing of the final results, new concepts are foreseen such as the correction of the fuel consumption for the difference between the test temperature (23°C) and the average European temperature value of 14°C and the correction addressing the effect of battery depletion during the test (battery State Of Charge correction). Finally, the current type approval extension mechanism, resulting in up to 4% lower emissions compared to the tested one, is abolished and a new definition of vehicle families and how the certification can be extended to vehicles of similar characteristics is introduced.

Errors and flexibilities in the test execution and road load determination have been also corrected.

This will contribute to achieving a more realistic certification value.

Table 2. Comparison of NEDC and WLTP.

Category	Item	in NEDC	in WLTP	Impact on CO_2
Road Load Determination	Vehicle test mass	Present	Modified	↑
	Tire selection	Present	Modified	↑
	Tire pressure	Present	Modified	↑
	Tire tread depth	Present	Modified	↑
	Calculation of resistance forces	Present	Corrected	↑
	Inertia of rotating parts	Absent	Introduced	↑
	Default road load coefficient	Present	Modified	?
Laboratory test	Driving cycle	Present	Modified	↑
	Test temperature	Present	Modified	↑
	Vehicle inertia	Present	Modified	↑
	Preconditioning	Present	Modified	↑
	Gear Shift Strategy	Present	Modified	↓
Processing test results	Battery state of charge correction	Absent	Introduced	↑
	Correction for the average EU temperature	Absent	Under discussion	↑
	Correction of cycle flexibilities	Absent	Under discussion	±

The impact of the introduction of WLTP on the average fleet-wide CO_2 is estimated to be of the order of 15-25%, increasing the average CO_2 of new passenger cars between 18 and 30g/km (although any calculation has a wide margin of uncertainty due to the fact that the new definitions in the protocol regarding vehicle classification, road load determination and type approval extension cannot be easily quantified). WLTP in its first stage is lacking any correction for the use of air-conditioning and there is no ex-post correction of the protocol based on the real-world performance of vehicles.

Due to the existence of specific CO_2 targets associated with the NEDC, the old procedure will remain as a legal reference for all CO_2 related targets until year 2021.

2.2. Describe the steps needed to adapting the new WLTC test cycle in AVL Cruise

In order to written and adapted the new WLTC test cycle to the Cruise simulation software for the proposed powertrain it is necessary to explain the main advantages of computerized simulation.

One way of studying the potential of improving vehicle operation is to simulate different working conditions using the AVL-CRUISE software. CRUISE is the prime tool for finding the right balance between fuel economy, emissions, performance and drive quality for conventional and alternative vehicle concepts. Several studies have been undertaken to predict fuel economy and carbon dioxide emissions, or to optimize these parameters, as well as developing new strategies for alternative power train architectures. Other studies even used these different modules to better predict performance and emissions during transient operation.

Such a study is developed in this paper, with the aim to adapting the new conditions of WLTC test cycle using AVL Cruise software, test cycle characterized by transient operation as compared to the NEDC test cycle. After that, a conventional powertrain will be created in the AVL Cruise software and simulate vehicle driving performance, fuel consumption and emissions over the new WLTC test cycle adapted.

To write and adapted the new WLTC test cycle in the context of software AVL Cruise finds a basic menu classified as follows: Project Explorer, Calculation Center, Result Manager.

In the Project Explorer submenu, we will encounter several branches as follows: Vehicle Model, Vehicle Data, Project Data, and Favorites.

In order to add a new WLTC test cycle, it is necessary to add a new simulation cycle as shown in Figure 4 in the Project data option.

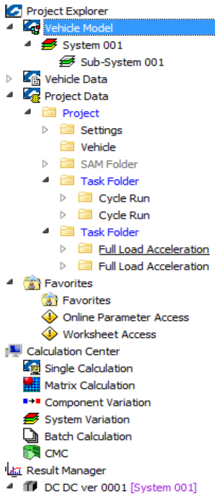

Figure 3. Overview of the AVL Cruise v2014 menu.

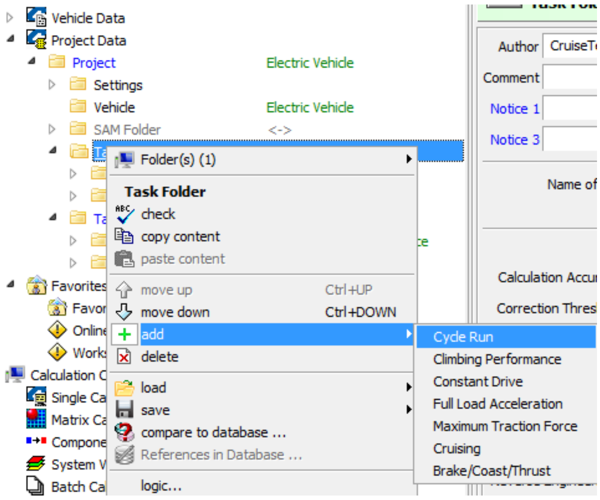

Figure 4. Adding a new simulation cycle.

Once the new simulation cycle is added, it will be necessary to load a proper cycle, characterized by the speed and time coordinates.
The new WLTC test cycle can be described as an excel table in the form of table 3. The table will have to contain the speed of the vehicle in seconds per second. In the example below only part of the WLTC test cycle is described and it is characterized by transient operating phases.

Table 3. Characteristics of the new WLTC test cycle.

Cycle WLTC			
Time [s]	Speed [kmph]	Slope [-]	Gear
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0,2	0	0
13	1,7	0	1
14	5,4	0	1
15	9,9	0	1
16	13,1	0	1
17	16,9	0	1
18	21,7	0	2
19	26	0	2
20	27,5	0	2
1534,976	61,37614	0	4
1535,976	63,15704	0	4
1536,976	65,54272	0	4
1537,976	68,33318	0	4
1538,976	71,52363	0	4
1539,976	74,82125	0	4
1540,976	78,31647	0	4
1541,976	81,71886	0	4
1542,976	84,82602	0	4
1543,976	87,34034	0	5
1544,976	88,96182	0	5
1545,976	89,97613	0	5
1546,976	90,58568	0	5
1547,976	90,99045	0	5
1548,976	91,48807	0	5
1549,976	91,98807	0	5
1550,976	92,68329	0	5
1551,976	93,3833	0	5
1552,976	94,1809	0	5
1553,976	94,8833	0	5
1772,976	62,77637	0	5
1773,976	59,7716	0	5
1774,976	57,06444	0	5
1775,976	54,65728	0	4
1776,976	52,25728	0	4
1777,976	49,75966	0	4
1778,976	46,86921	0	4
1779,976	43,57876	0	4
1780,976	39,98592	0	4
1781,976	36,48353	0	3
1782,976	33,27637	0	3
1783,976	30,56444	0	3
1784,976	28,3525	0	2
1785,976	26,34773	0	2
1786,976	24,44534	0	2
1787,976	22,54534	0	2
1788,976	20,54773	0	2
1789,976	18,25489	0	2
1790,976	15,56444	0	2
1791,976	12,37637	0	2

Once we set up the table with this time and speeds should be loaded in the cycle of previously created, as shown in Figure 5.

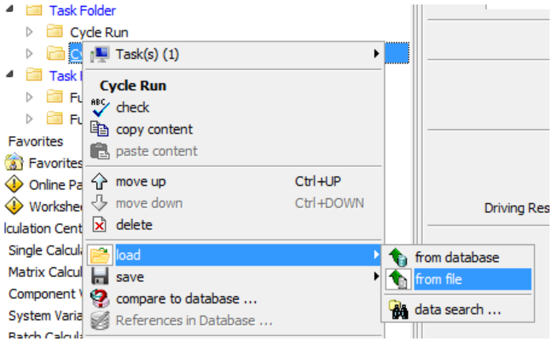

Figure 5. Loading the new WLTC test cycle.

Because the simulation with the new test cycle WLTC loaded can be functional a parameterization is required as shown in Figure 6 and Figure 7:

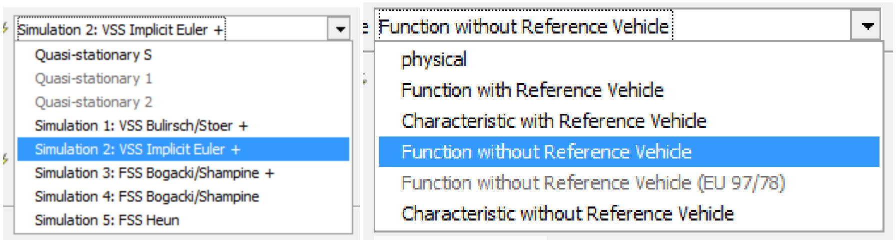

Figure 6. Parameterization of simulation version VSS Implicit Euler + and Driving Resistance.

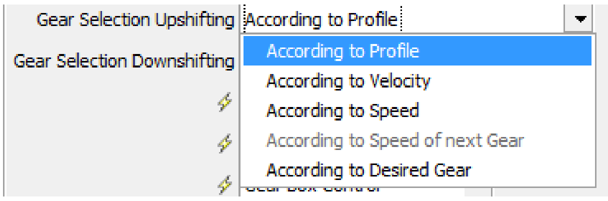

Figure 7. Parameterization of Gear Selection Upshifting and Downshifting.

Once these parameterizations have been made to the new WLTC teste cycle in the AVL Cruise simulation software, any simulation of a vehicle with this test cycle can be performed. In the following, a conventional powertrain simulation will be performed.

3. Simulation for the conventional powertrain with WLTC test cycle adapted in AVL Cruise

To perform a simulation, a conventional powertrain will be created in the AVL Cruise software and simulate vehicle driving performance, fuel consumption and emissions over the new WLTC test cycle adapted.

Table 4. General data of car.

Engine type	1.4 i 16V (75 Hp)
Power	75 CP /5000 rot/min
Capacity	1390 cm^3
Engine torque	126 Nm /3800 rot/min
Fuel type	Gasoline
Traction	Front-wheel drive
Transmission	Manual
Maximum authorised mass	1780 kg

Below are the results obtained after computerized simulation using AVL Cruise for conventional powertrain with the new WLTC test cycle adapted, making a comparison with a simulation against the NEDC test cycle.

Table 5. Fuel consumption and CO2 emission for conventional powertrain, by new WLTC test cycle.

	WLTC	NEDC
Fuel Consumption	7.3 [l/100km]	5.4 [l/100km]
CO2 emission	183 g CO2/km	133 g CO2/km
Comparison WLTC vs. NEDC [l/100km]	35.18 %	
Comparison WLTC vs. NEDC [g CO2/km]	37.59 %	

4. Conclusions

Application of simulation processes using AVL Cruise offers a number of advantages such as reduced costs for the car manufacturers and the opportunity to revise the car structure at any stage of the process.

The data obtained with a new WLTC test cycle as a result of computer simulation using AVL Cruise shows a noticeable increase of fuel consumption and CO2 emission in the transition loads for NEDC vs. WLTC.

The software can be used to analyze operational parameters for the entire vehicle, including the power unit, transmission and after-treatment system, throughout all the development phases. This greatly reduces the need for experimental trials and results in decreased development costs, with speedy identification of critical points where significant improvements can be achieved.

Simulation software can significantly reduce the time required for developing new technologies and control strategies in the automotive field. Therefore, the possibility of simulating a conventional powertrain operation using the AVL Cruise software was investigated. The results obtained by running the software were found indicative data that can be effectively will be useful for the automotive specialists and car manufacturers.

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