Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 18(7), 406–418
https://doi.org/10.12913/22998624/193081
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Received: 2024.08.13
Accepted: 2024.09.23
Published: 2024.10.06

Impact of Vehicle Engine Supply System on In-Service Changes in Body Geometry and Wheel Alignment

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ABSTRACT

This study assessed the effects of vehicle mileage on the floor panel geometry and the upper mounting of the McPherson struts, as well as on the wheel alignment parameters. Geometry changes were determined in cars with the same design parameters, differing only in the type of engine supply system. The cars were van-bodied vehicles with compression ignition engines fuelled with diesel fuel and spark-ignition engines fuelled with LPG. The vehicles differed significantly in the weight distribution on their axles. The study is distinguished by its comprehensive approach to identifying in-service body wear. A detailed analysis covered not only the main causes of changes in body geometry, namely the influence of the vehicles' mileage and design parameters, but also the effect of identifying the values of changes in the suspension and steering system geometry parameters. The body geometry and wheel alignment testing was carried out at a mileage of approximately 300,000 km. The study determined the relationships between changes in body geometry and wheel alignment. Changes in body geometry were determined by the type of basis point and the type of vehicle under analysis. Major changes in body geometry and wheel alignment were found in diesel-fuelled cars at the front of the vehicles and in LPG-fuelled cars at the rear of the vehicles. The greatest changes in body geometry in both vehicle types were noted within the area of the points associated with the mounting of the front and rear axle suspension system components.

Keywords: body geometry, wheel alignment, floor panel, car, diagnostics, operation.

INTRODUCTION

With the increase in society's mobility, there is a successive year-on-year increase in the average mileage of passenger cars used for private purposes [1, 2, 3]. There is also a growing demand for services and goods, which involves the transport of goods and contributes to a greater number of commercial vehicles [4, 5, 6]. When designing new vehicles, particular attention is paid to their safety levels [7].

A major challenge associated with vehicle operation is the proper diagnosis and maintenance of vehicles. Nowadays, at the vehicle manufacturing stage, one of the basic methods of assessing the condition of the car body is to check the shape and fit of body components using a 3D optical laser scanner [8]. The simplest method, however, is to check the defects in mirror surfaces, which are also represented by body components, using human vision [9, 10], which is largely based on a subjective assessment during vehicle acceptance. This process is difficult to automate while maintaining high quality standards. Particular attention is paid to the shape and fit of the body panelling components [11, 12]. In addition to their visual aspect, these damages and defects may contribute to the acceleration of in-service body wear processes and the shortening of the service life of vehicles [13].

The course of the process of changing the vehicle body geometry is determined by their manufacturing quality [11, 13], their involvement in road accidents and collisions [14, 15], and the operating conditions [16, 17]. Body wear and damage also occur in vehicles with a collision-free history, yet the intensity of changes in body geometry is considerably lower [17]. The body degradation process is spread over time, and no sudden damage to the body occurs [18, 19, 20]. The main factors contributing to body wear, in this case, are the forces and moments acting on the body during traffic, especially on poor-quality roads. These changes are largely related to the mileage of the vehicles [18, 19, 20, 21].

A car is a complex system that is affected during driving and, to a lesser extent, when parked by a number of variable kinematic and dynamic excitations with a wide spectrum of frequencies [21, 22, 23]. The forces and moments arising from the traffic conditions during driving are transmitted through the wheels and the suspension and steering system components to the body [21]. The body is loaded both statically and dynamically, and the nature of the excitations is largely linked to the state of road infrastructure. Changes in geometry are also contributed to by the inertial forces acting on the body when driving and gathering speed, which are proportional to the weight and acceleration, and by the forces generated during the braking process [24]. The vibrations acting on the vehicle not only originate from the road surface but also result from the engine operation and the drive system and are the cause of the deterioration of the technical condition of the body [17, 23]. All of the above-mentioned excitations contribute to changes in geometry within the area of the points representing the mounting of the front suspension components, the front subframe, the rear suspension, and the rear subframe [25, 26].

As soon as changes in body geometry occur in cars with integral bodies, changes in wheel alignment usually take place. In modern vehicles, the suspension and steering system components are mounted to the body components. Another major problem is that for most of these cars, there is no possibility of adjusting many of the wheel alignment parameters, i.e., the wheel camber angles, caster angles, and steering axis inclination angles [18, 26, 27]. However, research shows that they affect vehicle driving, driving stability, and safety [27, 28]. Driving a vehicle with abnormal geometry can be very unpredictable and dangerous due to the difficulty in following the correct driving line [16, 29]. A qualitative description of the impact of body condition changes on wheel geometry and safety can be found in the publications [18, 26], but there is no quantitative description of this issue.

The authors demonstrated in quantitative way in their previous studies [16, 17, 27] that changes in the geometry of the floor panel and the upper body are strongly influenced by vehicle mileage and operating conditions. The changes in geometry in vehicles with the mileage in the range of 250,000 km up to approx. 300,000 km reached up to 10 mm [17, 27, 24].

In one publication, the authors [24] analysed the influence of design parameters on body geometry changes. They quantitatively described the effect of several vehicle design parameters on changes in body geometry. However, they did not study the effect of body geometry changes on wheel geometry changes. The paper [17] presents the effect of the car mileage on the floor panel condition, taking into account variable environmental factors. The results were used to develop a model for forecasting changes of the floor panel geometry during car use. The probability of changes in the floor panel geometry was found to increase with the mileage. In this publication, the authors also did not investigate the effect of changes in body geometry on changes in wheel geometry. The paper [27] analyses changes in body geometry and related wheel geometry which may affect the wear of passenger car tyres. However, the cars analysed had varying mileage, ranging from 100,000 to 300,000 km. The authors in publication [24] also analysed the effect of body geometry changes on wheel geometry changes. In this case, the influence of vehicle design parameters on wheel geometry changes was not analysed.

The results of studies into changes in the floor panel geometry and the impact of body deformation on changes in wheel alignment are rarely addressed in the literature. The vehicle design parameters, mileage and the excitations acting on the vehicle during operation and contributing to changes in body geometry and wheel alignment are not identified in detail. The authors identified the impact of vehicle mileage on changes in floor panel geometry and then determined the contribution of changes in floor panel geometry to changes in the suspension and steering system geometry. They also identified the impact of vehicle design parameters associated with the varying distribution of weight on the vehicle axles, on changes in body geometry, and then on changes in wheel alignment.

In contrast to other studies, the authors of the paper decided to identify the effect of engine parameters on changes to the floor panel geometry. When comparing the effect of the internal combustion engine on the state of body geometry, the differences between vehicles equipped with spark-ignition engines fuelled with LPG and compression ignition (diesel) engines in the same car model were determined. The study presented in the paper is a holistic approach to changes to the technical condition of the bodies of passenger cars of different designs. The study presented in this paper represents a comprehensive approach to the wear of vehicle bodies in terms of changes in body geometry and the in-service deterioration of the body of cars. The authors assessed the effect of changes in body geometry on changes in wheel geometry over the course of operation. This is the first study of this type known to the authors. To date, no one has described an analysis of this issue. For this reason, the topic addressed in the paper appears innovative.

After analysing the available information, an analysis was conducted of how vehicle design characteristics affect the course of the processes of wheel alignment and body geometry changes.

In this study, the authors focused on analysing changes in body geometry and wheel alignment in van-bodied cars. The cars were manufactured in one of the European Union countries. The presented study distinguishes between two types of vehicle drive sources, i.e. compression ignition engines fuelled with diesel fuel and spark-ignition engines fuelled with LPG.

The aim of the study is to identify the impact of weight distribution between the vehicle axles on changes in body geometry and the associated changes in wheel alignment. Therefore, the article presents an analysis of the impact of:

- vehicle design parameters, influencing the distribution of weight on the vehicle axles, on changes in body geometry and in wheel alignment;
- changes in body geometry on changes in wheel alignment;
- the mileage of the vehicles on changes in body geometry and changes in wheel alignment.

RESEARCH METHODOLOGY

The test subjects in the study included a total of twenty cars with a gross vehicle weight of 2100 kg and a 4.63 meter-long glazed van body. The vehicles were manufactured by the same concern, and all represented the same car model. These were three-seat vehicles with seats in the front part of the body and an enclosed cargo space in the rear part of the body. Ten cars were equipped with a 1,560 dm^3 compression-ignition (diesel) engine, with the others equipped with a 1,587 dm^3 spark ignition engine fuelled with LPG. The conversion into an LPG-fuelled system required, inter alia, the installation of a gas tank located in the rear part of the vehicle, under the cargo space floor, behind the rear vehicle axle. The weight of the (full) tank, together with the mounting structure and weather protection covers, was 150 kg, which resulted in significant overloading of the rear vehicle part and a reduction in the permissible load capacity. The kerb weight of a vehicle with a compression ignition engine was 1450 kg, whereas an LPG-fuelled vehicle weighed 1500 kg. All of the vehicles had an independent front axle suspension based on a McPherson strut and semi-independent twist-beam rear axle suspension.

The cars were used by employees of one enterprise under similar environmental conditions and on roads of similar quality. None of the vehicles had been involved in road accidents or collisions, and no body repairs had been carried out on them. The operation of the vehicles did not differ from the standard, nor was the permissible loading capacity exceeded during use. According to the manufacturer's recommendations, technical inspections were carried out on all the vehicles. After three years of operation, at the time of the study, the vehicles had covered a mileage of approximately 300,000 km.

The measurements of floor panel geometry and the upper mounting of the McPherson struts were performed using a Gysmeter instrument manufactured by GYS. This was the Gysmeter Tech model 052093. The instrument was manufactured in 2014. The accuracy of the instrument was 1 mm, whereas the measuring range was between 400 and 2650 mm. During the body geometry measurements, a set of dedicated tips and gauge plungers matching the individual basis points were attached to the instrument. Allvis Light computer software, which included a database with the required basis point positions, was used during the body geometry measurements. Figure 1 shows a view of the floor panel and the body geometry measuring instrument.

The measurements of the suspension and steering system geometry (wheel alignment) were carried out using an Autoboss A860 computer-laser instrument, which enabled the identification of nineteen wheel alignment parameters for both the front and rear axles. The accuracy of

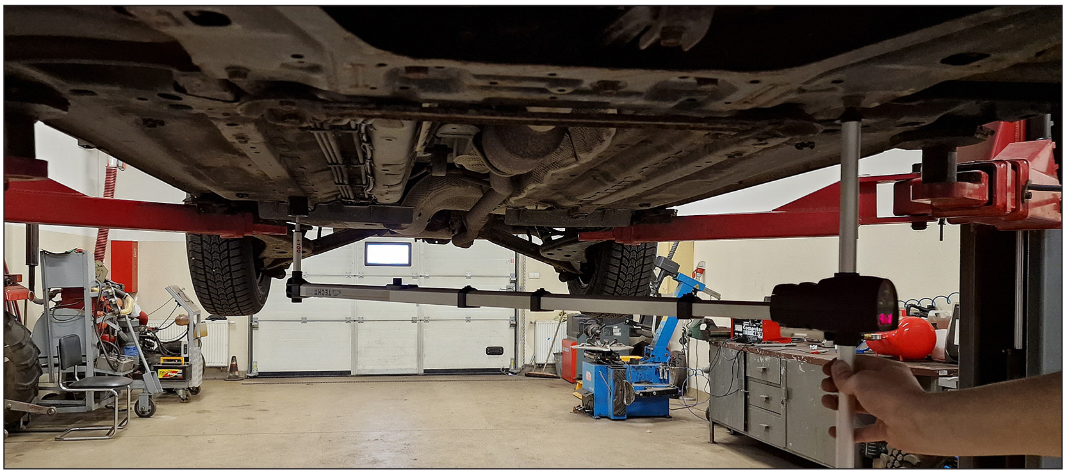

Figure 1. A view of the floor panel and a body geometry measuring instrument

the measurements of all wheel alignment parameters was 0.01°. The measurements used dedicated computer software that included a database containing the nominal and permissible values of the individual wheel alignment parameters.

The testing also used a Beissbarth STL7000 diagnostic line to identify the distribution of weight on the individual vehicle axles. In this case, the tests were carried out on vehicles with full fuel tanks. For the cars with compression ignition engines, 58% of the weight was borne by the front axle and 42% by the rear axle. In the cars with LPG-fuelled spark-ignition engines, 50.5% of the weight was borne by the front axle and 49.5% by the rear axle.

There were a total of 44 basis points on the floor panel of the test cars, which were used when identifying changes in the geometry of this body area. Based on a previous study, the authors [16, 17, 24, 27] concluded that it was not necessary to determine the shift of all the points. It is sufficient to identify the position of only 22 characteristic points of the floor panel, i.e. eleven points on the left and eleven points on the right side of the body. The identification of the position of these points provides the most information on in-service changes in floor panel geometry and contributes to changes in the suspension and steering system geometry. In order to identify the position of the characteristic points of the floor panel (22 points), it was necessary to determine the distance between these points and the reference points. Two points located in the central part of the floor panel were chosen as the reference points. It was an area in which no changes in floor panel geometry were found in any car. The location of the reference points was in accordance with the vehicle manufacturer's requirements. During the tests, each time, the measured distances were entered into the Allvis Light software, which enabled a comparison of the actual distances between points with the reference values for the test car model. Whereas, when identifying the position of the points associated with the upper mounting of the McPherson struts, it was possible to determine the distance between these points and the points on wheel arch reinforcements on the left and right sides of the body.

The authors repeated a single distance measurement three times. The authors repeated the measurement of each configuration related to one examined vehicle three times. The authors found no differences in measurement results between each repetition. As for the measurements of the floor panel geometry, changes in the location of characteristic points were determined using the following relationship:

$$C_{gi} = |RPL - APL| \text{ [mm]} \quad (1)$$

where: C_{gi} – changes in the position of a particular characteristic point of the floor panel [mm]; RPL – the required distance between the basis points of the floor panel [mm]; APL – the actual distance between the basis points of the floor panel [mm].

Whereas, changes in geometry within the area of the upper mounting of the McPherson struts were determined using the following relationship:

$$C_m = |RMP - AMP| \text{ [mm]} \quad (2)$$

where: C_m – a change in the distance between the points representing the upper mounting of the McPherson struts on the left and right side of the body and the reference points on the wheel arch reinforcements on the opposite side of the body [mm]; *RMP* – the required distance between the mounting basis points of the McPherson struts [mm]; *AMP* – the actual distance between the mounting basis points of the McPherson struts [mm].

For the testing, the following characteristic points of the floor panel and the points representing the upper mounting of the McPherson struts, shown in Fig. 1, were selected:
- 1L and 1R – points located on the front side member,
- 2L and 2R – points representing the front suspension mounting,
- 3L and 3R – points representing the front mounting of the front subframe,
- 4L and 4R – points representing the front suspension stabiliser mounting,
- 5L and 5R – points representing the rear mounting of the front subframe,
- 6L and 6R – points located within the bulkhead area,
- 7L and 7R – points representing the front mounting of the rear suspension beam,
- 8L and 8R – points representing the rear mounting of the rear suspension beam,
- 9L and 9R – points representing the front mounting of the rear suspension springs and shock absorbers,
- 10L and 10R – points representing the rear mounting of the rear suspension springs and shock absorbers,
- 11L and 11R – points located on the rear side member,
- 12 L and 12 R – points representing the upper mounting of the McPherson struts,
- PL and PR – reference points located in the central part of the floor panel.

The points located on the left side of the body were marked with the letter L, and those on the right side with the letter R, respectively. Figure 2 also shows, in green and purple colours, examples of the measured values of the distance between the characteristic points and the reference points.

The points at which the geometry measurements were carried out can be assigned to two categories. Points 1, 6 and 11 were associated with the passive safety of vehicles. They were located within the area of the body support structure components, on the parts of the crumple zone, which provides adequate strength for the body during an accident or collision and reduces the risk of injury to passengers during road accidents or collisions. Points 2, 3, 4 and 5 were associated with the active safety within the area of the front vehicle axle. In contrast, points 7, 8, 9 and 10 were associated with the active safety within the area of the rear vehicle axle. These points were associated with the active safety of the vehicles, as a change in the body geometry within their area causes changes in wheel alignment, which affects the driving of cars and, consequently, reduces the risk of road incident occurrence.

The permissible difference between the required and the actual position of the basis points (a change in geometry) must not exceed a value of 3 mm. This value is specified in the literature based on the technical requirements of most passenger car manufacturers [24, 30]. In the event of greater changes in geometry, a car is considered

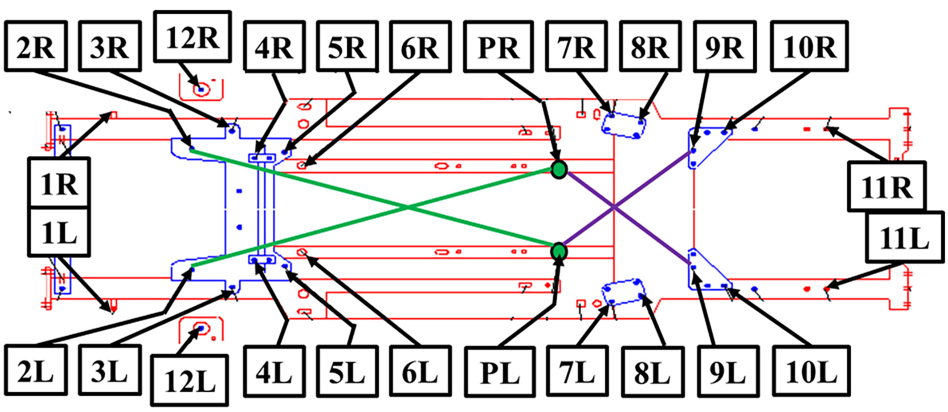

Figure 2. The distribution of points at which the geometry of the floor panel and the McPherson struts was measured

defective and should not be operated for safety reasons [24, 31].

For the purposes of the study, 22 basis points of the floor panel were divided into five categories. For the purposes of the study, the acronyms were introduced. The acronyms and their corresponding points be grouped in a Table 1.

Immediately following the measurements of the geometry of the floor panel and the upper mounting of the McPherson struts, measurements of the suspension and steering system geometry were carried out. The values of the following parameters (shown in Fig. 3) were identified:
- TFA – total front axle alignment,
- TLF – front axle left wheel toe-in,
- TRF – front axle right wheel toe-in,
- ILF – front axle left wheel camber angle,
- IRF – front axle right wheel camber angle,
- CLF – front axle left wheel caster angle,
- CRF – front axle right wheel caster angle,
- KLF – front axle left wheel steering axis inclination angle,
- KRF – front axle right wheel steering axis inclination angle,
- TRA – total rear axle alignment,
- TLR – rear axle left wheel toe-in,
- TRR – rear axle right wheel toe-in,
- ILR – left rear axle wheel camber,
- IRR – right rear axle wheel camber,
- DAS – deviation of the driving axis from the symmetry axis,
- DWB – differences in axle base,
- DWT – differences in wheel track,
- SWF – front axle wheel offset,
- SWR – rear axle wheel offset.

In order to illustrate the significance of the influence of the individual parameters whose effect on changes in body geometry was being identified, an analysis of variance was carried out. For each of the analysed parameter characteristics of the test cars, a null hypothesis about the lack of differences between the values of changes in geometry and an alternative hypothesis about the occurrence of significant differences in changes in geometry were adopted. In addition, for the purposes of the study, the following acronyms were introduced: PVS – points associated with the passive vehicle safety; AVS F – points associated with the active vehicle safety - front axle; AVS R – points associated with the active vehicle safety – rear axle.

RESULTS

In all the test cars, both with compression-ignition engines and with spark-ignition engines fuelled with LPG, changes in geometry were found within the area of all points of the floor panel and the upper mounting of the McPherson struts were noted during measurements carried out at a mileage of approximately 300,000 km. The results of geometry changes are provided in Figur 4. The smallest differences in geometry in all the cars occurred at the points located within the bulkhead area (6), followed by front side members (1) and rear side members (11). For the bulkhead, the differences amounted to approximately 1.5 mm, and those on the front side members to approximately 2.5 mm. On the other hand, for the rear side members, the offset of the basis points in LPG-fuelled cars was approximately 5 mm, whereas in diesel cars, it was approximately 3.5 mm. The permissible difference between the required and the actual position of the basis points (3 mm) been exceed. Vehicles should be considered defective and should not be operated for safety reasons. All these points were associated with passive vehicle safety. As regards these points in the cars with both types of fuel supply, equal or slightly higher point shift values were noted on the left side of the body. For the basis points located on the front side members, greater changes in geometry were noted in cars with compression-ignition

Table 1. The category of points and their corresponding points

Category of points	Category description	Basis point
PFVS	Points associated with the passive vehicle safety at the front of the vehicle	1L, 1P, 6L, 6P
PRVS	Points associated with the passive vehicle safety at the rear of the vehicle	11L, 11P
AVSF	Points associated with the active vehicle safety – front axle	2L, 2P, 3L, 3P, 4L, 4P, 5L, 5P
AVSR	Points associated with the active vehicle safety – rear axle (suspension beam mounting)	7L, 7P, 8L, 8P
AVSS	Points associated with the active vehicle safety – rear axle (suspension spring mounting)	9L, 9P, 10L, 10P

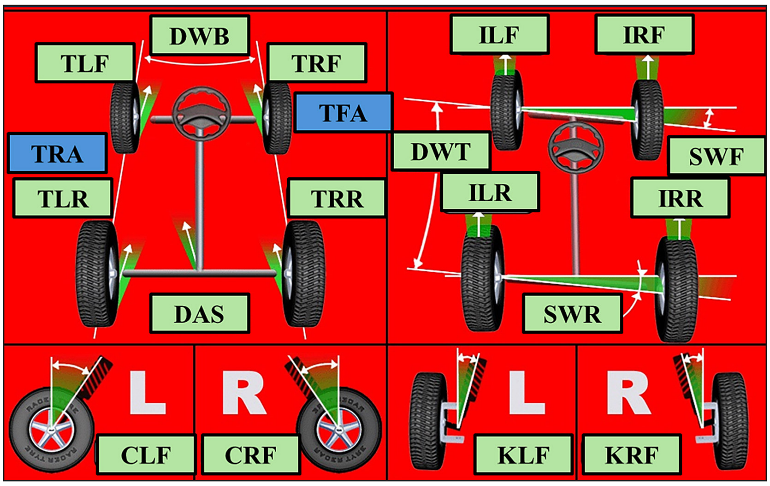

Figure 3. The wheel alignment parameters identified during testing

(diesel) engines. This was presumably due to the greater weight of the engine and the drive system in these vehicles. On the other hand, greater changes in geometry for the points located on the rear side members were noted in LPG-fuelled cars. This was due to the significantly greater load on the rear part of the vehicle resulting from the installation of the LPG tank.

When comparing the changes in geometry (Fig. 4) within the area of mounting of the vehicle front axle suspension components, it can be observed that greater shifts of the points occurred in all the vehicles on the right side of the body than those on the left side of the body. Greater point displacements in all vehicles on the right-hand side of the body than on the left-hand side of the body are related to the poorer condition of the right-hand side of the carriageway and the presence of curbstone on the road. The change values were similar for both engine supply types. However, slightly greater changes in geometry occurred in cars with compression ignition engines. These changes were due to the greater weight of the engine and the drive system in these vehicles. Different changes can be observed for the points associated with the rear vehicle suspension mounting. In this case, considerably greater changes in geometry were noted in cars with spark-ignition engines fuelled with LPG. Much greater changes occurred for both the points representing the mounting of the rear suspension beam and the rear springs and shock

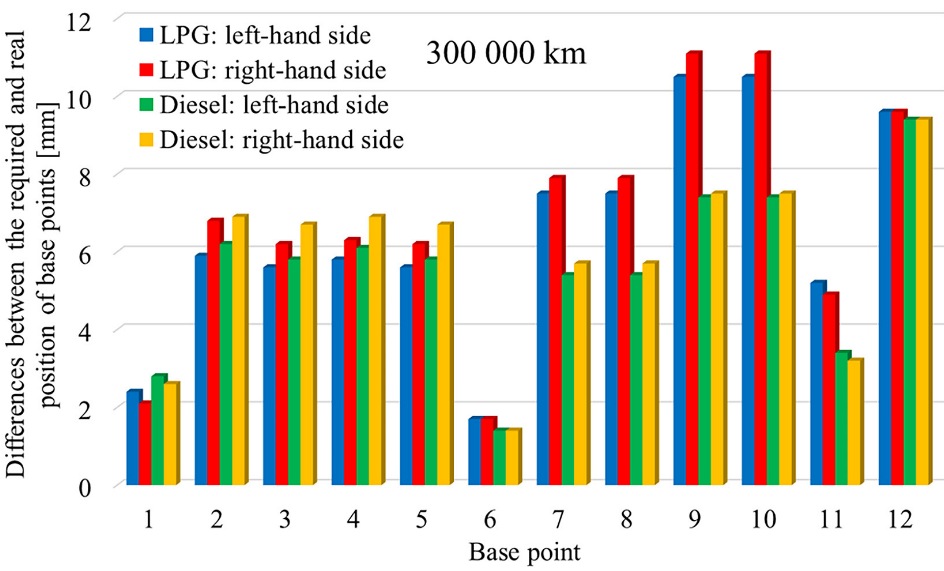

Figure 4. Changes in geometry of the floor panel and the upper mounting of the McPherson struts after a mileage of 300,000 km in cars with compression-ignition (Diesel) engines and with LPG-fuelled engines

absorbers. This was due to the much greater load on the rear part of the vehicle, in which an LPG tank was installed. This was particularly evident for the points representing the mounting of the rear springs and shock absorbers, for which a difference of 50% was noted, depending on the engine supply system type. Significant changes in geometry were also noted within the area of the upper McPherson strut mounting points. In this case, slightly smaller changes in geometry occurred in cars with compression-ignition engines. As for the LPG-fuelled cars, the points representing the mounting of the rear springs and shock absorbers were shifted by an average of approximately 11 mm. In contrast, in cars with compression-ignition engines, these changes amounted to an average of more than 7 mm. In both cases, the permissible value (3 mm) was exceeded several times. Repairs to the bodywork should be carried out on these cars. Wheel alignment should also be carried out. In some cases, vehicles may need to be scrapped. Particularly if the body repair or wheel alignment adjustment does not result in improved geometry. As for the points representing the upper mounting of the McPherson struts, the permissible value was also exceeded by more than three times. However, in that case, it applied to both types of test vehicles. The shifts of the basis points representing the mounting of the front suspension, front subframe and rear suspension components indicated that the distribution of weight in the test vehicles had an impact on changes in geometry. As for the front axle, greater changes were noted in the cars with diesel engines, in which 58% of kerb weight was borne by the front axle. In cars with LPG-fuelled engines, only 50.5% of kerb weight was borne by the front axle. As regards the rear suspension (rear beam) mounting points, the load on the vehicles had a decisive impact on changes in geometry. The greater load on the rear axle of the LPG-fuelled cars resulted in changes in geometry being greater by approximately 2 mm, as compared to the cars with compression ignition engines.As for the points associated with the active safety of the rear axle, within the area of both the mounting of the rear suspension beam (AVSR) and the mounting of springs and shock absorbers (AVSS), significant differences were noted between the test vehicle types (Fig. 5). As regards the points associated with the active safety of the front axle (AVSF) and the points associated with the passive safety of the front part of the vehicles (PFVS), no significant differences between the car types were noted. However, for the points associated with the passive safety of the rear part of the vehicles (PRVS), the differences between the car types were significant.

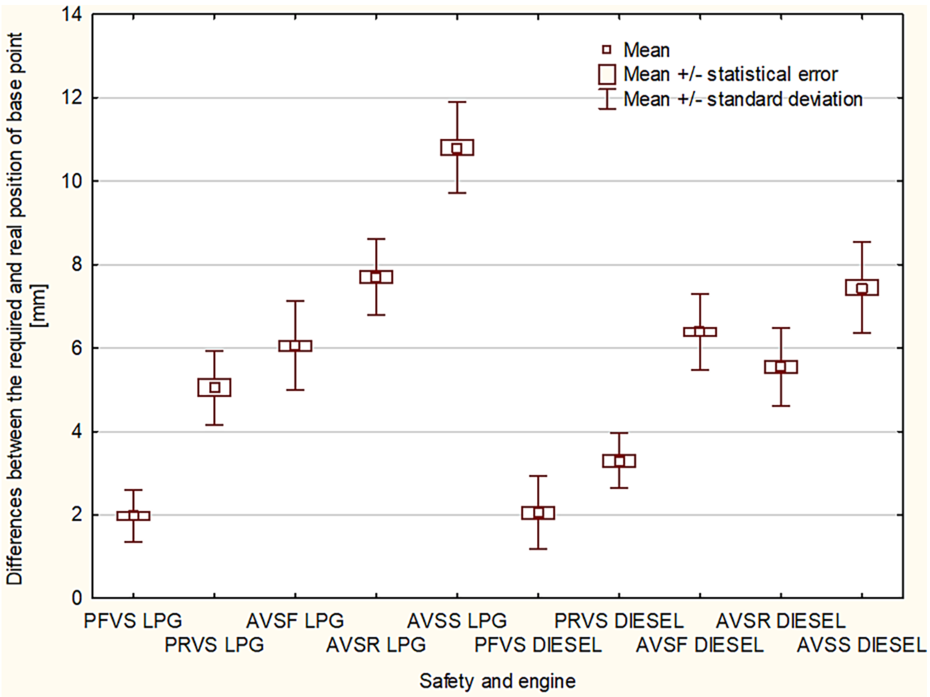

Figure 5. A comparison of changes in floor panel geometry in cars after covering a mileage of 300,000 km, depending on the vehicle safety type and the fuel supply system type

As for the front end of the vehicles, there were no significant changes in the geometry of the floor panel and the upper mountings of the McPherson struts between the cars with compression-ignition engines and those with spark-ignition engines fuelled with LPG. Slightly greater changes occurred for the former. However, as regards the rear part of the vehicle, changes in geometry in the LPG-fuelled cars were significantly greater than those in the diesel-fuelled cars. This was particularly true for the points representing the mounting of the rear suspension beam (approximately 7.7 and 5.6 mm, respectively) and of the rear springs and shock absorbers (approximately 10.8 and 7.5 mm, respectively). In addition, there were also large differences at the points located on the rear side members. The differences in geometry changes between vehicle types were mainly due to the different distribution of weight on the axles of the vehicles. In conclusion, not only in-service changes in the car floor panel geometry are significantly affected by the mileage but also by the vehicle weight and its distribution on the vehicle axles. In the LPG-fuelled cars, 49.5% of the weight was borne by the rear axle, whereas in the diesel-fuelled cars, it was only 42%.

Based on the results obtained, assumptions were made for the in-service passenger car floor panel wear model. It was assumed that the model of floor panel geometry changes developed in this study only applied to passenger cars with a collision-free history in which no conditions beyond standard operation occurred. After introducing these assumptions, the model representing in-service changes in floor panel geometry (W_{cb}) took the following form:

$$W_{cb} = f(G_e) \tag{3}$$

where: G_e – changes in geometry caused by operating conditions

$$W_{cb} = C_m \cdot I_{gn} \tag{4}$$

where: C_m – vehicle mileage, in thousand km; I_{gn} – intensity of changes in geometry at a particular basis point, depending on the vehicle type.

Throughout the operation of the vehicle, the value of the intensity of changes in geometry at a particular basis point on the floor panel for the particular vehicle type remains constant [17, 27]. It is determined by the type of safety for which a particular basis point is responsible, the function of a particular point, and the side of the vehicle on which the point is situated. Using this data, the intensity of changes in floor panel geometry at a particular basis point on the floor panel for a particular vehicle type was determined (Table 2).

Figure 6 summarises changes in the geometry of the suspension and steering systems in the test cars and shows the nominal values of the individual parameters and the permissible changes in these parameters. In addition, the figure shows changes in the parameters under analysis at a mileage of approximately 300,000 km in cars with compression ignition engines and with spark-ignition engines fuelled with LPG. It can be observed that in both vehicle types, each wheel alignment parameter has changed significantly over the course of operation, as compared to the nominal values. During the measurements carried out at a mileage of 300,000 km for both vehicle types, the limit values for each wheel alignment parameter were significantly exceeded for both the front and rear axles. During the testing, slightly greater changes in the front axle geometry parameters occurred in cars with compression-ignition engines, which was probably related to the greater weight of the power unit and, therefore, to the greater load on the front axle of the vehicles. It was particularly evident for changes in the front axle wheel camber angles. On the other hand, in the cars with LPG-fuelled spark-ignition engines, changes in the rear axle wheel alignment parameters were greater than those in the cars with compression ignition engines. Very large differences between vehicle types were noted for the rear wheel camber angles. Significant differences also occurred for the rear wheel internal toe-in, and were due to the greater load borne by the rear part of the body in the LPG-fuelled cars. By relating the results of measurements of the individual wheel alignment parameters to the permissible values, it can be concluded that for the test cars, particularly significant changes in geometry occurred for the rear axle in both vehicle types. This was largely attributable to the nature of the operation and the purpose of the vehicles that transported loads. At a mileage of 300,000, the permissible values of the rear wheel internal toe-in were exceeded up to more than ten times, whereas the rear wheel camber angles in the cars with LPG-fuelled engines and the front wheel camber angles in the cars with compression ignition engines, were exceeded by more than three times.

Table 2. The value of changes in the geometry of the floor panel and the body within the area of the upper mounting of the McPherson strut

Basis point		The value of an average offset of a particular basis point [mm] at a mileage of		Intensity of geometry changes [mm/10,000 km]	
		LPG	DIESEL		
		300,000 km	300,000 km	LPG	DIESEL
1L	Front side member [mm]	2.4	2.8	0.08	0.09
1P		2.1	2.6	0.07	0.09
2L	Front suspension mounting [mm]	5.9	6.2	0.20	0.21
2P		6.8	6.9	0.23	0.23
3L	Front mounting of the front subframe [mm]	5.6	5.8	0.19	0.19
3P		6.2	6.7	0.21	0.22
4L	Mounting of the front suspension stabiliser [mm]	5.8	6.1	0.19	0.20
4P		6.3	6.9	0.21	0.23
5L	Rear mounting of the front subframe [mm]	5.6	5.8	0.19	0.19
5P		6.2	6.7	0.21	0.22
6L	Bulkhead area [mm]	1.7	1.4	0.06	0.05
6P		1.7	1.4	0.06	0.05
7L	Front mounting of the rear suspension beam [mm]	7.5	5.4	0.25	0.18
7P		7.9	5.7	0.26	0.19
8L	Rear mounting of the rear suspension beam [mm]	7.5	5.4	0.25	0.18
8P		7.9	5.7	0.26	0.19
9L	Front mounting of rear suspension springs and shock absorbers [mm]	10.5	7.4	0.35	0.25
9P		11.1	7.5	0.37	0.25
10L	Rear mounting of rear suspension springs and shock absorbers [mm]	10.5	7.4	0.35	0.25
10P		11.1	7.5	0.37	0.25
11L	Rear side member [mm]	5.2	3.4	0.17	0.11
11P		4.9	3.2	0.16	0.11
12L	Upper mounting of the McPherson struts [mm]	9.6	9.4	0.32	0.31
12P		9.6	9.4	0.32	0.31

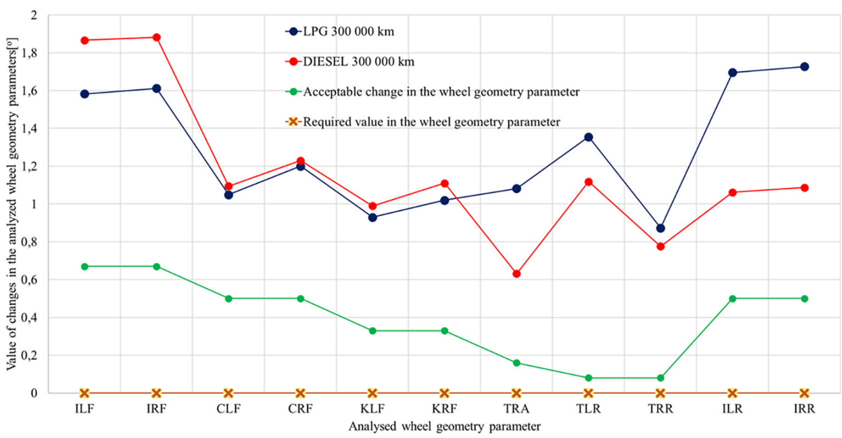

Figure 6. Changes in wheel alignment in the cars with compression ignition (diesel) engines and with LPG-fuelled engines

The results of measurements of the body geometry, carried out when conducting this study, provided a basis for the identification of its in-service wear. It was also possible to identify the impact of changes in body geometry on changes in the geometry of the steering and suspension systems. The changes in wheel alignment were affected by changes in floor panel geometry within the area of the mounting of the suspension and steering systems and within the area of the upper mounting of the McPherson struts. These changes should be considered separately for the front axle and for the rear axle.

There is a relationship between changes in the geometry of the front axle suspension and steering systems and changes in boy geometry at the front of the vehicle and a relationship between changes in the geometry of the rear axle suspension and steering systems and changes in body geometry at the rear of the vehicle.

In the cars with a collision-free history, changes in floor panel geometry at the front of the vehicle (W_{cbf}) and at the rear of the vehicle (W_{cbr}) were determined by the vehicle mileage (C_m), which was described by relationships 5 and 6. Table 2 shows the values of changes in intensity within the area of the individual basis points.

$$W_{cbf} = C_m \cdot I_{gnif} \tag{5}$$

$$W_{cbr} = C_m \cdot I_{gnir} \tag{6}$$

where: I_{gnif} – intensity of changes in floor panel geometry within the area of the basis points associated with the active safety in the front part of the vehicles, I_{gnir} – intensity of changes in floor panel geometry within the area of the basis points associated with the active safety in the rear part of the vehicles.

Table 3. Intensity of changes in geometry for a category points, depending on the vehicle type

Category of points	Intensity of geometry changes [mm/10,000 km]	
	LPG	DIESEL
PFVS	0.068	0.07
PRVS	0.165	0.11
AVSF	0.204	0.211
AVSR	0.255	0.185
AVSS	0.36	0.25

Unfortunately, it is not possible to define some mean quantity from all this results. Authors identified the position of 22 characteristic points of the floor panel, i.e. eleven points on the left and eleven points on the right side of the body. The authors identified 22 values intensity of changes in geometry at a particular basis point, depending on the vehicle type. It is possible to define several mean quantity intensity of changes in geometry for a category points (according to Table 1), depending on the vehicle type. The intensity of change is shown in Table 3.

In detailed terms, it is difficult to determine a numerical relationship between the impact of a shift of a particular basis point of the floor panel and the upper mounting of the McPherson struts on the individual wheel alignment parameters. It should be considered in a generalised way, separately for the front and the rear axle, i.e. the impact of the average values of the shift of the basis points associated with the active safety in front of the vehicles on the average values of changes in the front axle wheel alignment parameters, and the impact of the average values of the shift of the basis points in the rear part of the vehicles on the average values of changes in the rear axle geometry parameters should be identified (Table 4).

Based on the test results, it was possible to identify the value of the (k_{ti}) coefficient that represents the relationship between changes in wheel alignment for a particular axle (the front axle: G_{wf} and the rear axle: G_{wr}) and changes in body geometry in a particular part of the body (the front part: W_{cbf} and the rear part: W_{cbr}). The value of this (k_{ti}) coefficient is determined by the vehicle type and whether the front or the rear axle is concerned.

$$G_{wf} = k_{ti} \cdot W_{cbf} \tag{7}$$

$$G_{wr} = k_{ti} \cdot W_{cbr} \tag{8}$$

The k_{ti} coefficient values are presented in Table 3, separately for the cars with spark-ignition engines

Table 4. The values of the coefficient representing the relationship between changes in wheel alignment for a particular axle and changes in body geometry

Parameter	LPG		DIESEL	
	Front	Rear	Front	Rear
k_{ti}	4.91	6.55	4.68	6.43

fuelled with LPG and for the cars with compression ignition engines fuelled with diesel fuel.

CONCLUSIONS

The study identified areas in which the greatest changes in floor panel geometry, as well as areas of lesser change intensity, occurred depending on the type of internal combustion engine power system and the associated varying distribution of weight on the vehicle axles. Greater changes occurred for the front suspension and front subframe mounting points, as well as for the rear suspension mounting points.

At a mileage of 300,000 km, in both vehicle types (LPG and DIESEL), the points representing the mounting of the front suspension components and the front subframe to the floor panel exceeded the permissible value by two times. However, the points representing the upper mounting of the McPherson struts were shifted by more than 9 mm in both vehicle types, which exceeds the permissible geometry change values by three times. In the LPG-fuelled cars, a shift of the rear suspension spring and shock absorber mounting points by over 10 mm was noted. The permissible value (3 mm) was exceeded several times. Repairs to the bodywork should be carried out on these cars. In some cases, vehicles may need to be scrapped. Particularly if the body repair does not result in improved geometry.

Smaller changes in body geometry were noted for the basis points associated with the passive safety of the vehicles. At a mileage of 300,000 km, they did not exceed the 3 mm limit value. Greater changes occurred on the rear side members, particularly in the LPG-fuelled cars. Changes in body geometry in all the test cars were significantly affected by the vehicle safety type (passive or active). However, in vehicles with compression ignition engines, there were no significant differences between the passive safety of the front and rear axles.

The differences in geometry changes between vehicle types were mainly due to the different distribution of weight on the axles of the vehicles. In conclusion, not only in-service changes in the car floor panel geometry are significantly affected by the mileage but also by the vehicle weight and its distribution on the vehicle axles. Immediately following the body geometry measurements, wheel alignment measurements were carried out. For both vehicle types, each of the wheel alignment parameters significantly exceeded the permissible change value for both the rear and front axle. Smaller changes were noted for the rear wheel camber angles in the cars with compression ignition engines and for the caster angles and the steering axis inclination angles in both vehicle types, but they also considerably exceeded the permissible values.

There is a relationship between the body geometry and the wheel alignment. It was, therefore, possible to determine the relationship between changes in wheel alignment for a particular axle and changes in body geometry. The study presented in this paper represents a comprehensive approach to the wear of vehicle bodies in terms of changes in body geometry and the in-service deterioration of the body of cars with different distributions of weight on the axles. The identification of the impact of changes in the vehicle body geometry on changes in the suspension and steering system geometry parameters was indirectly aimed at determining the impact of body wear on vehicle safety.

In subsequent studies, the authors will investigate changes in the geometry of the floor panel and upper mountings of the McPherson struts and carry out measurements of the suspension and steering system geometry parameters in cars for which conditions exceeding standard operation occurred.

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