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Safety as a key aspect in the creation of motor vehicles

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In this article, the authors attempt to define vehicle safety. They indicate selected elements of passive safety, which in their opinion contribute to a significant reduction in injury to participants of various road incidents. The goal is to prove the following thesis: Safety as a key aspect of vehicle design. They prove it by analyzing the results obtained during frontal collisions and presented by NHTSA in twelve reports. Six of them are from 1993–1997, the rest are from 2011–2016. In the final part of this work they indicate potential ways of developing safety in vehicles.

Keywords: Vehicle safety, crumple zones, passive safety

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And the sense of security, even the most warranted, is a bad councillor
Joseph Conrad

Introduction

The intensification of transport work carried out in recent years in various branches of transport, in particular using road infrastructure, caused by an increase in the export and import of goods and the flow of people, contributes to a constantly increasing number of vehicles and thus car accidents. They necessitate the development and implementation of further technological and legal solutions, the purpose of which is to increase the safety of all road users and change the negative trend. The purpose of this article is to verify the following thesis: "Safety as a key aspect of motor vehicle design". The authors do this by citing and subjecting multi-faceted analysis of data recorded by sensors during leading crash tests on twelve vehicles, based on reports by the American organization NHTSA[1]. Six of them are from the 1990s, the rest are from the second decade of the 21st century. The analysis presented in this article takes into account the following car models:

1. Ford F150 (year of production: 1993);
2. Ford F150 (year of production: 2015);
3. Ford Mustang (year of production: 1994);
4. Ford Mustang (year of production: 2015);
5. Honda Civic (year of production: 1994);
6. Honda Civic (year of production: 2016);
7. Toyota Corolla (year of production: 1994);
8. Toyota Corolla (year of production: 2015);
9. Toyota RAV4 (year of production: 1997);
10. Toyota RAV4 (year of production: 2015);
11. Volkswagen Passat (year of production: 1994);12.
12. Volkswagen Passat (year of production: 2011).

[1] The history of NHTSA dates back to September 9, 1966, when the then 36th President of the United States of America, Lyndon Baines Johnson (1908–1973), due to the constantly increasing social pressure, signed the road safety act by which the National Highway Safety Bureau was established. (NHSB). After 4 years of operation, pursuant to the amendment to the Act, the National Highway Traffic Safety Administration (NHTSA) was created in 1970. Subsequent amendments and the creation of other legal acts increasing the competence and scope of its activities have contributed to the improvement of safety in motor vehicles through the possibility of issuing independent opinions. The generally available nature of publications containing data obtained during safety tests has somewhat forced vehicle manufacturers to seek such technological solutions that will increase the chance of survival of a serious accident by people inside the vehicle will increase (*Understanding the National Highway Traffic Safety Administration (NHTSA)* (2017)).

Their detailed characteristics are included in the section entitled „Crash test results”. The research methods used by the authors are: method of analysis and criticism of literature (for chapters entitled *Definition of car safety*, *Characteristics of the frontal impact test, parameters measured during it and dummies*) and the method of testing documents (it was used in chapters entitled *Crash test results*, *Summary*).

Definition of car safety

Considerations for car safety should begin with clarifying the very term safety. As Skubisz (2017: 61–62) indicates, this concept is present in many areas of human life. This multiplicity and often ambiguity results above all from a practical point of view. For example, the following types of security have been created by man today, including in particular: national, internal, external, military, social and the like. Therefore, it is necessary to add to it an adjective specifying in such a way that one knows who personally or what it concerns. Therefore, creating one, sufficiently comprehensive and universal definition regulating all the aforementioned areas is a difficult task, and all attempts, as a consequence, may end with its even non-functional sound. Historically, great Greek philosophers have dealt with security. The definitions they created were exemplifying, and thus illustrated by the example of war and peace. This state of affairs resulted primarily from the primary role of the then armed conflicts. Today, security can be called a state where a person can objectively determine freedom from all threats understood as the presence of factors that may cause damage to health, life, freedom, peace and the like. In the sense of car safety, we can talk about systems that, with their functionality, are able to support the driver's decision-making during normal driving and during dangerous situations, and when it turns out to be insufficient, they should minimize the consequences of an accident and injuries sustained during their operation. These technologies must be able to provide protection regardless of actions or intentions undertaken by man. Undoubtedly, they play a key role in vehicle development, being in a way an indicator of their quality on the market. Contemporary literature on the subject divides car safety into active and passive.

Active safety (in the literature on the subject the active name is also active safety) is a set of technological solutions that, by their functionality, contribute to avoiding situations threatening the life or health of people in the vehicle. As Krzyszkowska (2015: 2 (15)) indicates, even several dozen security systems are designed for the automotive industry each year. They are often created by adding additional functionality to an existing system.

In turn, **passive safety** of the vehicle are called technical and constructional features of the vehicle that through the properties given in the production process ensure maximum protection for the driver and passengers. In the authors' opinion, among the most important elements affecting protection are crumple zones consisting of specially shaped metal elements with an admixture of other elements, whose purpose is to change their durability, strength or physical properties. At the time of the accident they often deform irreversibly. This is desirable, because only in this way they are able to absorb and disperse energy, while increasing the chances of survival of people inside the vehicle. Other equally important technological solutions are:

a. **Airbags** – the purpose of which is to minimize the effects of body impact on vehicle components and collision shock absorption. Their design consists of: an activation system (inertial sensors[2], computer), a gas generator (released by means of a pyrotechnic material detonated by a fuse) and a flexible bag (made of polyamide material or nylon-cotton fabric). Airbags can be divided into (Drabik, 2011: 7–8):
   - **For driver and passenger –** their capacity is 35–75 dm^3 and 80–140 dm^3 respectively. They are opened with a delay of several thousandths of a second from the moment the electronic sensors detect a collision. It takes about 30 ms to fill one of them. Within the next 120 ms from the end of the filling process, the pads are emptied. This time is sufficient to limit injuries and prevents possible suffocation of victims, for example when they lose consciousness. The correct operation of these safety components is conditional on the person adopting the correct position in the chair and adjusting the seat belts correctly;
   - **Side –** installed in the side edge of the chair or under the lining covering the inner surface of the door. Its activation is to contribute in particular to limiting head, spine or chest injuries which may occur as a result of a side impact;
   - **Curtains** – located in the inner edges of the car roof. Its activation resulting from a side impact or rollover is designed to protect the head and face of people located inside the vehicle;
   - **Knee** – mounted under the steering column and opposite the passenger's knees. The force generated as a result of impact can lead to displacement of people on the seats, thus intensifying their injuries. Their function is therefore to protect these joints during frontal collisions by correctly positioning the limbs;
   - **Protects the driver's feet** – installed under the floor, next to the pedals. The capacity of this type of airbag is 10 dm^3. When activated, its task is to

[2] Inertial sensors (also known as impact or shock sensors) – electronic components that are designed to detect a delay in vehicle movement caused by an impact exceeding a threshold value set by the vehicle constructors. When such a situation occurs, their purpose is to send a signal to the computer, which, after analysis, sends the appropriate information to the detonators activating the pillows appropriate for the type of collision. In addition, they are able to turn off the engine, for example, by cutting off the power supply to the fuel pump control system in order to protect the victims (who may lose consciousness as a result of the collision) from a fire or explosion that threatens their health or life (*Czujnik zderzeniowy – co to jest?*).

minimize the risk of foot jamming between the pedals and reduce the risk of bone fractures building it.

b. **Three-point inertial seat belts and pyrotechnic pretensioners** – the purpose of which is: to reduce contact of bodies of persons in the vehicle with elements of its equipment, transfer of forces acting on impact to the stronger bones of the human body (pelvis and chest), or to prevent situations where there is a high risk of falling out of the car. According to data presented by the Polish National Road Safety Council (KRBRD, pol. *Krajowa Rada Bezpieczeństwa Ruchu Drogowego*), their use contributes to reducing the risk of death by up to 45%. In Poland, the rate of use of seat belts for passenger cars by drivers and passengers in 2014 was 90% (Krajowa Rada Bezpieczeństwa Ruchu Drogowego, 2015: 1). Contemporary belts are made of synthetic materials (e.g. polyester). Their length is not specified in advance – it depends on the vehicle manufacturer, while the width is about 48 millimeters. It must be equipped with two systems: retractor and pyrotechnic tensioner. The retractor (also called a winder) is located at the post. His goal is to block the belt during a hard blow (Potwora: 6–9). In turn, the pyrotechnic tensioner is located in the castle. It consists of a piston, igniter and pyrotechnic charge (usually formed on the basis of nitrocellulose) detonated when strong impact is detected. The pressure resulting from the explosion causes the lock to move back down. Its role is therefore to tighten the tape (as in the case of the retractor) and shorten it by a few centimeters in such a way as to reduce the possibility of moving the body forward, thereby minimizing the amount of injury sustained in a frontal accident (Witkowski, 2011). Correct fastening of the belt is achieved by pulling it to the other side and fastening in a place intended for it. Its lower part should be as low as possible – under the hip spines. The upper fragment should adhere from the center of the arm through the center of the sternum. Only this setting in the event of an accident will transfer the forces associated with the impact to the more durable bones of the body. Its incorrect fastening can lead to damage to internal organs.

c. **Head restraints** – the design of contemporary designed seats, as indicated by Jasztal, Nadra and Milczarek (2014: 3 (249)) must be based on a rigid skeleton, in addition it must be equipped with mechanisms to adjust parameters such as height, distance from the steering wheel and pedals or the angle of the backrest. Today, manufacturers use a “bucket” type of seats. They owe their name to the presence of additional elements in the form of a sponge placed on the edges of the seat and backrest. As indicated by the NHTSA report on the frontal impact test for the Ford F150 from 1993 (more on this subject in the section entitled *Crash test results*), this vehicle differed from the others, among other things in the use of the “bench” type of seats. This solution had a significant disadvantage – at the moment of negotiating sharp turns and no speed adjustment to them, the bodies of people in the vehicle were shifted, increasing the risk of injury and, in extreme cases, leading to loss of control over the vehicle. This risk is effectively minimized by bucket seats guaranteeing a stable position of the driver and passengers. In addition to the chair itself, it is extremely important to use a headrest mounted in the upper part of the seat. According to research, even a low collision speed (about 20 km/h) can contribute to trauma to the cervical spine as a result of very strong and sudden head bending backwards. The following types of head restraints are available on the market (Jasztal, Nadra, Milczarek, 2014: 3–4 (249–250)):

- **Passive** – height or tilt angle adjustment is possible. Their function boils down to acting as a support, and the effectiveness depends on the correct positioning of the shape of the head.
- **Reactive** – they react to the occurrence of a road collision by moving the headrest forward due to the pressure exerted by the sitting person on the backrest and the sensors installed in it. This phenomenon protects the cervical spine from accepting loads that may be the cause of death or temporary and permanent disability.
- **Active** – the main difference between reactive and active is the use of advanced electronic systems measuring the acceleration occurring in the car and the pressure exerted by the back on the backrest. Based on the measurements and calculations made by the system, the position in which the headrest should be should be selected to minimize the risk of accelerating the cervical spine.

Therefore, in reactive and active system, as indicated by Jasztal, Nadra and Milczarek (2014: 4 (250)), the effect of „chasing the head" occurs in the reactive and active system. In addition, modern armchairs can be fitted with an additional system, such as Whiplash Protection System (WHIPS) or Anti-Whiplash System (AWS). The principle of their operation is to lower the back of the chair when it is detected by the rear impact system in such a way that the body, which due to the force of the impact is thrown forward, falling down managed to lose speed, thus reducing the strength of the back impact. Head restraints are compulsory equipment for vehicles under the Council Directive of 16 October 1978 on the approximation of the laws of the Member States relating to head restraints of seats of motor vehicles (78/932/EEC). The document specifies how to determine the optimal dimensions (for values such as height, width, angle of inclination and the like) of head restraints. Meeting these criteria is the basis for issuing the approval certificate (Council Directive of 16 October 1978, pp. 1–9). Elements of passive safety will be discussed later in this work.

Characteristics of the frontal impact test, parameters measured during it and dummies

Crash tests despite the long history of the automotive industry began to be carried out only at the turn of the 1930s and 1940s. Initially, cars were dropped from the cliff, and then, after analyzing their damage, conclusions were drawn about their safety. Over time, a concrete wall began to be used, where a man jumped out of the speeding vehicle a few seconds before the impact. These tests were often carried out by car manufacturers, which affected the bias of published expert opinions and the high probability of covering up important facts revealed during the inspection of the wreck (*Krótka historia testów zderzeniowych*, 2018). In addition to volunteers, human corpses were used for testing, however, due to the constant problems of finding a dead body without external or internal damage, engineers began work on the construction of humanoid mannequins. The first effects of the work were shown in 1949 by Samuel Alderson (1914–2005), a designer of American origin who created a mannequin called *Sierra Sam*. Sierra represented his figure of a 95 percentile man (weight about 100 kg with a height of 188 centimeters), and his main purpose was, among others, participation in tests of aircraft catapults. Nowadays, the frontal collision according to the information contained in the NHTSA reports takes place by accelerating the car to a speed of 54 km/h and colliding it in a symmetrical or asymmetrical way with a deformable barrier covered with an aluminum layer.

The appearance of the dummy and its position are shown in Figures 1 and 2:

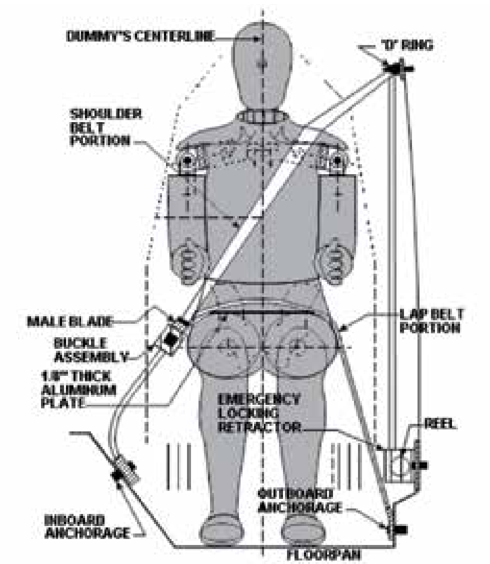

Figure 1. Front view of the dummy used in car crash tests

Source: Report number: NCAP-CAL-15-003, New Car Assessment Program (NCAP), Frontal barrier impact test, Toyota Motor Corporation, 2015 Toyota RAV-4 SUV, pp. 16 (2–10).

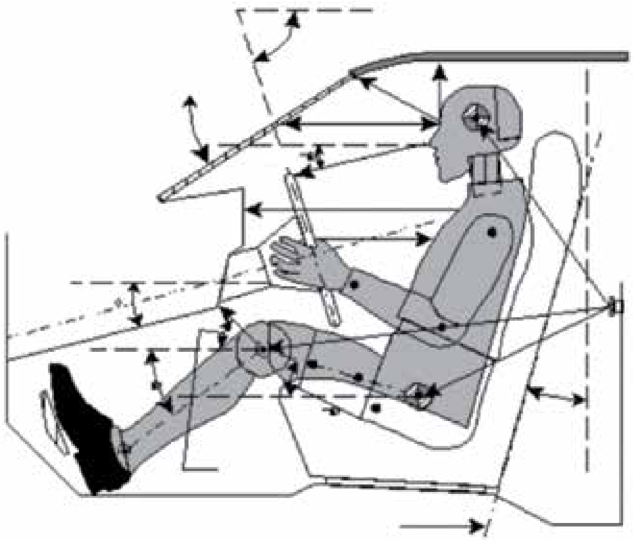

Figure 2. Side view of the dummy used in car crash tests

Source: Report number: NCAP-CAL-15-003, New Car Assessment Program (NCAP), Frontal barrier impact test, Toyota Motor Corporation, 2015 Toyota RAV-4 SUV, pp. 14 (2–8).

This article presents the results obtained from two dummies (Jaśkiewicz, Turecki, Witaszek, Więckowski, 2013:1–4 (22–25)):

1. **Driver, i.e. a 172-centimeter man weighing 78.4 kilograms (50-centiles)** – a dummy representing the average car user. His head was made of aluminum and covered with rubber. Inside it there are three sensors responsible for the calculation: displacement, impact force and acceleration. The neck was equipped with detectors responsible for measuring the deflection of the spine relative to the chest. Another of their tasks is to measure the force causing its stress or deflection occurring during collisions. Collars made of aluminum alloy thanks to installed sensors are used to collect information on the behavior of shoulder straps. The chest consists of six high-strength steel ribs whose deformation is identical to that of a human. Sensors mounted inside are responsible for measuring: chest displacement, injuries sustained by the use of fastened seat belts, or acceleration..
2. **Passenger, i.e. a 150-centimeter woman weighing 50 kilograms (5-centiles)** – presents a statistical adult woman. Its equipment does not differ much from the previous one – only the ribs are made of high quality polymer resistant to damage.

During crash tests, the following values are measured, among others:

a. **Head Injury Criterion [HIC_{15}]** – parameter used by NHTSA to assess potential head injuries in vehicle collision situations. This number includes the calculated value from the acceleration due to the impact and its duration using an advanced mathematical apparatus. The higher the acceleration value, the shorter its duration should be to minimize the damage (McHenry, 2004: 4–6).

b. **Displacement [mm]** – a value indicating the displacement and deformation of the chest due to the acceleration force (caused by sudden braking or collision with an obstacle) and the opposite value resulting from correctly adjusted seat belts.
c. **Newton [N]** – unit of force in the International System of Units (SI). It is the force that gives an object with a mass of one kilogram acceleration of 1 meter per second^2. Used to record the strength of the human body.
d. **Acceleration [g]** – it is a situation in which an object is subject to an external force other than gravity and its resultant value causes acceleration causing an increase in body weight compared to the weight in normal conditions. In the literature, another common definition is to determine acceleration as a multiple of standard gravitational acceleration. According to these definitions, it is a vector with characteristic features such as direction and turn. In NHTSA reports, acceleration has been marked with the symbol [Gs]. One of the reasons for measuring this value is the health aspect. In the event of collisions, the eyeballs and the brain are particularly vulnerable to damage due to acceleration – the increased blood flow to them, and thus the increase in pressure in these organs carries the risk of permanent or temporary disability. Reports do not mention its safe upper limit, because every human body is different and hence its endurance is different. Acceleration of the order of 8 [g] average person (by which is meant a person without prior preparation consisting of practical exercises with the simultaneous use of theoretical knowledge eliminating effects) is able to withstand for no more than 5 [s]. After which he loses consciousness due to ischemia of key brain areas (Czubkowski, 2016). Its further impact can lead to death.

The maximum values of HIC15, displacement and forces that can affect individual body parts are listed in Table 1.

Table 1. Maximum allowable values that may affect individual body parts

The measurand		Driver (man)	Passenger (woman)
Head injury criterion [HIC_{15}]		700	700
Maximum threshold of chest displacement [mm]		63	52
Maximum threshold on femur [N]:	left	10 008	6 805
	right	10 008	6 805

Source: own study based on: Report number: NCAP-CAL-15-003, New Car Assessment Program (NCAP), Frontal barrier impact test, Toyota Motor Corporation, 2015 Toyota RAV-4 SUV, pp. 14 (2–8).

In the case of this study, the following parameters were compared:
a. Acceleration of the head [Gs];
b. Acceleration of the chest [Gs];
c. Head Injury Criterion [HIC15];
d. Forces affecting the femur [N].

The study does not include a summary for the maximum deformation of the chest, forces acting on the shoulder and hip belt due to the incompleteness of data in NHTSA reports.

Crash test results

The analysis consisted in comparing the measured parameters with each other and drawing conclusions based on observations made. For the analysis, as already mentioned by the authors, a total of 12 collision reports were used for the following vehicles (six of them come from the end of the 20th century, others from the second decade of the 21st century): Ford F150 (1993 and 2015), Ford Mustang (1994 and 2015), Honda Civic (1994 and 2016), Toyota Corolla (1994 and 2015), Toyota RAV4 (1997 and 2015), Volkswagen Passat (1994 and 2011). Their detailed characteristics are presented in Table 2.

Table 2. Characteristics of vehicles used in frontal impact testsSource: own study based on NHTSA reports included in the bibliography

Data: / Type of vehicle:		Ford F150		Ford Mustang		Toyota RAV4		Volkswagen Passat		Honda Civic		**Toyota Corolla**	
Year of production		1993	2015	1994	2015	1996	2014	1994	2011	1994	2016	1993	2015
Number of doors		2				4				4			
Speed of crash collision [km/h]		56.3	56.4	56.3	56.3	56.0	56.3	56.0	56.3	56.0	56.1	56.2	56.4
Type of collision		Frontal impact				Frontal impact				Frontal impact			
Type of vehicle		Pickup		Coupé		SUV		Sedan		Sedan		Sedan	
Year of test		1994	2015	1994.0	2015	1997	2015	1994	2011	1993	2016	1994	2015
Weight of vehicle [kg]:	Net	2016.0	2150.5	1415.0	1600.0	1363.0	1635.0	1417.0	1455.6	1051.0	1250.5	1158.0	1299.2
	With load	2301.0	2427.5	1608.0	1771.8	1651.0	1845.8	1650.0	1762.2	1249.0	1436.5	1352.0	1480.3
	Difference	285.0	277.0	193.0	171.8	288.0	210.8	233.0	306.6	198.0	186.0	194.0	181.1
Number of dummies		2				2				2			
Weight [kg]:	Dummies	149.0	141.0	148.8	141.0	152.0	147.0	151.6	140.6	152.0	141.0	149.0	139.3
	Load	136.0	136.0	44.2	30.8	136.0	63.8	81.4	166.0	46.0	45.0	45.0	41.8
Engine capacity [l]		5.0	3.5	3.8	3.7	2.0	2.5	2.8	2.5	1.5	2.0	1.8	
Type of drive		Rear-wheel drive	4x4	Rear-wheel drive		4x4		Front-wheel drive		Front-wheel drive		Front-wheel drive	
Size of wheel		P235/ 75R15	265/ 70R17	P205/ 65R15	P235/ 55R17	215/ 70R16	P225/ 65R17	215/ 50R15	215/ 60R16	T105/ 80D13	215/ 55R16	P185/ 65R14855	P205/ 55R16
Type of seats in frontal part of vehicle		bench	bucket			bucket				bucket			

Data: / Type of vehicle:		Ford F150		Ford Mustang		Toyota RAV4		Volkswagen Passat		Honda Civic		**Toyota Corolla**	
Dimensions of vehicle before crash test [mm]:	Right side	5340	5390	4530	4050	4005	4340	–	4701	4225	4418	4270	4395
	Center	5350	5886	4605	4790	4177	4565	4595	4866	4385	4605	4372	4630
	Left side	5540	5390	4515	4045	3999	4345	–	4701	4230	4418	4270	4390
Dimensions of vehicle after crash test [mm]:	Right side	4790	5056	3910	3690	3630	4043	–	4365	3730	4112	3805	4069
	Center	4700	5258	3960	4196	3611	4126	4373	4354	3745	4179	3907	4100
	Left side	4870	5056	3925	3675	3604	3991	–	4349	3765	4074	3810	4050
Difference in vehicle dimensions before and after crash test [mm]:	Right side	550	334	620	360	375	297	500	336	495	306	465	326
	Center	650	628	645	594	566	439	222	512	640	426	465	530
	Left side	670	334	590	370	395	354	415	352	465	344	460	340

Acceleration of the driver and passenger heads [Gs]:

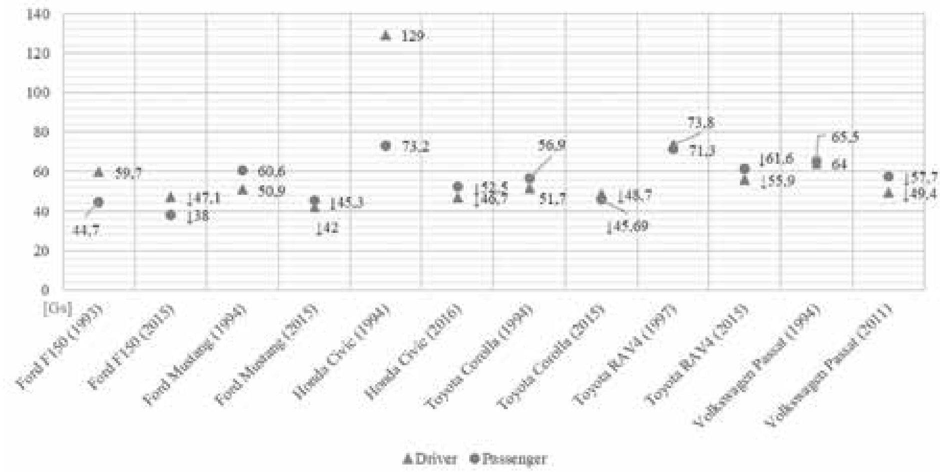

Chart 1. Acceleration of the driver and passenger heads

Source: own study based on NHTSA reports included in the bibliography.

The values of accelerating of passenger heads for cars obtained during head-on collisions undoubtedly illustrate the downward trend in newer models. The largest decrease occurred for Honda brand Civic vehicles – In the case of driver and passenger it was 82.3 [Gs] and 20.7 [Gs] respectively. The vehicles of this series from 1994 also recorded the highest values among other vehicles produced in the 20th century and included in this study. In the same period, taking into account the same parameter, the Toyota RAV4 turned out to be the worst vehicle in the 21st century, obtaining 55.9 [Gs] and 61.6 [Gs] for the driver and passenger. Ford vehicles manufactured in 2015 did the best. On Mustang the acceleration was 42 [Gs] for the driver, while the passenger felt acceleration of 38 [Gs] on the F150.

Acceleration of the driver and passenger chests [Gs]:

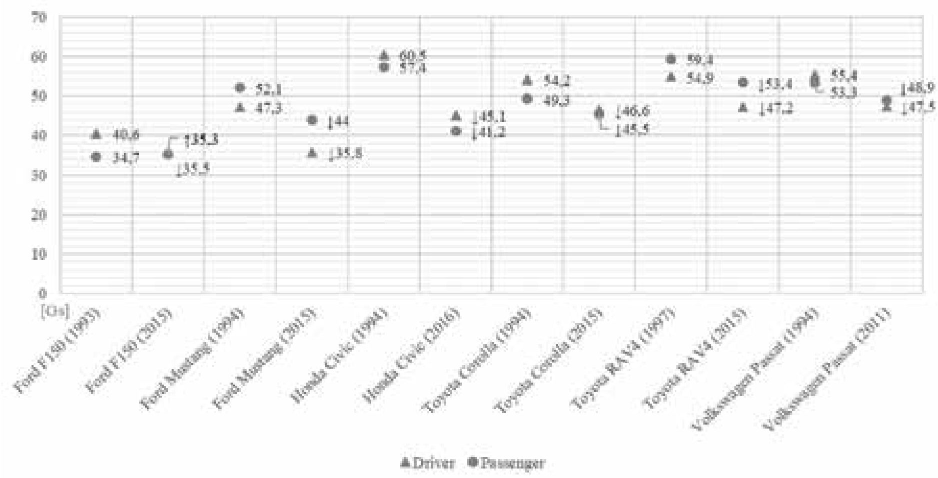

Chart 14. Acceleration of the driver and passenger chests

Source: own study based on NHTSA reports included in the bibliography.

An interesting observation in this statement of results is a Ford production vehicle, specifically the F150 from 2015, where the passenger registered an increase in recorded acceleration by 0.6 [Gs]. Due to the low value of the increase, it can still be concluded that the downward trend in values obtained in the tests is dominant. The largest decrease was observed in Honda Civic vehicles – its value was 15.4 [Gs] and 16.2 [Gs] respectively for the driver and passenger. In the vehicle of this series produced in 1994, the indications were the highest for the driver (60.5 [Gs]). In the case of a passenger, the highest number of 59.4 [Gs] was registered in Toyota RAV4. The highest value in vehicles produced in the second decade of the 21st century occurred in the Toyota RAV4 vehicle reaching 55.5 [Gs] and 61.6 [Gs] for the driver and passenger. The lowest values in the 20th century were recorded in the Ford F150 (respectively 40.6 [Gs] and 34.7 [Gs] for driver and passenger). Similarly in 2015 – here the same model guaranteed high protection, which resulted in the lowest acceleration values for driver and passenger – 35.5 [Gs] and 35.3 [Gs].

Head Injury Criterion for the driver and passenger [HIC_{15}]:

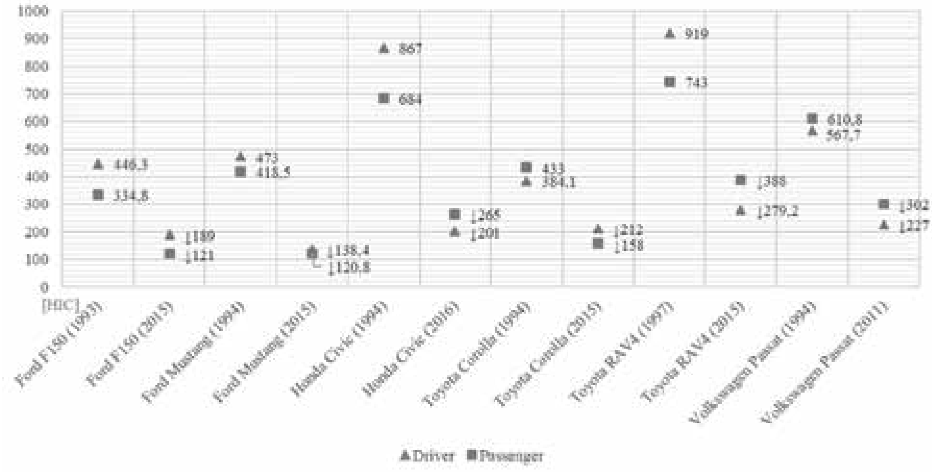

Chart 15. Head Injury Criterion [HIC_{15}] for the driver and passenger

Source: own study based on NHTSA reports included in the bibliography.

‘The criterion of head and passenger head injury has undoubtedly a downward trend in newer vehicles. The maximum value obtainable in tests conducted in the 20th century was 1000 [HIC15]. At the beginning of the 21st century, this criterion was tightened and its value after recalculation was reduced to 700 [HIC15] in order to guarantee better protection of people in the vehicle. The largest values recorded in the 20th century for the driver and passenger were those from the Toyota RAV4 from 1997 – they were 919 [HIC15] and 743 [HIC15] respectively. In the corresponding ranking of cars produced above 2000, this model again achieved the highest score of 279.2 [HIC15] and 388 [HIC15] respectively. The greatest progress aimed at limiting this value was in Honda Civic vehicles – the decrease for the driver and passenger was 666 [HIC15] and 419 [HIC15] respectively. The lowest values registered by the devices come from Toyota Corolla manufactured in 1994 (384.1 [HIC15] for the driver) and Ford F150, where the value was obtained at the level of 334.8 [HIC15] for the passenger. For cars produced in the second decade of the 21st century, the smallest head injuries were recorded in the Ford Mustang – 138.4 [HIC15] for the driver and 120.8 [HIC15] for the passenger.

Forces affecting the driver's femurs [N]:

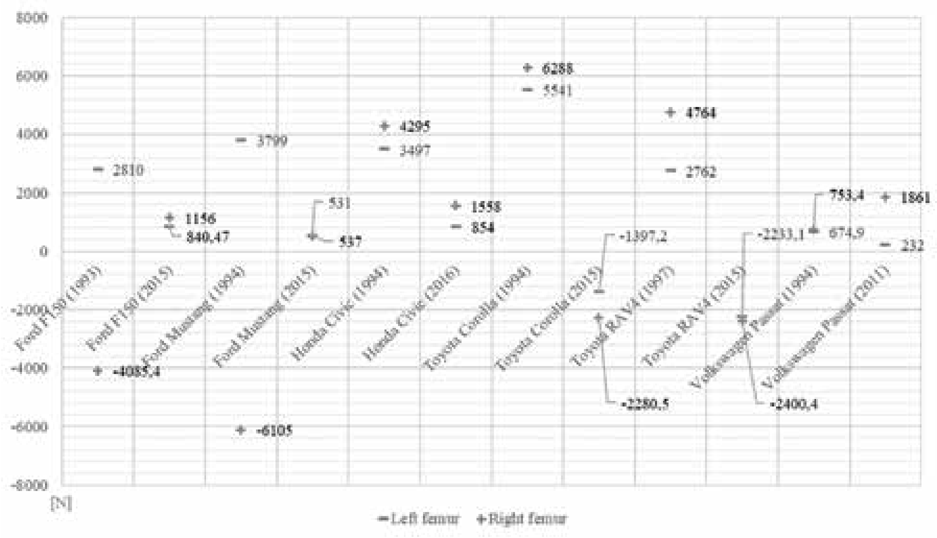

Chart 16. Forces affecting the driver's femurs [N]

Source: own study based on NHTSA reports included in the bibliography.

Forces affecting the passenger's femurs [N]:

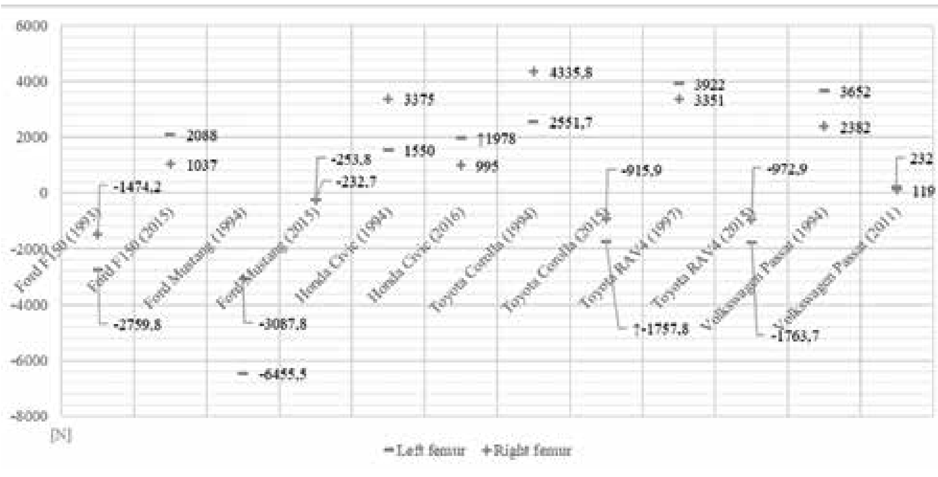

Chart 17. Forces affecting the passenger's femurs [N]

Source: own study based on NHTSA reports included in the bibliography.

Almost all vehicles of the newer generation (except for the Honda Civic and the left femur of the passenger, where the force increased by 428 [N] and Volkswagen Passat and the right femur of the driver, where the strength increased by 1107.6 [N] noticeable there is a decrease in forces acting on these measured areas. Positive and negative signs are caused by a change in the direction of the force, which may occur as a result of knees hitting the hard elements of the vehicle or the activation of knee airbags present in newer generation vehicles. Therefore, when interpreting the results, you should not suggest a sign, but a number, because the damage caused by the action of force in this case does not depend on its direction. The highest values recorded for drivers in the late 20th century came from Toyota Corolla – in the case of the left femur 5541 [N], right 6288 [N]. On the other hand, for the passenger in the analogous set taking into account data from the sensors, the largest number comes from Ford Mustang (1994) –6455.5 [N], 4355.8 for the left and right legs. The lowest indications of the devices occurred in the Volkswagen Passat manufactured in 1994 and they were for the left and right bones respectively 674.9 [N] and 753.4 [N]. The lowest values in cars produced in the second half of the 21st century for the left femur of the driver and passenger were in Volkswagen Passat and in two cases amounted to 232 [N]. For the right bone of driver and passenger – 537 [N] in Ford Mustang and 119 [N] again in the Volkswagen Passat.

Summary

The following conclusions summarize the thesis at the beginning of this article:

1. All vehicles manufactured in the 21st century did not record any increase in acceleration of driver and passenger heads compared to the results obtained for cars manufactured before 2000. An interesting observation is the Ford Mustang sports vehicle manufactured in 2015 – it guaranteed the best head protection against acceleration on background of other vehicles.
2. Almost all vehicles produced in the 21st century saw a decrease in acceleration of the chest acceleration of the driver and passenger – the only increase in this value occurred in the case of Ford F150 from 2015 compared to 1993, where the number was higher by 0.6 [Gs].
3. For the head injury criterion [HIC15] – all new vehicles guaranteed a decrease in the values obtained during this test. An interesting observation is the 2015 Ford Mustang sports car – it obtained the lowest ratio, both for the driver and passenger among other collided vehicles.

The fragments cited above and the data presented in the charts in the section entitled *Crash test results* defend the thesis contained in the introduction – the design of modern vehicles has been redesigned in such a way that it becomes definitely more resistant to transmitting forces directly to people in the vehicle, absorbing a significant part of them.

A solution that may contribute to an even greater decrease in the number of seriously injured or fatal victims is the more dynamic development of autonomous vehicles broadly characterized by Damian Kociemba in the article entitled *The use* *of artificial intelligence methods in creating autonomous vehicles* (pol. *Wykorzystanie metod sztucznej inteligencji w tworzeniu pojazdów autonomicznych*) published in the 28th issue of the magazine entitled "Innovative Management in Economy and Business" (pol. "Zarządzanie Innowacyjne w Gospodarce i Biznesie"). The author cites and discusses in it inter alia the actions taken by the Polish and European legislator.

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Report number: NCAP-MGA-2015-061, New Car Assessment Program, Frontal barrier impact test, Ford Motor Co., 2015 Ford F-150 SuperCab XL 4x4.

Ford Mustang:

Report number: CAL-94-N08, New Car Assessment Program, Frontal barrier impact test, Ford Motor Company, 1994 Ford Mustang.

Report number: NCAP-KAR-15-022, New Car Assessment Program, Frontal barrier impact test, Ford Motor Co., 2015 Ford Mustang.

Honda Civic:

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Report number: NCAP-MGA-2016-045, New Car Assessment Program, Frontal barrier impact test, Honda Mfg. of Indiana LLC., 2016 Honda Civic LX str.

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Report number: NCAP-TRC-15-002, New Car Assessment Program, Frontal barrier impact test, Toyota Motor Corporation, 2015 Toyota Corolla.

Toyota RAV4:

Report number: NCAP-TRC-97-003, New Car Assessment Program, Frontal barrier impact test, Toyota Motor Corporation, 1997 Toyota RAV4.

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Directives

Council Directive of 16 October 1978 on the approximation of the laws of the Member States relating to head restraints of seats of motor vehicles (78/932/EEC).

Streszczenie
Bezpieczeństwo jako kluczowy aspekt projektowania pojazdów samochodowych

Autorzy podejmują w artykule próbę zdefiniowania bezpieczeństwa w pojazdach. Wskazują na wybrane elementy bezpieczeństwa biernego, które w ich ocenie przyczyniają się do znacznej redukcji obrażeń uczestników różnych zdarzeń drogowych. Za cel obierają sobie udowodnienie tezy, iż bezpieczeństwo to kluczowy aspekt projektowania pojazdów samochodowych. Dowodzą jej za pomocą poddania analizie wyników uzyskanych podczas zderzeń czołowych i zaprezentowanych przez NHTSA w dwunastu raportach. Sześć spośród nich pochodzi z lat 1993–1997, reszta natomiast z okresu 2011–2016. W końcowej części pracy wskazano potencjalne drogi rozwoju bezpieczeństwa w pojazdach.

Słowa kluczowe: bezpieczeństwo pojazdów, strefy zgniotu, bezpieczeństwo bierne