Evolution and state of the art of the vehicle aerodynamics and onboard diagnostics and their connection in case of road vehicles

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Abstract: The purpose of this paper is to give a comprehensive presentation of vehicle aerodynamics and onboard diagnostics evolution. Examination is created of the possible corporation methods between aerodynamic applications and on-board diagnostics in order to improve vehicle parameter such as driving stability or fuel-consumption. The development of the vehicle's aerodynamics is presented. The main periods, the well-known shapes, and engineers e.g., Jaray's shape are introduced. Due to statistic and measurement data, the effect of the panel's shape, vehicle configuration and other parameters on the vehicle behavior are examined. The possible parameters of a vehicle, which can be modified by aerodynamic applications are collected. Based on these, methods and equipment's are listed to be able to create the system of the on-board diagnostics.

1. INTRODUCTION

The very first moment of the automotive evolution was the invention of the steam engine by Thomas Newcomen in 1712, which was developed further by James Watt in the late 18th century (Toyoda 1998). Based on the steam engine, the first vehicle (Fig 1.) was developed in 1769 by Nicolas-Joseph Cugnot (Encyclopedia 2023), who was a French engineer.

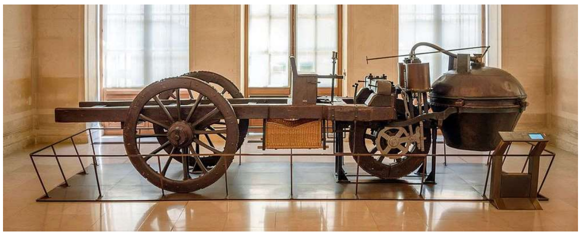

Fig 1. The first vehicle of the history (Patowary 2021)

The next milestone of automotive evolution is the invention of the internal combustion engine (ICE). The first, four-stroke, ICE engine was designed in 1861 by Nikolaus Otto (Britannica, Nikolaus Otto 2023), who was a German engineer. His construction got the widely known 'Otto-motor' name. The first ICE powered vehicle was presented in 1886. Karl Benz (Benz n.d.), who was the inventor of this vehicle, designed a one-cylinder two-stroke construction with 0.75 horsepower (Fig 2).

After the appearance of the first vehicles, several vehicles were designed. The next milestone of the automotive invention is the appearance of Ford Motor Company. Henry ford (Hystory.com 2020) the founder of the abovementioned company, designed firstly the Model A, then the Model T in 1908 which was ultimate success. The company could not serve the orders with the previous manufacturing volume, therefore, mass production was applied for the manufacturing of the Model T (Fig 3.) This was the first vehicle which was available for everyone and overall, 15 million pieces had solved. This model laid the foundation of the automotive industry with IC engines.

Fig 2. The first ICE engine powered vehicle (Benz n.d.)

Fig 3. T-model designed by Henry ford in 1908 (Museum n.d.)

Electric cars have been developed since the 19th century, but significant development just arrived in the 20th century with the new constructions of batteries. The greatest milestone in the electric vehicle evolution was in 2008, when Tesla, lead by Elon Musk presented the Tesla Roadster (Fig 4.) completely electric vehicle. From this point, other automotive suppliers start to develop completely electric vehicles, and nowadays a lot of type of electric vehicles are exist on the market. Besides the development of the electric vehicles, the autonomous system has also started to appear in the automotive industry from 2009 with a lot of driving assistance systems. Hybrid vehicles are also appeared in the market at this time. The first hybrid vehicle was the Toyota Prius, which was presented in 1995 in Japan (Toyota 2017). Nowadays hybrid vehicles as the completely electric ones are becoming increasingly popular among users.

Fig 4. Tesla Roadster 2008 (Lavrinc n.d.)

2. EVOLUTION OF VEHICLE AERODYNAMICS

The development of the vehicle aerodynamics had been started at the beginning of the 20th century (Jenő 2022) . The process of the evolution until today can be divided into four main periods which, the borrowed shapes, the streamlining, the detail optimization, and the shape optimization periods.
The borrowed shapes period had been started at 1900 and finished 30 years later. The basis of this period was to borrow shapes from other areas. One of the most popular shapes from this period is the Torpedo-shape. The basis of the shape - as the name suggest - come from the military torpedo. One of the most popular vehicles from this time is the La Jamais Contente (Fig 5.), which was the first automobile, which reached the 100 km/h.

Fig 5. La Jamais Contente 'borrowed' shape vehicle (Depris 2002)
This electric vehicle was developed in 1899 in Belgium. Lots of other shapes were borrowed from other areas, such as, boat tail, where the vehicle back has boat shape. A very popular model connects to this shape, which is the Audi Type C from 1912. The airship shape was the closest to a vehicle shape so far. A lot of models was designed in this style, e.g., Siluro Ricotti which was created by the Italian, Castagna in 1914.
The streamlining period had been lasted from 1921 to 1955. Streamlining means, that the shape of the body is design in order to the air flow around the vehicle as smooth as possible and create less turbulence. The most important moment from this section is the Jaray's shape.
Paul Jaray (Járay Pál) is a Hungarian engineer, airplane designer who obtained the Jaray's shape. The basis of the Jaray's shape is that the upper half of the vehicle is rounded or so called streamlined, where the air could flow smoothly with low turbulence, but the bottom of the vehicle is straight, which helps to build up the ground effect. The ground effect is when between the underbody and the ground the air is speed up and lower pressure zone is generated, which sucks the vehicle to the ground.
There are several famous vehicles remained from this period, for instance Tatra T87, the Ley T6, the Rumpler (1921-1923) (Fig 2.) or the Schlörwagen (Fig 6.) vehicle, which are designed based on the Jaray's shape.

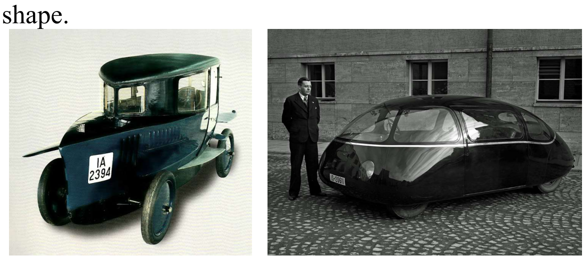

Fig 6. Rumpler (Progress is fine 2022) (left side) and Schlörwagen (Mobilwelten n.d.)(right side) as 'streamlined' vehicles
Besides the huge invention, the Jaray's shape had some disadvantages. Because of the changed shape, the centre of gravity has moved up, overall, the vehicle has less downforce, and the rotating wheels are exposed. The further developments are in the detail optimization period.
In the detail optimization period, which has started in 1972, smaller modifications were applied on the vehicles, but their effects were significant on the car's aerodynamic properties. For example, rounded edges around the vehicle, modified inclination angles could decrease the drag coefficient and effect positively the aerodynamic and driving stability properties.
The shape optimization has started in 1983 and the basis of this section is the fine tuning the part of the vehicle for example, put undercover to the underbody to hide the inequality or put disk cover on the wheel to reduce the drag.
The listed applications in the detail and shape optimization sections modify the aerodynamics properties of a vehicle. It is important to detect, store and process this information to be able to examine these effects. To complete this purpose, the on-board diagnostics could be a solution.

3. EVOLUTION OF ON-BOARD DIAGNOSTIC

The on-board diagnostics is a special part of the automotive diagnostic (Nagyszokolyai Iván 2011). The automotive diagnostic is the summary of the measurement by diagnostic methods for the condition assessment of the vehicle. Generally, diagnostic collect information from hosting, without breaking the object. However, in some cases, this will not work, e.g., in case of a pressure transmitter, where the direct contact with the sensor is indispensable. There are two main types of diagnostics are existed: the off-board diagnostic, which is occasional and external measuring system is needed, and the on-board diagnostic, which provides continuous on-board state monitoring.

The diagnostic usage has been started around 1930, because of the World War II. There was huge need for quick and appropriate maintenance for the vehicles. After that, the measuring devices were rapidly developed from 1950 in the USA and from 1960 in Europe. In Fig 7., a lightometer is depicted from 1950, which was able to read light values (Taranovich 2016).

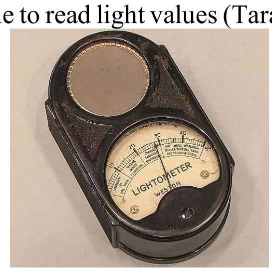

Fig 7. Weston Model E703 Lightometer for measuring general light intensity (Taranovich 2016)

A modern road vehicle is equipped with complex mechatronic systems (Fig 8.), so the mechanical part of the vehicle e.g., brake system or the engine is controlled. Information could be collected from the vehicle for 3 reasons. A vehicle could be monitored via diagnostics, because of the regular technical inspections, maintenance, or data collection.

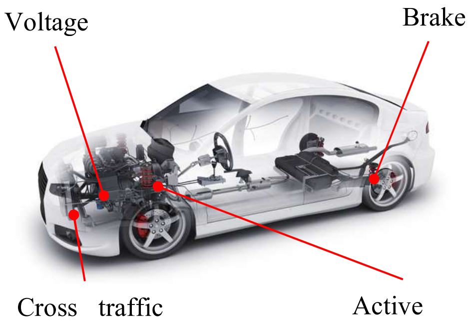

Fig 8. Some parts of the mechatronic system in a vehicle (Tanuja P. Mote 2016)

The devices and softwares are part of the basic vehicle system in case of on-board diagnostic. Measurements are automatically carried out continuously or periodically, while the data procession is periodically.

The on-board diagnostic can be monitoring several parameters and collect data in different ways. It could read error codes, read system parameters on-line, coding control unit or code data collection.

4. STATE OF THE ART OF THE ON-BOARD DIAGNOSTIC

As presented in the previous sections, on-board diagnostic can be used for different type of applications. This data collecting method is constantly evolving, new devices and applications are published constantly. Because of these, this is a very popular theme in the research field, several papers are presented recently. Meeanakshi Malik with his partners studied driving styles and vehicle operations in case of different environmental and road conditions. For their research, OBD-II tool was used (Meenakshi Malik 2023). M. D' Agostino and his partners worked with the theoretical background of Hybrid Electric Vehicle transformation. These vehicles can be only used with active gear, and they measured its properties via OBD (M. D'Agostino 2014). G. Macias-Bobadilla with his partners studied the optimal time for hydrogen injection into an internal combustion engine. The properties were measured by Raspberry-Pi 3 programming board with serial connection OBD-II port. The aim of this paper two examined how the green house gas emission could be decreased and how the fuel efficiency of the engines could be increased (G. Macias-Bobadilla 2020). Sung-hyun Baek and his partner examined the available OBD-II ports and collect the functions of different OBD-II ports in order to create one OBD-II port which could satisfies all the average user demands. This paper shows an OBD-II port with Wi-Fi, Bluetooth and WCDMA modules (Sung-hyun Baek 2015). Yu Jiang with his partners examined heavy-duty vehicles (HVD) from emission point of view. Forty-five vehicles were measured with selective catalytic reduction. One part of the vehicles had check engine light one, the other part had malfunction-indicator light on. Measurement was carried out with these and without these errors and compared the results. The data was collected by OBD based I/M program (Yu Jiang 2021). Liuhanzi Yang and his partners studied three diesel and three hybrid buses from emission point of view. Second-by-second profiles of carbon dioxide and nitrogen oxides data were collected with remote on-board diagnostic program (Liuhanzi Yang 2016). Hao Xie with his partners also examined the emission of vehicles, but they used portable emission measurement system (PEMS) too for their purpose. This measurement tool is one of the most accurate method currently, but it is expensive, and the measurement time is higher. This paper contains measurement from PEMS and on-board diagnostics in order to examine road vehicle emission and compared the result in different ways (Hao Xie 2021). Dimitrios Rimpas and his partners examined consumption and operation of vehicles using OBD-II diagnostic protocol. They monitored the key parameters of a vehicle and briefly present the mechanics of the applied sensors. The measurements were carried out in low and heavy traffic with 5 km testing range (Dimitrios Rimpas 2020). Tin Vaiti and his partners studied traffic emission in urban areas. The aim of the paper to estimate emission patterns using OBD-II dataset with machine learning algorithms (Tin Vaiti 2022).

5. STATE OF THE ART OF THE VEHICLE AERODYNAMICS

As presented in the previous section, lots of research is created in theme of on-board diagnostics in case of vehicles. However, it is important to examine the research field of the vehicle aerodynamics separately to get a complete overview of this research field too. M. Corallo and his partner examined the vortices at C-pillar and the connection of the C-pillar and the rear slant angle (M. Corallo 2015). Lots of research is created with CFD simulations e.g., the interaction between the flow separation and the released vortex wake was studied with Multidomain spectral Chebyshev–Fourier solver by M. Minguez (M. Minguez 2008). Different constructions of the underbody were investigated by Filipe F. using spectral element discretisation (Filipe F. Buscariolo 2021). An examination was carried out of the near wake flow behind the vehicle with Large Eddy simulation by Wang Bing-xin and his partners (Bing-xin Wang 2019). Several research are presented in fuel consumption. Sabry Allam and Ashraf Mimi Elsaid examined the pleated air filter to improve engine performance. For this approach a diesel engine was used (Sabry Allam 2020). The hydrogen consumption of a fuel vehicle was studied by Ying Tian and his partners. The velocity distribution of water and hydrogen was modelled in a Coriolis flowmeter with different mass flows (Ying Tian 2022). Mohammad Zandie studied the fuel consumption of a diesel engine using biodiesel-gasoline mixture. The fuel efficiency, emissions and other parameters were analysed. The research was completed with the help of CFD simulations.

CONCLUSIONS

As presented in the paper, on-board diagnostic and vehicle aerodynamics have a lot of common points and highly affect each other. Fuel consumption, driving stability, autonomous systems and lots of other properties are affected and can be modified or improved by the cooperation of on-board diagnostic and vehicle aerodynamics. Based on the current research and the trends of internal combustion-, hybrid- and electric vehicles, the cooperation of on-board diagnostic and vehicle aerodynamics is a key factor to improve the modern vehicles and help the development of the automotive industry.

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