INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2023, VOL. 7, NO:4, 394-402 www.ijastech.org e-ISSN: 2587-0963

A Study on the Comparison of Engine Performance and Vehicle Losses of a Gasoline Vehicle in WLTC and Artemis Rural Driving Cycles

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Abstract

The updating of automotive driving cycles to encompass contemporary driving conditions and conducting driving tests with these cycles hold significant importance in determining vehicle performance. In this study, engine performance and vehicle energy losses of a passenger-type vehicle with a gasoline internal combustion engine were examined in 2 different driving cycles of the new generation with the help of the GT-SUITE vehicle simulation program. All parameters of the vehicle and the driving cycle were defined with the help of the simulation program. According to the simulation results, the number of gear changes and transmission losses were higher in the Artemis driving cycle, which had a higher average acceleration (0.62 m/s^2) and deceleration (-0.56 m/s^2) acceleration, along with it. Torque converter losses were 4.73 times less in the Artemis cycle, where the torque converter locking clutch was used in greater quantities. The high average acceleration also increases tire and braking losses. When a comparison was made in terms of vehicle energy losses, it was found that Artemis driving cycle losses were 22% higher. When the driving cycles are compared in terms of specific fuel consumption, a specific fuel consumption of 386.7 g/kWh was obtained in the Artemis driving cycle and 548.9 g/kWh in the WLTC driving cycle.

Keywords: Artemis driving cycle, vehicle modeling, transmission losses, WLTC driving cycle

Research Article

https://doi.org/10.30939/ijastech..1361010

Received 15.09.2023
Revised 14.12.2023
Accepted 25.12.2023

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1. Introduction

Thanks to technological developments, automobiles are developing very rapidly and are becoming vehicles that more and more people have access to [1-2]. The rapid increase in the number of vehicles worldwide, the depletion of fossil fuels and environmental pollution problems [3] are reducing the advantages of choosing internal combustion engine vehicles (ICEV) [4]. Most of the oil consumption in Turkey comes from vehicles used on highways. The increasing number of vehicles and fuel costs every day increases the importance of vehicle energy efficiency. In order to reduce fuel consumption, vehicle usage should be optimized, traffic signs should be arranged, public transportation should be encouraged, and the engines, power transmission and external bodies of the vehicles should be designed to minimize fuel consumption. There are many motion resistances that affect vehicles as motion resistance and vary depending on the technical characteristics of the vehicle (clutch systems [5-9], transmission, differential, axle, brakes, tires, etc.). In addition to these, especially on urban roads with a large number of intersections, the impact of vehicle speed, traffic cruising speed, changes in acceleration, deceleration, idle time and traffic flow on vehicle energy losses is very large [10]. In addition, environmental factors such as road conditions and weather conditions also affect the emissions and losses of vehicles. For these reasons, it is not a good method to evaluate vehicle energy distributions, fuel economy and losses depending on the actual values measured on the roads [11]. In order to overcome these problems, a series of standardized tests have been developed to measure the energy consumption and emissions of vehicles under repeatable conditions, which will also be adopted by automobile manufacturers and governments around the world. Vehicle simulation programs can be defined as the study of how a vehicle or a system belonging to a vehicle works by modeling it in a computer environment. After the request model is created in the simulations, various parameters and conditions can be changed to make predictions about the system behavior [12]. MATLAB /Simulink [13-14-28-30], ADVISOR [15], PSAT (The Power System Analysis Toolbox) [16] and Gamma Dec. Special vehicle programs such as GT-SUITE [17] are the most preferred simulation programs to examine vehicle performance. While creating the vehicle model examined in this article, GT-SUITE simulation software, a product of Gamma Technologies, which produces engine and vehicle technology software, was used.

1.1 Driving cycles

Vehicle driving cycles are generally test procedures that are performed to keep fuel consumption and environmental pollution under control by operating vehicles at specified speeds and accelerations and that allow the comparison of different vehicles. In the driving cycles defined in 2 main headings as standard and non-standard, non-standard driving cycles are created with data obtained from real driving conditions [21-22]. It can also cover driving data in rural conditions. In this study, Artemis and WLTC driving cycle data, which are the most intensively used driving cycles in recent periods, were used in automobile driving cycles. The speed-time graph of the driving cycles is given in Fig. 1 and the driving characteristics are given in Table 1 [23-24].

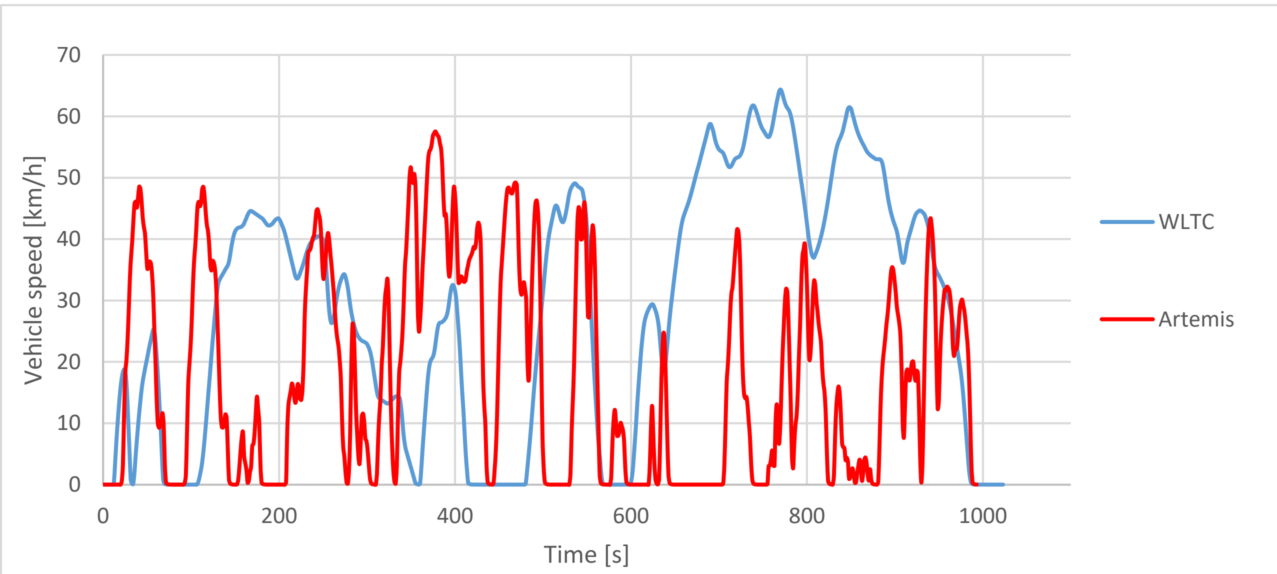


Fig 1. Vehicle speed-time graph of Artemis and WLTC driving cycles

Table 1. Performance characteristics of driving cycles

	Driving cycle	
Parameter	**WLTC**	**Artemis**
Total distance (m)	8096	4866
Average vehicle speed (km/h)	28.5	17.6
Maximum vehicle speed (km/h)	64.4	57.6
Driving cycle average acceleration (m/s^2)	0.21	0.62
Driving cycle average deceleration (m/s^2)	- 0.2	- 0.56
Time (s)	1023	1083

Driving cycles are defined as applicable to a specific type of vehicle and region by representing the actual driving conditions in the best way [18]. Driving cycles are vehicle speed-time graphs used to calculate the fuel consumption and emissions of vehicles in urban, intercity or mixed driving [19-20]. The critical parameters of the driving cycles used are given in Table 1. In this article, the vehicle energy losses of a passenger-type car with a spark plug-ignition engine according to the WLTC and Artemis driving cycles have been studied. The entire model of the vehicle was created with the GT-SUITE simulation program and performance graphs were obtained. The driving cycles used in the simulation program are current driving cycles employed in the automotive industry.

2. Material and Methods

In the model created, the vehicle, engine, gearbox, torque converter were modeled and then the driving cycles were selected. The inputs for the vehicle are shown in Table 2. The engine cylinder volume is defined as 1508 cc, and the inertia value is specified as 0.15 kg m^2. In the model created, an ICE (Internal Combination Engine) controller was used to simulate engine applications such as idling and fuel cutting. This controller is recommended for simulations in order to maximize fuel economy. The ”driver controller" module is a model-based control device used in driving cycle analysis. The driver module has been created to simulate the behavior of the driver controlling the vehicle, taking into account the vehicle path and the accelerator pedal, brake pedal and gearshift status during gearshift. The created model has a feed-forward component that calculates the engine load torque required to correlate the desired vehicle speed or acceleration. The Transmission Controller Device has been used to simulate the use of automatic transmission control in the driving cycle. This controller (Gearbox Controller) has the ability to determine the desired gear status and recall the gearbox shifting action. An automatic gearbox with a torque converter and 6 forward speed levels was chosen as the gearbox. In the model, Lock-up clutches connection is used in the torque converter with fuel economy in mind. In addition, an environmental module was used to identify the aerodynamic resistance forces affecting the vehicle and the environmental weather conditions. The environmental module determines air density (1.18 kg/m^3), including ambient air temperature (17 °C), relative humidity and atmospheric pressure (1 atm). The schematic view of the modeled vehicle is given in Fig. 2.

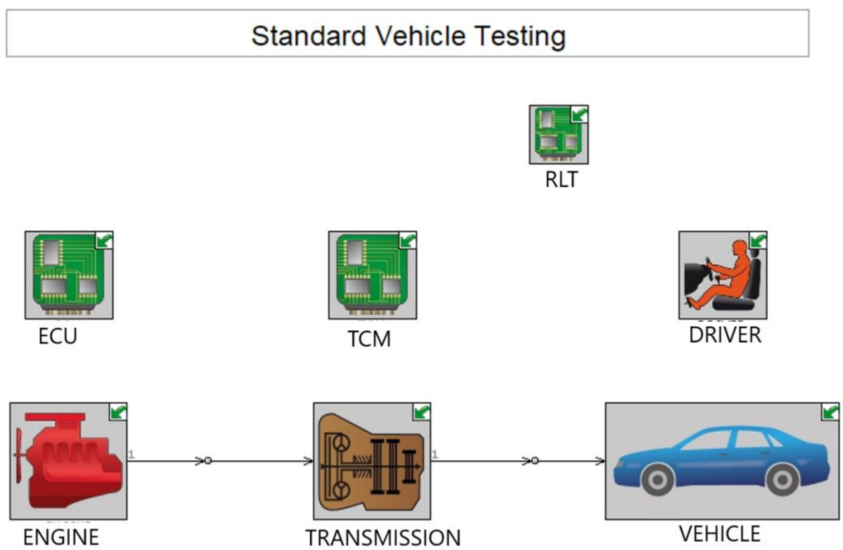


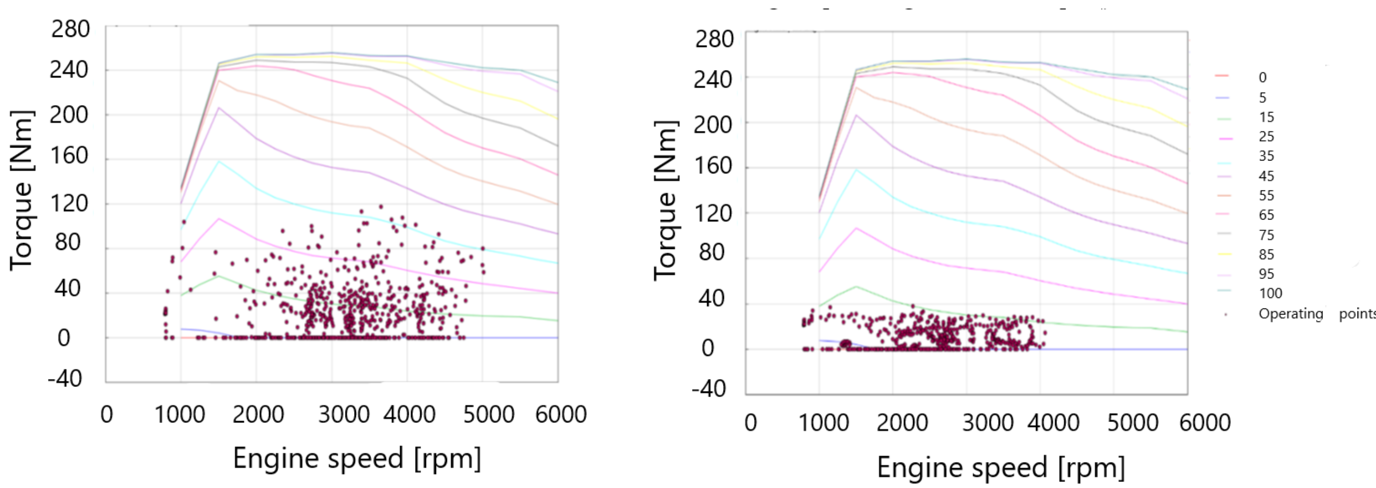
Fig 2. Schematic view of the modeled vehicle

Table 2. Model input parameters of the vehicle

Parameter	Value
Vehicle mass (kg)	1500
The front surface area of the vehicle (m^2)	2.38
Wheel radius (m)	0.334
Acceleration of gravity (kg/m^2)	9.81
The density of the air (kg/m^3)	1.18
Aerodynamic coefficient of resistance (-)	0.33
Rolling resistance coefficient (-)	0.01
The angle of inclination of the road (°)	0
Engine type, fuel	4 stroke, gasoline
Engine displacement (cc)	1508
Transmission type	Automatic

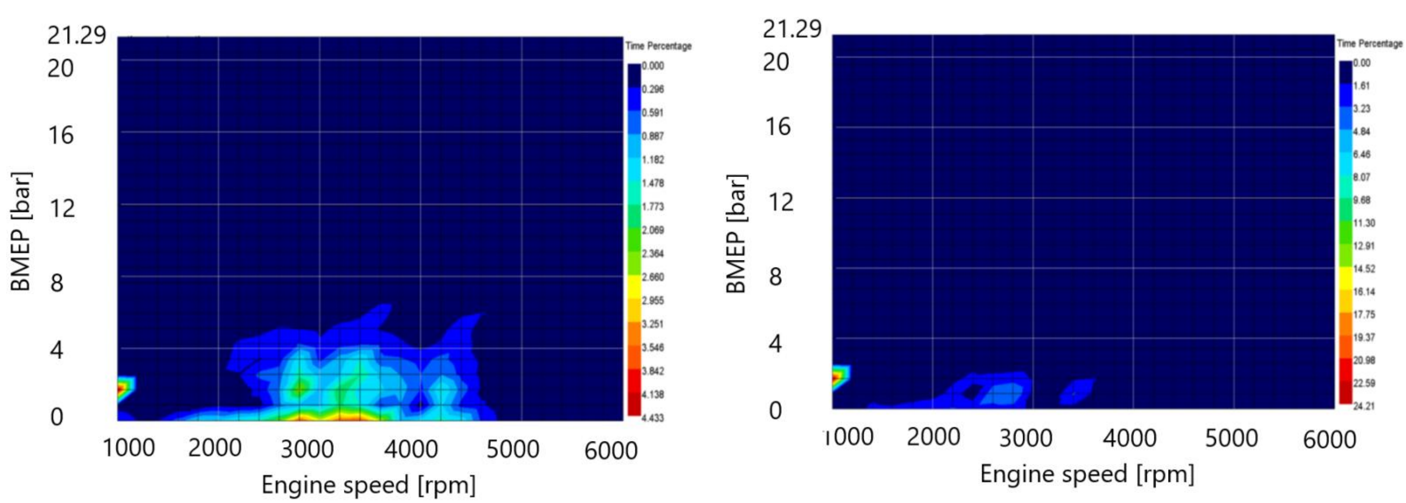
3. Findings and discussion

Fig. 3 shows the engine torque change and engine operating points at different engine loads depending on engine speed. Additionally, in this graph, variations in the engine torque under different loads can be observed. The Artemis drive cycle has higher acceleration acceleration than the WLTC drive cycle. These values are shown in Table 1. This is the reason why higher engine speeds are achieved while driving. High engine load and engine speed will increase engine mechanical friction. This situation is seen in Table 3. In the Artemis engine cycle, operating points above 40 Nm engine torque were achieved, while in the WLTC driving cycle, 0-40 Nm engine torques were obtained in the 850-4000 rpm engine speed range. In the Artemis driving cycle, the engine was operated in the engine speed range of 850-5000 rpm.



a)Artemis cycle b) WLTC cycle

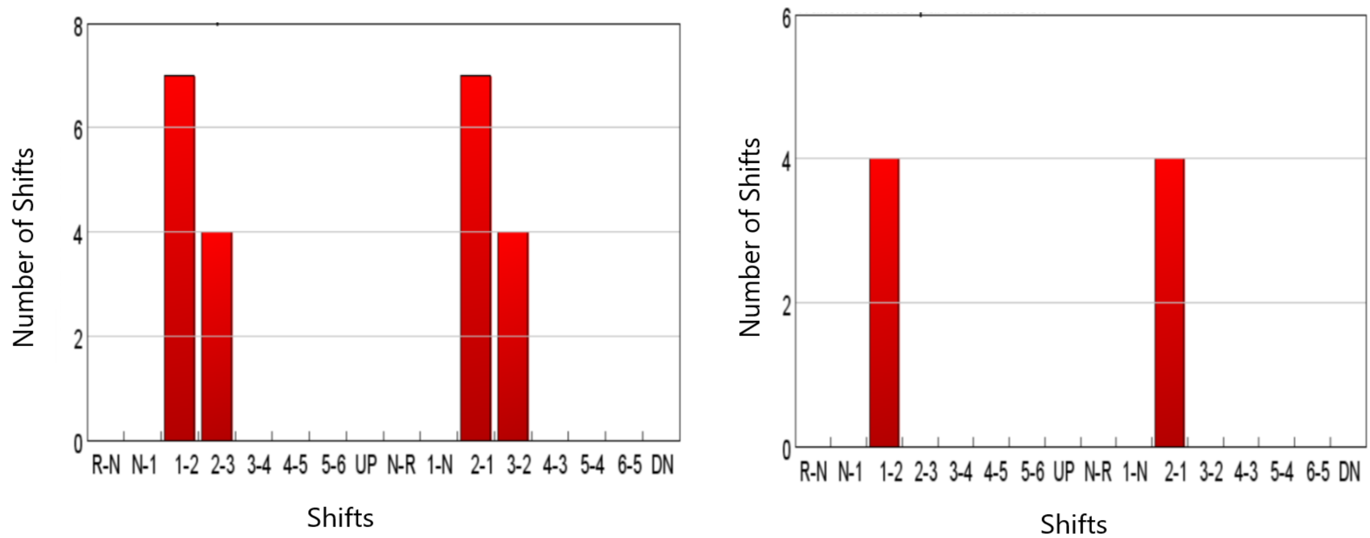
Fig 3. Engine torque change due to engine speed and engine operating points



a) Artemis cycle b) WLTC cycle

Fig 4. BMEP change depending on engine speed and engine operating points

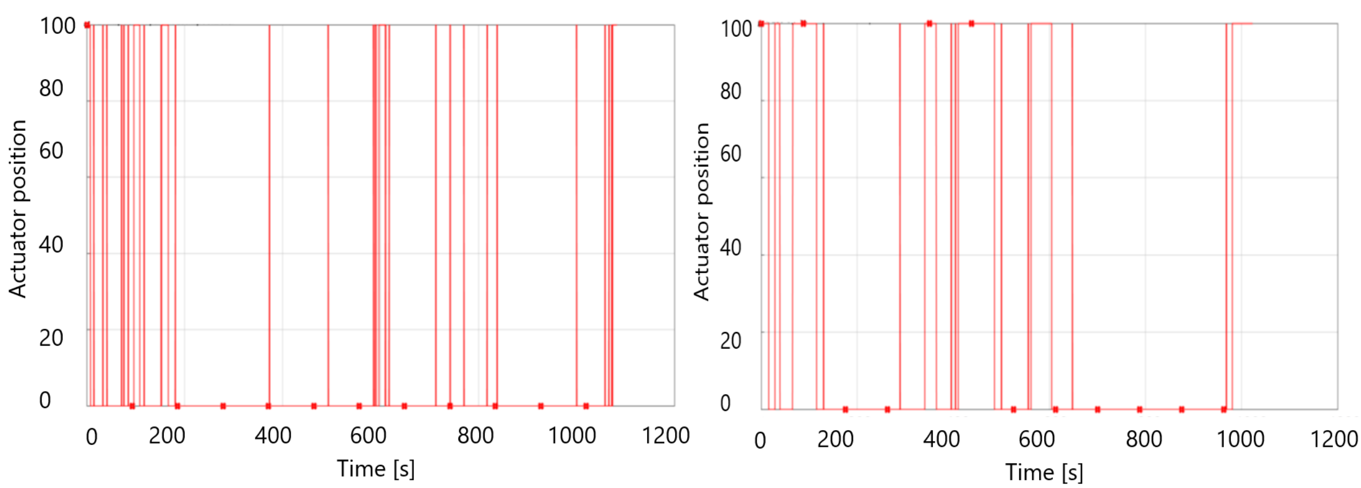
Fig. 4 shows BMEP change at different engine loads depending on engine speed and engine operating points as a percentage. Artemis was used more intensively at low BMEP values in the speed range of 2500-3500 rpm, confirming the density in the engine operating points graph in the driving cycle. In this driving cycle, the highest BMEP value was obtained at 3700 rpm engine speed. In the WLTC driving cycle, the engine speed range of 1600-3000 rpm was used up to 3 bar BMEP. In this driving cycle, the engine was used at a density percentage of 24.21% at 2 bar BMEP at 1000 rpm engine speed. Furthermore, in the Artemis driving cycle, operating regions above 4 bar BMEP occur, while in the WLTC driving cycle, operating regions higher than 3 bar BMEP do not occur. This condition has led to a higher specific fuel consumption value in the WLTC driving cycle



a) Artemis cycle b) WLTC cycle

Fig 5. Graph of the number of gear stages used in driving cycles

Fig. 5 shows the graph of the number of gear stages used throughout the driving cycle. In the Artemis drive cycle, the number of acceleration gear stages is 1-2 more than in the WLTC drive cycle. 7 1-2 gear stage accelerations and 4 2-3 gear stage accelerations were achieved in the Artemis driving cycle. In the WLTC driving cycle, 4 1-2 gear stages of acceleration were achieved. This is due to the Artemis drive cycle having higher acceleration and deceleration accelerations. The decrease in the number of gear stages in driving cycles increases vehicle movement resistances and powertrain losses.



a)Artemis cycle b) WLTC cycle

Fig 6. Torque converter Lock-up clutch usage chart throughout the drive cycle

Fig. 6 shows the Lock-up clutch operation graph of the vehicle throughout the driving cycle. Clutch actuators generally consist of electropneumatic, electrohydraulic and electromechanical systems [25]. Among these actuators, electropneumatic and electrohydraulic clutch actuators are widely used in vehicles due to their performance in low friction, high normal force and self-locking features [26-27]. According to this table, the locking clutch is used much more in the Artemis driving cycle. The torque converter lock-up clutch consists of lock-up clutch and torsional dampers.

This clutch provides a more efficient power transfer by balancing the power losses caused by the incomplete torque transmission, prevents the wear during take-off, reduces the energy loss and cuts the noise. Increased use of the lock-up clutch will reduce torque converter losses.

Table 3. Vehicle energy losses during the driving cycle

	Artemis cycle		WLTC cycle	
	Energy [kJ]	% of all losses	Energy [kJ]	% of all losses
Engine	-30927.5	78.0	-15071.2	84.5
Vehicle	-8724.1	22.0	-2765.3	15.5
Energy machines	0	0	0	0
Battery	0	0	0	0
Mechanical	0	0	0	0
User energy loss RLTs	0	0	0	0
TOTAL	-39651.6	100.0	-17836.6	100.0

Vehicle energy losses for 2 different driving cycles are given in Table 3. According to the results obtained, 78% of the energy losses in the Artemis driving cycle come from the engine and 22% from the vehicle. In the WLTC driving cycle, 84.5% of the energy losses are caused by the engine and 15.5% by the vehicle. The main reason why the Artemis driving cycle has higher energy losses in terms of energy consumption is due to the higher probability of positive and negative acceleration values of the driving cycle. The high kinetic energy obtained increases braking, tire, powertrain and aerodynamic losses.

Table 4. Powertrain and aerodynamic losses throughout the drive cycle (Artemis cycle)

	Energy [kJ]	% of vehicle losses	% of all losses	% of fuel energy
Clutches	-3.9	0	0	0
Torque converter	-85.3	1	0.2	0.2
Transmission and gears	-260.3	3	0.7	0.7
Differential, Transfer cases	0	0	0	0
Axles (Bearings)	0	0	0	0
Brakes	-2856.5	32.7	7.2	7.2
Retarder	0	0	0	0
Tires (Roll resistance, friction)	-2538.3	29.1	6.4	6.4
Tires (Steering)	0	0	0	0
Aerodynamic drag	-2979.8	34.2	7.5	7.5
TOTAL VEHICLE LOSSES	-8724.1	100	22	22

Table 5. Powertrain and aerodynamic losses throughout the drive cycle (WLTC cycle)

	Energy [kJ]	% of vehicle losses	% of all losses	% of fuel energy
Clutches	-0.3	0	0	0
Torque converter	-403.6	14.6	2.3	2.3
Transmission and gears	-71.4	2.6	0.4	0.4
Differential, Transfer cases	0	0	0	0
Axles (Bearings)	0	0	0	0
Brakes	-536.3	19.4	3	3
Retarder	0	0	0	0
Tires (Roll resistance, friction)	-1190.2	43	6.7	6.7
Tires (Steering)	0	0	0	0
Aerodynamic drag	-563.6	20.4	3.2	3.2
TOTAL VEHICLE LOSSES	-2765.3	100	15.5	15.5

In Table 4, powertrain and aerodynamic losses of Artemis driving cycle is given. According to the results obtained, higher (-3.9 kJ) clutch losses were obtained in the Artemis driving cycle. These losses are related to the lock-up clutch trying to operate the torque converter at high efficiency. In the Artemis driving cycle, the lock-up clutch operates more often. Increasing the number of operations of the locking clutch also increases its losses. Less operation of the lock-up clutch increases torque converter losses (-403.6 kJ) in the WLTC drive cycle (Table 5). In Table 5, powertrain and aerodynamic losses of WLTC driving cycles are given. When the losses in the gearbox and gear mechanisms are compared, a greater amount of loss (-260.3 kJ) occurred in the Artemis driving cycle. This is related to the use of a greater number of gear stages in the Artemis drive cycle. Increasing the number of gear stages increases gear loads, friction, and gearbox viscous and non-viscous friction. The reason for higher braking (-2856.5 kJ) and tire losses (-2538.3 kJ) in the Artemis driving cycle is that the average acceleration and deceleration acceleration of the Artemis driving cycle is higher. The higher the speed change, the higher the braking and holding losses. The same is true for the aerodynamic drag force. In the Artemis driving cycle, 5.29 times more aerodynamic drag force was generated compared to the WLTC driving cycle. When looking at the percentage distribution of total energy losses, it was determined that the highest energy loss percentage belonged to braking losses with 32.7%. Power losses in automotive transmissions depend on the design features of each part that makes up the system. Determining all the causes of power loss while driving and the behavior of the parts during vehicle use is extremely difficult and requires precise analysis .

Table 6. BSFC and fuel consumptions throughout the driving cycle (Artemis cycle)

	TOTAL	ACCEL.	DECEL.	CRUISE	STAT.
Time	1083	540	467.2	40.2	35.4
Fraction of time [%]	100	49.9	43.1	3.7	3.3
Mass of fuel consumed [g]	937.5	680.6	214.1	34.1	8.6
Fraction of fuel consumed [g]	100	72.6	22.8	3.6	0.9
Volume of fuel consumed [l]	1.202	0.873	0.275	0.044	0.011
Fuel consumption rate [kg/h]	3.12	4.54	1.65	3.05	0.88
Brake energy output [kW-h]	2.4241	2.1561	0.1718	0.0786	0.0177
BSFC [g/kW-h]	386.7	315.7	1246.6	433.4	486.8

Table 7. BSFC and fuel consumptions throughout the driving cycle (WLTC cycle)

	TOTAL	ACCEL.	DECEL.	CRUISE	STAT.
Time	1023	405.7	395.5	21.3	200.6
Fraction of time [%]	100	39.7	38.7	2.1	19.6
Mass of fuel consumed [g]	421.7	233.8	129.4	9.4	49.1
Fraction of fuel consumed [g]	100	55.4	30.7	2.2	11.6
Volume of fuel consumed [l]	0.541	0.3	0.2166	0.012	0.063
Fuel consumption rate [kg/h]	1.48	2.07	1.18	1.59	0.88
Brake energy output [kW-h]	0.7683	0.5607	0.0917	0.0144	0.1014
BSFC [g/kW-h]	548.9	417	1410.3	655.2	484

Fuel consumptions for 2 different driving cycles is given in Table 6 and Table 7. When the driving cycles are compared, higher percentage acceleration (49.9%) and deceleration (43.1%) rates were obtained in the Artemis driving cycle. This is also the reason for the higher fuel consumption amount (3.12 kg/h). In the Artemis driving cycle, operating the engine at engine speeds where higher thermal efficiency was achieved resulted in a higher amount of useful energy (2.4241 kW-h). When the specific fuel consumption values were compared, it was seen that the engine achieved lower specific fuel consumption values (386.7 g/kW-h) in the Artemis driving cycle. While 72.6% of the fuel consumed in the Artemis driving cycle was spent for acceleration, 55.4% was spent in the WLTC driving cycle. This has resulted in higher powertrains in the Artemis drive cycle.

4. Conclusions

According to the driving cycle simulations of the modeled vehicle, in the WLTC driving cycle, which has lower average acceleration and deceleration acceleration, the internal combustion engine was operated at engine speeds where lower torque values were obtained. Starting the engine in this way reduced the number of gear changes made during the driving cycle. In the WLTC driving cycle, torque converter losses occurred more and the Lockup clutch was used less frequently. In this case, it shows that the difference between the pump and turbine speeds, which are the torque converter elements, is higher in the WLTC driving cycle. When compared in terms of vehicle energy losses, the vehicle losses of the Artemis driving cycle are higher (22%). In addition, the higher acceleration values of the Artemis driving cycle increased braking and tire losses.

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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