Universitatea
Transilvania
din Brașov

INTERDISCIPLINARY DOCTORAL SCHOOL

Faculty of Product and Environmental Design

Ing. Alexandru THIERHEIMER

RESEARCH ON THE ANALYSIS OF THE MECHANISM OF ABDOMINAL INJURY IN THE EIGHT WEEKS PREGNANT WOMAN CAR DRIVER

SUMMARY

Scientific leader

Prof.dr. ing. Cătălin ALEXANDRU

BRAȘOV, 2024

Introduction

Every year, thousands of people are involved in road accidents resulting in serious injuries, pregnancy loss and, last but not least, deaths. However, European Community statistics indicate a reduction in the number of injured people for the last decades, a fact due to the introduction of passive safety systems such as airbags, seat belts, etc.

As a result, comfort is directly influenced by the level of active and passive safety presented by the car.

Active safety is assigned all the technical components intended for the collection, processing and transmission of information in order to warn and control the circumstances that favor the occurrence of road traffic accidents, while passive safety includes the technical components that contribute to reducing the consequences of such an unpredictable process. Thus, it will be identified at the level of the configuration of the essential features, for: the organization of the resistance elements of the automobiles, such as: the controlled deformation of the steering wheel column, the lateral glazed space above the shoulders; devices to limit the involuntary movements of the victim, such as: safety belts at multiple points, airbag cushion with multiple pressurization, seat back with side supports and headrest; protection of participants from outside the vehicle, such as drivers of two or three-wheeled vehicles, and/or pedestrians; the safety of the phase carried out from the separation of the cars to the establishment of the final position.

Safety improvement can be achieved both by driver assistance systems, in order to avoid road accidents, and by modifying the resistance structure of the vehicle for better protection at the time of collision. The ultimate goal is to avoid or even eliminate risk elements, and new technologies contribute to the fulfillment of these goals. It goes without saying that in the short or medium term, knowing how to reduce the severity of injuries is a major requirement in improving the study of road accidents.

Particular attention is being paid lately to the increasing use of computer technology, that is, the tactics used in the acquisition and interpretation of data (measurement, conditioning, storage and presentation), using PC-compatible systems, necessary for experimental research.

Taking into account all the logical arguments presented, the content of this thesis, with the title Research on the analysis of the mechanism of abdominal injury in the case of the eight-week pregnant woman driver, aims to carry out theoretical and practical experimental research on the mechanism of injury in general and the biomechanical behavior of the abdomen-uterus-embryo complex in particular.

1

Current status of surrogate anthropomorphic devices for experimental trials

1.1 Surrogate anthropomorphic devices in crash tests

Experimental injury estimation procedures were also conducted with the help of human volunteer operators. These volunteer operators were equipped prior to the crash tests with sensors and transducers that measured the variables of interest. The established diagnosis, regarding the injuries suffered by the operator following the collision tests, was analyzed in relation to the measured variables. Under these conditions, in order not to affect the bodily integrity or the health of the volunteer human operator, the aggressiveness of the collision tests was reduced to the limit of producing injuries, which is why no information could be obtained about the demand loads that produce severe injuries. [95, 102, 309, 329].

Analyzes of injury possibilities using volunteer human operators for experimental test samples contain flawed results due to the protective equipment used during the tests, the specific differences between the operators and not least the consequences of muscle contraction and voluntary reactions due to the a priori knowledge of the sample which are also difficult to quantify [329].

The use of human cadavers in tests to determine the degree of injury is the procedure that completely eliminates the human operator and implicitly his injury.

The disadvantage of this procedure is generated by the erroneous conclusions obtained due to the advanced age of the deceased person who presented degraded vital functions of the body during life, but also by the complicated acquisition of the corpses.

The sizes of the measurements performed on the corpses are closely related to the way of preservation and the condition of the corpses (time since death, frozen, embalmed). Keeping corpses in a saline environment, saline mist, maintains muscle elasticity.

The experimental tests carried out with the help of surrogate animals, such as monkeys and pigs, facilitated the knowledge of the way of producing injuries as well as the dynamics of the victim (occupant of the car) during the collision.

The reconstruction of road accidents through technical laboratory experiments is a more efficient procedure for establishing injury criteria and very useful for establishing road safety standard sizes, even if some tolerances must be kept to find out the causes. When the real environment in which the road event takes place is precisely constructed and the injuries of the victims are accurately diagnosed, it follows that the accidents can be reproduced by using anthropomorphic devices for ATD (anthropomorphic test device) mannequin tests specially oriented towards a certain activity from the set of experimental tests of collision, frontal, side, roll and/or rollover.

In the procedures of experimental tests to improve the safety conditions of the occupants of a motor vehicle, mannequins have a decisive role, that is why their continuous improvement is necessary regarding the fidelity of the biomechanical behavior to the human one as well as the performance of reproducing injuries in order to quantify them.

Computer virtual models (virtual mannequins) are considered modern procedures for analyzing the attitude of car occupants to road events, through technical experiments of experimental trials. The degree of accuracy of virtual models is increasingly high depending directly on the computer system and computer resources (hard, soft) that reproduce the characteristics of the human operator.

The advantage of using virtual dummies instead of physical test dummies is that they more accurately approximate the biomechanical characteristics of the victims and do not physically degrade during the experimental trials.

The use of these procedures in combination made it possible to derive human resistance limits with extreme magnitudes for quantifying the level of protection using a manikin.

Extensive research techniques are required when establishing the limits of injury and protection for children using intended mannequins, and human-child operators should not be used in experimental trials under any circumstances.

The process of determining the reference values of the protection is based on experimental tests with mannequins which, however, present different degrees of biofidelity but also measurement systems with different performances, which means that the qualitative modernization of the mannequins is a permanent priority measure. The qualitative modernization of the mannequins must be achieved by improving the biofidelity, in areas of application, followed by the optimization of the own measurement chains. The resolution of these desideratum also entails the definition of norms for determining the level of danger in extreme areas such as the lower limbs, as well as the formulation of criteria in the case of estimating injuries to the lower torso, the pelvis area, respectively the femur [95, 196, 329].

It is recommended for experimental test samples, as:

- meeting all injury criteria;
- specifying how to use the dummy for each sample;
- recording of additional observations for injuries to the extremities of the lower limbs;
- to estimate the possibilities of abdominal damage, of the thigh area, specific procedures and equipment must be provided.
- the procedures and the technical systems with the devices specifically dedicated to the assessment of the probability of damage to the abdominal region, the thighs and the calves should be stipulated clearly and precisely.

The evolution of the mannequins intended for the research of the demands of the human body, of frontal and side collisions, of the pregnant woman are shown in tabular form.

For the experimental tests of automobiles in frontal collisions, specialized dummies are presented, dummies that can also be used as pedestrian dummies or drivers of two-wheeled vehicles or recreational vehicles. The Hybrid III dummy has a measuring system with up to 60-70 measuring chains.

Complex dummies are not used in any type of testing. The testing of various components such as the steering system, the bumper or the engine hood in contact with the pedestrian victim or elements from the interior, will be carried out with simplified models such as the chest module, the lower limb and the skull cap in free fall.

Fig. 1.16 Pregnant woman mannequin

The reproducibility of the tests with the same manikin will lead to similar measured data under the conditions of repeating the same experimental test sample. It should be noted that after each crash test the dummy with the apparatus and sensitive measuring devices will be carefully inspected. Taking into account the fact that the calibration process of the measurement system requires time-consuming activities and high costs, the manikin as a whole must be reliable for several consecutive test cycles without inducing gross measurement deviations.

The protection criteria of the manikin established with the help of the physical quantities measured by the transducers placed on it are associated with the injury criteria of the human body and legislated imperatively with a normative character by the legislator as tolerance limits, i.e. the maximum values borne by the man.

The Head Injury Criterion HIC (Head Injury Criterion) represents the quantification of injuries to the head which is carried out with the help of a triaxial accelerometer, with a measurement range of ± 2000 g, located in the center of mass of the head. Biomechanically, the maximum tolerated stress load applied directly to the head is recommended to be limited to a maximum range of 36 ms.

The generalized model of accelerations for determining the tolerance limit of GAMBIT brain damage, in addition to knowing the components of the linear acceleration and the knowledge of the orthogonal components of the angular acceleration, the measurement of which is carried out with a triaxial accelerometer with a range limited to 100 krad/s2.

Aggressive deformation of the chest as a result of its direct loading can damage the internal organs through the compression-squeezing effect.

The pregnant female manikin is a small female Hybrid III manikin to simulate pregnancy and fetal injuries at the end of gestation, figure 1.16. This load-bearing manikin construction was designed to evaluate motion-limiting devices by measuring the contact forces between them and the load-bearing abdomen. The disadvantage is that it does not provide inside information such as accelerations, speeds and displacements.

The cover of the abdomen being made of urethane with high rigidity and the spine in the lumbar area with an anterior contour, slightly exaggerated, without lordosis, which leads to unreal interactions of the abdomen responsible for the body movement limitation systems and with other components inside the car.

1.2 The objectives of the work

Passive safety has the role of protecting the driver and his companions in general and pregnant women in particular at the time of the collision, providing them with sufficient non-lethal space.

For this role of passive safety to be realizable, it is necessary to know how the main collision force is transmitted from the place of impact to the interior of the passenger compartment, the shape and amplitude of the deformations, the variation Δv of the speed, and the compatibility of the rigidities of the deformed areas of the motor vehicles/motor vehicle.

Determining the forces exerted on the victims during frontal collisions requires a deep knowledge of the injury conditions, the severity of the injuries, the energy lost before, during and after the collision, as well as the working method of the measurement systems, acquisition, memorization and data processing regarding the dynamic behavior of the car, the stress of the pregnant female occupant and her dynamic behavior in various modes and types of frontal collision.

In this way, theoretical models will be designed to simulate the cooperation of the victim's behavior with that of the car, allowing the quantification of the monitored quantities only for the type and mode of collision modeled and carried out in real conditions.

In the framework of the thesis, the main objectives consist in the analysis of injury criteria, the quantification with the help of MEMS sensors of the stresses and deformations of the abdomen so that the behavior of the embryo can be analyzed.

Primary data processing in order to optimize the network of MEMS sensors equipping the anthropomorphic device to determine the severity of the stress on the abdomen as a result of contact with the movement limitation systems but also with the steering wheel and/or other elements inside the car.

Through the experimental research, the mechanism of injury production, their severity, and especially the behavior of the abdomen with a pregnancy of up to eight weeks, will be followed, to the stress generated by the movement limitation system, belt-airbag.

Taking into account these desired, the author has structured the following main objectives to be followed within the thesis, such as:

1. To conduct an essential, comprehensive documentary review of the history and current achievements of anthropomorphic devices for experimental trial testing, providing data on their construction and biomechanical performance limits;

2. Elaboration, based on recent bibliographic works, of a thorough and in-depth examination of the way to assess the severity of the injury, respectively the characteristic parameters of the movement limitation systems that influence the human load;

3. The formulation of own analytical models, for the simulation of the centric frontal collision with total coverage in virtual conditions, aiming at the simulation of the frontal collision with a respective car with a rigid and fixed barrier;

4. Establishing a stand and implicitly the procedures for specific experimental tests that allow the study of the influence of the pressurization of the airbag cushion on the female driver occupant, so that the crash tests are carried out in real and optimal reproducibility conditions, without external influences on the results;

5. Carrying out numerical analyzes of the synthesis of the frontal collision with the help of mathematical models regarding the consequences of the contact of the movement limitation systems on the human trunk and implicitly on the severity of the victim's injuries in order to eliminate major risks;

6. Practical realization of the installation for measuring and spatial tracking of the trajectory described by the human body and its respective embryo-uterus-mother complex with respect to the center of mass of the car, structured on MEMS inertial navigation technology, with electronic filters and memorization of sizes of specific interest with a high degree of confidence;

7. The presentation of the driver's dynamic posture in relation to the steering wheel, respectively the dashboard and the devices for limiting movement at the time of the collision, the causes identified as possible sources of flawed investigations, with the essential measures established to reduce errors;

8. Confirmation of the information resulting from the theoretical study, through analytical confrontation with the data resulting from the experimental tests and the establishment of the related link sizes, the exposition of the final conclusions with the operational recommendations, and proposals for future research directions.

1.3 Conclusions

In this section, for a better perception and determination of the degree of injury, the current state of the art in the field of anthropomorphic device technology and passive safety has been critically presented.

The passive safety standards were analysed, at the beginning of the chapter, making a description of them regarding the human-vehicle-road operating system in order to identify the provocative causes of road accidents in general and injuries in particular.

As a result of the analyses, the injury criteria and the mechanism of injury production based on biomechanical studies that provide useful knowledge in the procedures for establishing the probability of injury are further exposed. Injury severity is determined by the injury criterion for distinct regions of the body mechanically stressed, stresses that can degrade anatomical tissues and implicitly distort the normal functionality of the body.

Thus, the criteria for quantifying the severity of injuries were taken into account in close dependence on the dynamic behavior of the human-driver subject, respectively the behavior/dynamic behavior of the vehicle. Also, the bibliographic research carried out reveals the importance of the procedures used in the experimental tests, the physical and/or virtual equipment such as the anthropomorphic devices for ATD tests - dummies with their advantages and disadvantages.

2

State of research on automobile safety and injury criteria

2.1 Automobile safety

In the driver's task to protect the traffic participants, there are obligations provided by the legal norms and the car must be constructively equipped with adequate devices to ensure protection.

National and international legislation for automobile safety details and classifies the criteria for protection in constructive norms and procedures for assessment [343]. Government organizations aim to meet these measures by periodically and randomly withdrawing new cars from the manufacturing process to check safety standards [53]. The road legislation in some states provides for separate articles that affect the construction and equipment of automobiles. As for the legal norms for passive safety, they are formulated in a general way, leaving the car manufacturer to build without limitations and without asking him to account.

Taking into account the fact that the automobile is seen as a product intended for exchange through sale-purchase, but at the same time it is required to ensure during circulation the protection of traffic participants and/or the products or animals transported, after 1991 the ECE recommendations contributed to the realization a common road policy, while also facilitating the elimination of impediments of a commercial nature.

The directives, however, are not implemented directly, so they must be adopted by all member countries through a national law. EU or ECE directives are optional, they are assimilated supplantatively by national legislations, assimilation called optional harmonization process.

The EU member states are forced not to accept in national road traffic cars that do not meet the rules, mandatory harmonization process.

Recommended decisions and positions are not necessarily integrated into national legislation and implemented without reservations.

Under the given conditions, the different requirements of national legislation must be correlated by adopting a common EU/ECE methodology so that a car approved in one member state is recognized by all member states, without additional approvals.

2.2 Road traffic safety

The safety of road traffic can no longer be ensured when, in its movement, the car comes into contact with fixed or mobile elements positioned on the road platform or outside it, in the setting, thus consuming a road event. The number of people injured or dead, respectively the costs of the damage as a whole (material, medical) represent the unpleasant and dangerous consequences of a road event and implicitly allow the estimation of its extent.

The collection, processing and understanding of specific data, regarding the state of the car after the collision, the way the injuries were produced and their severity, provide knowledge about the dynamic behavior of the car in all stages of the road event, which are decisive sources for clarifying the causes of its production.

Road safety is achieved through the intervention of new construction techniques of automobiles, through the quality of the roads as a whole, as well as through essential dispositions carried out by the decision-making elements at different points in the road traffic sector. It identifies, recognizes and proposes elements to eliminate the conditions for road accidents or to reduce their consequences [11, 29, 30, 44, 51, 77].

The human subject as a direct participant (driver, passenger, pedestrian), vehicles and the space in which road traffic is carried out are in equal proportion the component elements of the transport system.

2.3 The limits of biomechanical resistance and the mechanism of injury production

2.3.1 Biomechanics

For the active safety of the car, biomechanics studies are focused on the elements that compete to initiate the risk conditions, and in passive safety research biomechanics establishes the mechanical resistance characteristics of the human occupant at the time of a collision.

Injuries can be produced as a result of a load of mechanical stress exerted from the outside on the occupant or as a result of contact between him and fixed, hard elements with which he comes into contact [9,.10,.17,.19,.51].

Biomechanics mainly studies the dynamic wear of the victim and its tolerance to the external load loads produced as a result of the contact with the fixed, hard elements inside the occupant cell at the time of the road event.

Biomechanics research aims to experimentally test the occupant's dynamic posture, determine how injuries occur, facilitate the extension of analytical models, and refine biofidelity mannequins. The main problems treated by biomechanics refer to the area of: the head, neck, chest, abdomen, pelvis, knee and lower limbs, however, the need to develop procedures that allow deepening the particularities of the tissues of the human body is felt [71,.131, .170,.172].

2.3.2 The extent of the trauma

The general diagnosis of the severity of the trauma is carried out with the help of the Abbreviated Injury Scale (AIS) separately for each person who suffered the consequences of a road accident [270, 271, 272, 320]. This scale constitutes one of the most important anatomical coding and classification systems. The scale indicates rather the index of endangering life in relation to the type of injury, and not the individual assessment of the severity of each individual injury.

The types of trauma are distributed within the AIS scale by major anatomical groups of the body, as follows: head, face, neck, thorax, abdomen-pelvis, spine, upper limbs and lower limbs respectively [15, 25, 42, 192].

The maximum AIS index or the maximum abbreviated injury score MAIS (Maximum Abbreviated Injury Score) is used as a benchmark for the analysis of specific injuries and their severity compared to the type and severity of injuries produced in the same car model but after the improvements made to protect the occupants or pedestrians, determining whether these improvements contributed to the reduction of the severity level or not.

The ISS Injury Severity Index is a more expressive method of injury estimation than the abbreviated MAIS maximum injury score (AIS maximum) used by most biomechanics. It has long been considered the most important parameter for the classification and evaluation of trauma caused by road traffic events. The ISS compared to the MAIS provides a more effective estimate of overall trauma prognosis.

2.3.3 Criteria for trauma assessment

Convincing performance research requires the continuous improvement of anthropomorphic devices-mannequins for experimental trials. The resolution of this desideratum is carried out simultaneously with the development of criteria for assessing the level of risk in the chest, abdomen and lower limbs as they are subject to an important probability of injury. Assessment of neck lesions is of major importance in knowing the various processes of lesion formation [27,71, 83, 136].

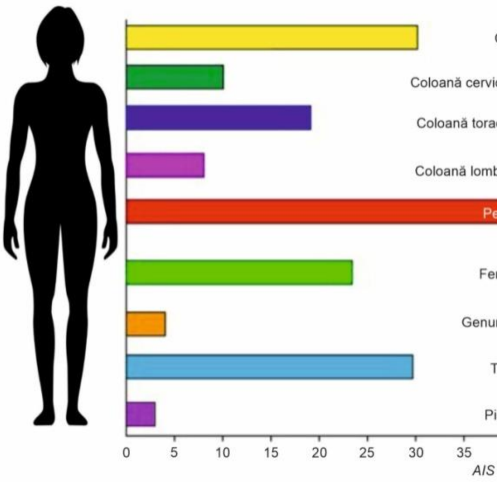


Fig. 2.6 Percentage distribution of lesions

Thus, the experimental tests must: ensure the possibility of estimating all the criteria for assessing the injuries; clearly state the type and manner of use of the manikin with the express interpretation of injuries to the extremity of the lower limbs; to concretely indicate the specific procedure and equipment for assessing the risk of injury to the abdomen and the knee complex.

The way of formation of injuries and the modification that exceeds the non-lethal limit of the biological system, as a result of the mechanical demands of the human body during traffic events, is investigated by biomechanics, figure 2.6.

The trauma assessment criteria assess the severity of the victims' injuries as a result of the collision [146, 158, 216].

When quantifying the severity of the victim's trauma, two fundamental types of injury criteria are used, namely: those based on the dynamics of the vehicle, and those based on the dynamics of the occupant.

To reduce the risk of injury to occupants, constructive safety solutions must take into account the norms regarding biomechanical performance limits. The assessment of the risk of injury is carried out only on the basis of the dynamic behavior of the car at the time of the road event, based on well known criteria.

2.4 Conclusions

The risk of injury to the occupants can be determined using the data and information obtained during the tests of experimental trials on surrogates: mannequins, animals, cadavers, where the variables of interest such as displacements, accelerations, and their demand loads have been measured in conjunction with the data measured on the vehicle, such as speed variation, acceleration, speed and displacement, but also information obtained from real accident reports.

The criteria for the assessment of injuries, based on the values acquired in experimental tests or from the research of real accidents, can be the basis for the initiation of changes in biomechanical performance limits.

Currently, the field of research and construction of movement limitation devices, safety belts, airbag cushions, regarding the reduction of collateral effects that produce contusions or excoriations remains open for new constructive solutions.

3

Damage analysis in frontal collision with full coverage

3.1 Frontal collision study

Impact is an event, generally of short duration, involving the interaction of at least two or multiple bodies, leading to a change in their speeds and directions of movement. In these events, the final momentum remains constant.

Collision describes the interaction between two or multiple vehicles, or even between an obstacle and a vehicle, occurring within a specified time interval. The duration of contact is finite and is known as the impact time. This time is significantly shorter than the time available for observing motion conditions in other motion states, which vary significantly. The results of the contact cause the bodies to suddenly decelerate and deform. The energy of the body in relative contact with another body becomes deformation energy and another quantity will become caloric energy. Thus, the total deformation of the body elements is reached, and the vehicles begin to separate, the speed of the automobiles begins to increase again. This collision process is divided as follows: the compression phase followed by the restitution phase (until complete separation) and before this phase is the compression phase

At the moment when the compression begins, the bodies have come into contact, and also then the difference in speed recorded by the cars is totally reduced from the one at the time of the collision, and the deformation reaches its maximum amplitude.

Recovery begins at the point of maximum deformation and ends when the bodies are no longer in contact.

The durations of the phases, compression and restitution respectively, are different, but their sum is equal to the total time of the collision. In a real impact, the kinetic energy is not completely consumed in the deformation, it will be consumed in various processes until the cars come to a complete stop.

The application of the law of conservation of momentum is the most used procedure for determining the impact speed of motor vehicles. In this situation, the vectors of the collision forces (impulse) are collinear with the velocity vectors, regardless of whether or not the trajectory of the vehicle is collinear with the velocity vector. When the direction of the collision force vectors of the vehicles is identical to the direction of the velocity vectors, then this is called the PDOF (Principal Direction of Force) resultant force of the collision. From Newton's third law it follows that the resultant force of the collision, for one vehicle, must be equal and opposite to the resultant force of the collision of the other vehicle, regardless of their mass.

Full coverage frontal impact occurs when the collision velocity vectors of the involved automobiles overlap, the resultant impact force being directed toward their center of gravity. When one of the motor vehicles is at rest at the time of the collision, this body, which is not always a motor vehicle, may be involved in the collision. Following a plastic centric head-on collision, the two vehicles are assumed to move in tandem as a single-mass solid with the same velocity. Forces act on vehicles that during collisions do not induce moments of rotation, but sometimes, during the separation phase of the vehicles, a roto-translation can occur that determines the final position.

The frontal collision of two vehicles can be centric or off-center. In centric collisions, the resultant force of the collision passes through the vehicle's centers of mass. Both vehicles, during the collision, describe a common motion with the speed v_c, without the effect of recoil or rotation. If the velocity vectors of the centers of mass are not collinear, but are parallel, then the resultant force does not pass through the center of mass, and the vehicles will describe different movements with different speeds in the post-collision phase.

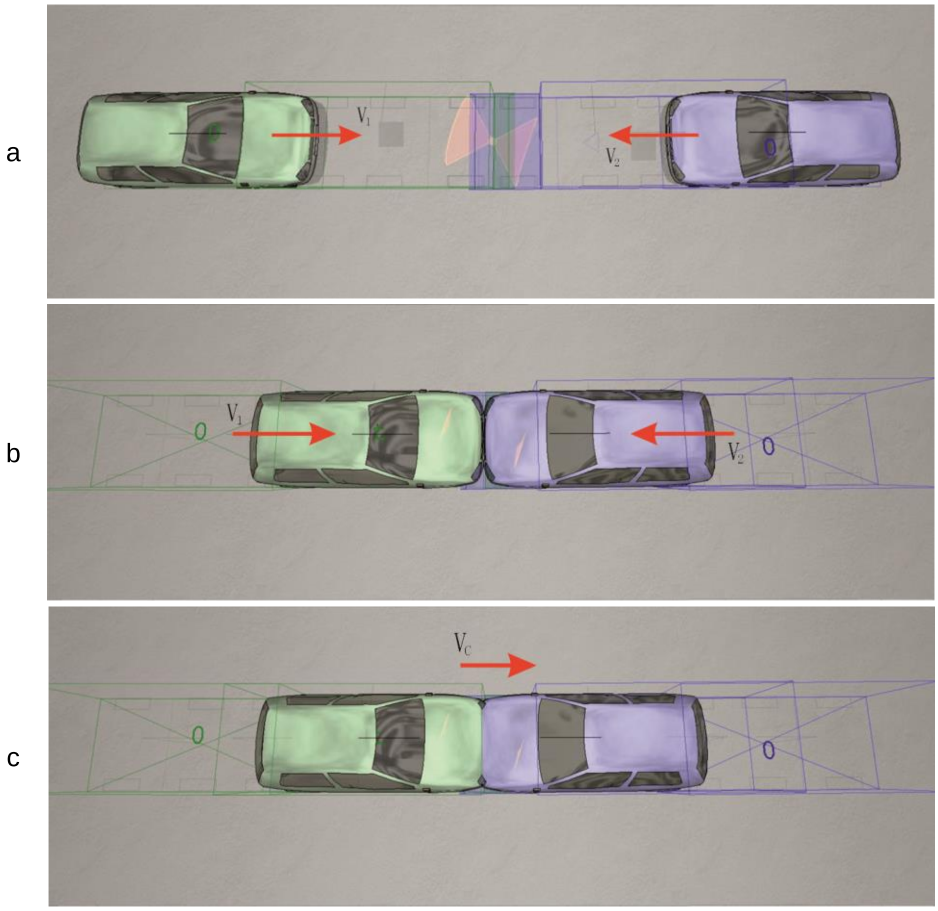


Fig.3.1 The phases of the centric frontal collision

Figure 3.1 shows a head-on collision between two vehicles, where the side involved in the collision is deformed at a similar speed. The impact is without recoil, and after the impact, the cars move simultaneously in one direction, like a rigid, according to figure 3.1 c. According to relation (3.13), each car exerts the same force during the collision, as shown in figure 3.2:

- m_1 și m_2 are the masses of the automobiles expressed in [kg];

- k_1, k_2 elastic constants $[\mathrm{N/m}]$;
- x_1, x_2 the movements of the center of mass of each vehicle in the impact $[\mathrm{m}]$;
- x the total displacement of the system formed by the two vehicles in collision $[\mathrm{m}]$.

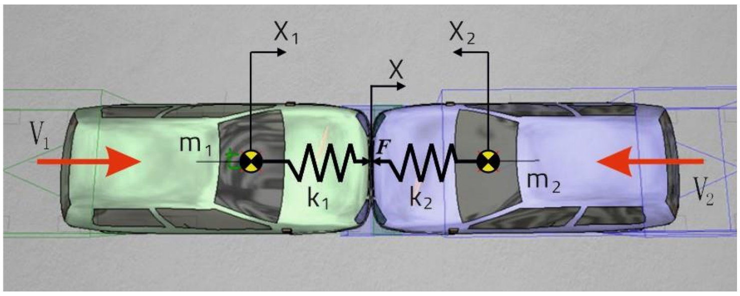


Fig. 3.2 Centric frontal collision, mathematical model

The first law of thermodynamics states that the total energy of an isolated system remains constant.

Restituition

Modeling the variation of the speed of a car analytically, a parameter called the coefficient of restitution is introduced, which characterizes the energy consumed during the collision.

This coefficient as the difference in speeds, calculated at the center of gravity of the vehicles for the stage after the impact, and that at the initial moment of the impact is defined as a ratio. Also, for collisions with total coverage, the coefficient can be expressed [13, 134, 164]:

If the collision of two vehicles is collinear, then the coefficient of restitution is a dimensionless number, given by the relation (3.66). If a recoil or mutual repulsion effect occurs, an analytical model for a quasi-plastic collision can be used [217, 203, 208].

3.2 The collision model

The crucial goal for road accident analysis is to determine the speed of the vehicles after the impact. Methods using damage severity data involve the use of analytical models to express the relationship between the impact force pressure per unit of damaged area and the magnitude of the deformations.

The static model describes the relationship between the impact force and the residual plastic deformation of the vehicle, while the dynamic models explore the relationship between the impact force and the total deformation of the vehicle, considering this dependence to be directly proportional. The model of the collision stage also considers the energy consumed when the car is damaged. The quantification of the Δv variation in relation to the residual deformations can be achieved by assimilating the car to a spiral elastic element.

The relationship between the impact force and the amplitude of the residual deformation facilitates the calculation of the stiffness coefficients. A method widely used in the quantification of the energy consumed during deformation [148], being integrated in the collision simulation algorithms of computer programs such as the CRASH family [166, 303]. These models include certain simplifying assumptions, such as: the identified overall damage and vehicle stiffness coefficients will be derived from crash tests at 40 and 45 km/h, keeping the assumption of linear force-deformation relationship; the energy is transformed into mechanical work to perform the damage [148, 202, 212].

The determination of the vehicle speed difference Δv is based on the energy consumed in body deformation, including residual deformations. The way the vehicle deforms is compared to the behavior of a helical elastic element. Limited data and insufficient information on experimental crash tests require detailed research. The modeling used in the evaluation of deformations is elaborated in specialized works [213, 201], and is implemented in the family of CRASH programs [303].

The frontal impact shown in figure 3.3 is centric and full coverage, involving a fixed and non-deformable barrier. Considering these aspects, for accurate energy evaluation, mass-elastic-element-non-deformable barrier modeling is used, according to figure 3.4.

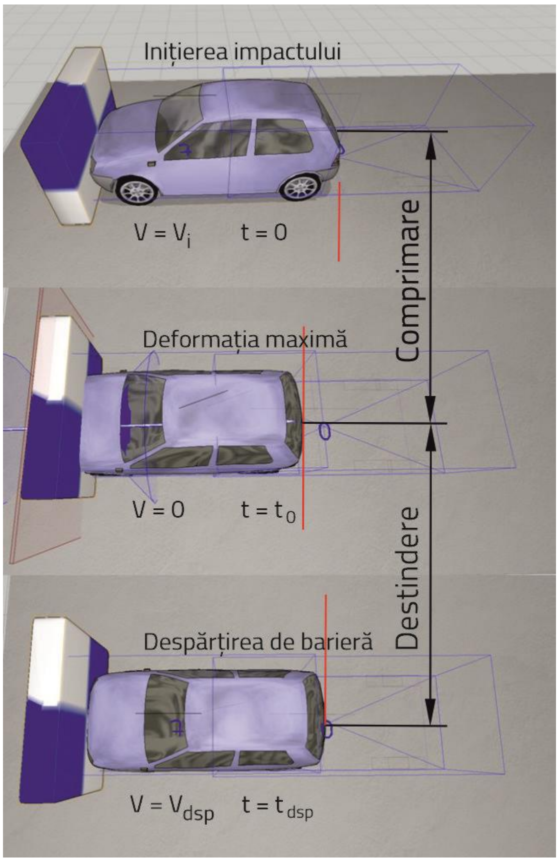


Fig. 3.3 Center collision with full coverage

Equivalent barrier speed (EBS) and speed variation (Δv)

Also called the speed equivalent to the collision with the fixed barrier BEV - Barrier Equivalent Velocity or the speed equivalent to the energy at the collision with the barrier EEBS - Energy Equivalent Barrier Speed, it is identical to the speed of the vehicle, whose deformation produced in reality is equal to the deformation produced in the collision with the barrier [120, 135].

If there is post-collision motion, then the EBS differs from the impact velocity [195]. EBS can be in one of the following situations in relation to Δv: EBS is greater than Δv when colliding with a moving and non-deformable body; EBS will be smaller than Δv in the case of collision of a deformable and massive body respectively EBS and Δv will be equal when the vehicle hits an obstacle whose stiffness is proportional to the ratio between the mass of the obstacle and the mass of the vehicle [159, 199, 201] .

Therefore, it is recommended to ignore the coefficient of restitution in the strain energy calculation. If, however, it is necessary, then its consideration will only be in the determination of Δv. As for Δv, there are some opinions that it should be used in the determination of stiffness coefficients, a proposal that could generate appreciable errors in the determination of the deformation energy, at low collision speeds, when the coefficient of restitution is greater than 0.1.

3.7 Locating and recording deformations

The energy consumed to deform the vehicle and the kinetic energy lost can be determined from the amplitude of the deformations. When we correctly assess these deformations, it is necessary to make precise measurements of the damaged area.

The measurement of the depth of deformations follows a standard protocol, illustrated in figure 3.9. Dimensioned rods are used to accurately determine the side- or longitudinally deformed surface of the car. Rods define the limits for measuring and the width of the deformed surface. Labeling of measurements is done with Cn,, where n represents the number of measurement locations, which can be 2, 4, 6, 8, 10, or 12, numbered from 1 n. These measurement points are uniformly distributed over the entire fault area , and the results obtained are expressed in meters [m].

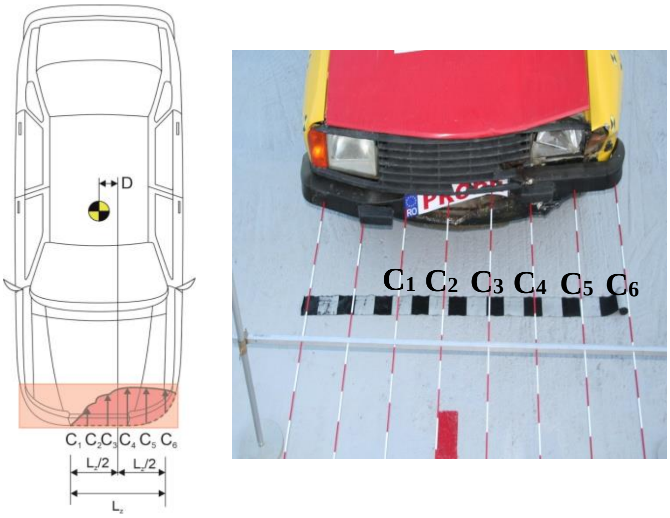


Fig. 3.9 Deformation measurement

Cn determinations are labeled C1, from left to right for damage located frontally or posteriorly across the entire width of the affected area, as shown in Figure 3.9. After the damaged area is measured, measurements are made at the same points on an unaffected vehicle (identical in make and model). The strains for each measurement point are determined by the differences taken from the two rows of measurements.

Dimensioning of deformations

The graduated rods, with the help of which the depth of the damaged area is measured, are placed horizontally, at equal distances, along its entire width. The width of the damaged zone includes both direct and indirectly induced deformation.

Thus, the damaged area is analyzed under two dimensional aspects: the first aspect is the one called the width of the damaged area proper L_z, which allows establishing the number of measurement places and implicitly the deformed surfaces. The number of deformed surfaces is one less than the number of measurement sites.

The damaged area

After locating the damaged area, it will be measured perpendicular to the deformed section of the vehicle (front, side, rear, floor, roof). Locating the deformed area is relatively easy, figure 3.10. However, there are situations when the deformed area includes the corner of the vehicle (joining the front/rear part with the side part), figure 3.11. Thus, the resulting force of the collision can pass either through the frontal plane or through the side plane. Under the given conditions, the choice of stiffness coefficients for the mathematical models will be made with caution.

As is known, cars are not parallelepiped bodies with straight sides and 90° angles. Cars have convex shapes for the front and rear, rounded corners and concave sides. All these geometric combinations are the consequence of the conditions of economy, performance and form. We notice that there are free spaces between the contour of the actual shape of the car and the sides of the rectangle given by the gauge dimensions (L·l) contained in the projection plane of its view.

3.8 Conclusions

In the contents of the chapter, the ways and algorithms of collision research and the technique of dimensioning the depth of deformations are explained with the argumentation of each type separately. The principle used ensures the implementation of reasoning in analytical programs used separately or combined with specialized programs for accident analysis.

The collision model was also presented in which the determination of the stiffness of the car, the analysis of deformations with the volume of the deformed area and its measurement is presented.

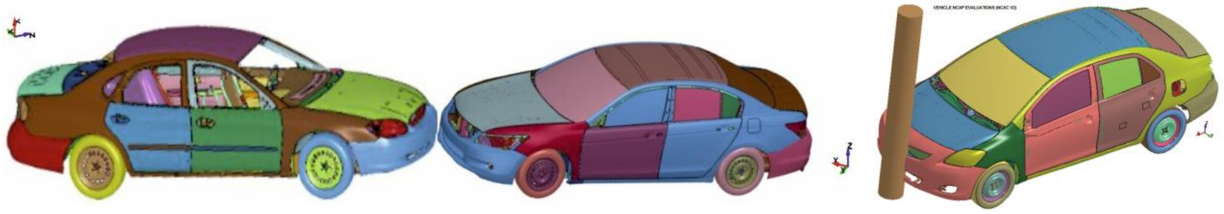
Also developed are the ways of estimating the energy lost during the deformation of the elements, the interval of the collision with its difficulty, but also the need to correct the force resulting from the collision.

4

Modeling the kinematic and dynamic behavior of the system car-seat-occupant in the frontal collision

4.1 Modeling-simulation of frontal impact with full coverage

For the analysis of the frontal collision in the framework of the completed thesis, the attitude of the complex car-seat-driver self-devices for limiting the movement was followed throughout the road event. Statistically, the most frequent frontal collisions are between a car and a rigid plane body (wall, bridge head), fixed vertical rigid cylindrical body (pole, tree) figure 4.1 b, or between two cars.



a b

Fig. 4.1 Frontal collision: a) car-car; and b) automobile-cylindrical vertical obstacle

The experimental tests reconstructed frontal collisions with full coverage with the direction of the resultant force of the collision (PDOF) normal to the front, figure 4.1 a. several types and models of cars were used in the tests, following the behavior of the female dummy with a pregnant abdomen in eight weeks, own constructive solution, and the influences of motion limitation systems on it.

The virtual simulations are carried out with the help of the kinematic-dynamic model of the Hybrid III 5th - female 5% mannequin contained in the LS-Dyna subroutines for frontal impact, but also with the help of the MADYMO models from the specialized program PC-Crash 15 own license, and for the checks it was used the program VirtualCrash 2.2.

Impact tests were performed at different speeds starting from 20 km/h and reaching 50 km/h from 10 to 10 km/h for the vehicle, and the distance between the vehicle and the fixed barrier was set to 0.4 m.

When analyzing the kinematic as well as the dynamic behavior of the mannequin, those of the speed for the duration between 0-160 ms of the speed-time characteristic are considered representative. During this time period the speed has changed from 13,360 mm/ms, i.e. the maximum speed reached, and to the zero value when the vehicle establishes its final position t3 and reaches 160 ms.

4.2 Modeling the occupant-seat-device system for passive protection

The modeling and simulation process allows the determination of the demands and movements performed by the driver during a frontal collision, based on a dynamic and kinematic model. It also includes the construction of a stand for experimental tests, which includes basic elements: the dashboard, the dummy, the adjustable seat, the steering wheel and the steering column, but also the pedals, according to figure 4.5.


a b c

Fig. 4.5 Dummy-steering column--pedal bridge system

The figure shows the virtual stands LS-DYNA position a respectively PC-CRASH position b and the stand for laboratory samples of own design and construction, position c. The elements introduced in the construction of the experimental model are intended to reproduce as faithfully as possible the driving position and to adjust the mannequin posture in accordance with the actual situation.

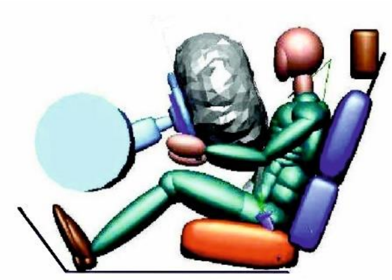


Fig. 4.6 Virtual model with airbag

4.3 Model composition

From the desire to measure the impact stresses of different parts of the body and to assess the type and severity of injuries, by imitating the occupant's dynamic responses to impact, has led to a growing interest in the design and development of models as close as possible to the human body, in terms of size but also functionality [149].

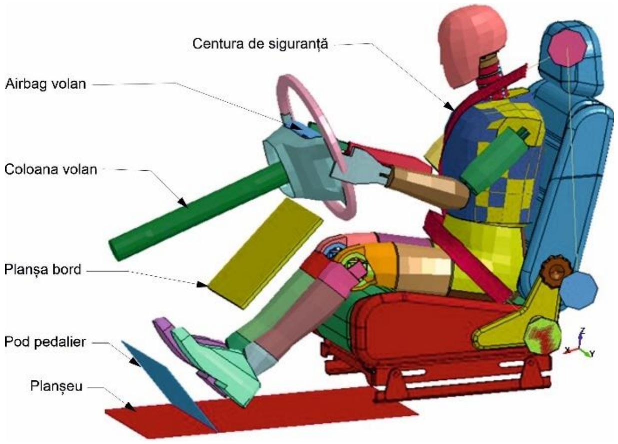


Fig.4.9. Model for virtual experimental tests

The Hybrid III 50% dummy is the standard model for crash tests, especially frontal impact tests, figure 4.9. This is generally positioned on the driver's seat [176] and the weight and dimensional characteristics of the segments/component elements.

4.3.1 Structural considerations on the type of virtual mannequin

The virtual model of the Hybrid III dummy whose kinematic behavior was analyzed in the simulation of a frontal collision is processed with the LS-DYNA program package. This type of dummy consists of a total of 123 component elements. Every element of the human body finds its correspondence in the structural scheme of the Hybrid III male mannequin, with the exception of the internal organs. After the discretization of the model, 4333 elements and 7473 nodes were obtained.

The main component elements of the mannequin, by analogy with the structure of the human body, are presented in figure 4.10, the position of:

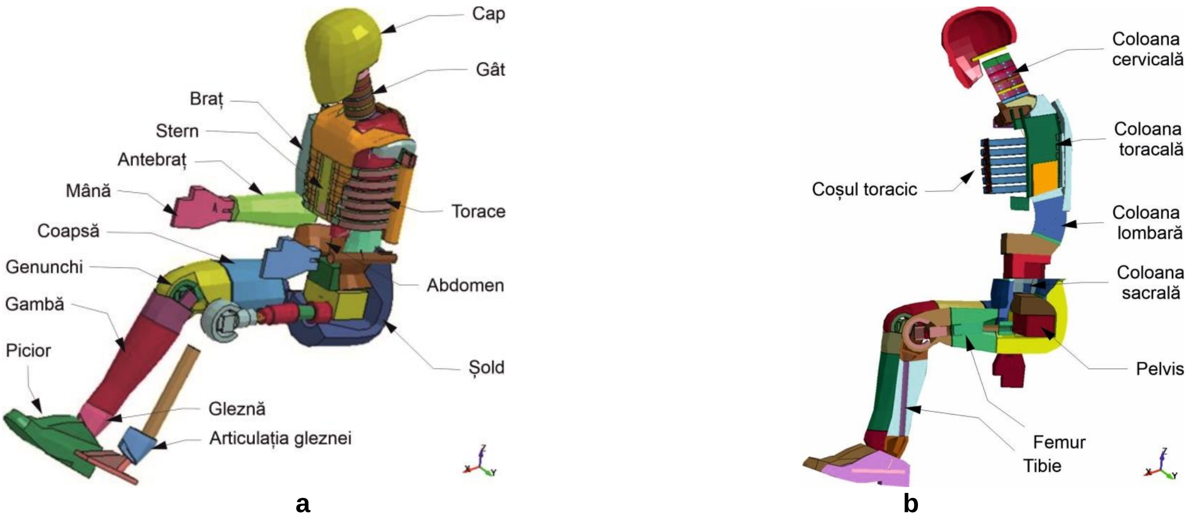


Fig. 4.10 The Hybrid III female mannequin: a - the main elements; b - longitudinal section

Figure.4.10, position b, shows the longitudinal section, along the X axis, in which the component elements of the internal structure of the dummy can be observed.

4.4.2 The dynamic model of the Hybrid III 5% female mannequin

At the same time, if the contact with friction between the elements is set, the tangential stress loads can also be analyzed. The coefficient of static friction will be higher than the coefficient of dynamic friction when it is desired to switch from static to dynamic analysis conditions. As a rule, this type of contact is used when the master is a rigid body, and the penetration checks are performed only on the nodes of the slave element, defined by the user.

Since the Surface to Surface type contacts have a symmetrical character, which leads to identical results regardless of the modeling of the surfaces of the slave and master elements, for the virtual frontal collision tests, the formulation and setting of the Contact_Automatic_Surface_To_Surface contact was chosen. This option is only a result of the investigations of road events with frontal collision, since the mutual positions and relative displacements of the elements cannot be anticipated, and the amplitudes of the deformations of the body elements are generally large.

4.9 Conclusions

In the study of the dynamic posture of the female victim with a pregnant abdomen in the frontal collision with full coverage of the car, analytical CAD, kinematic-dynamic models were formulated. Thus, movements were described with the help of Newton-Euler equations based on the procedure of Lagrange multipliers. For the value solution, the created models were run in the Maple utility, being designed a program of sequences with a flexible structure, which facilitates the research of the constructive solution of the abdomen with the proposed load, which takes into account the initial state and the existing contour conditions.

The laws of time variation of the connection forces between the elements of the kinematic couplings of the mannequin were determined, in dynamic mode, taking into account two possible forms, namely the reference to the external system S0, as well as the reference to the local Si. Abdominal-pelvic girdle mobility and hip-thigh mobility were analyzed.

In the last part of the chapter, a model was created for establishing the coordinates of the center of mass starting from the fact that collision tests in real conditions require measuring equipment dependent on it.

5

Experimental investigation of human abdominal stresses in the frontal collision with full coverage

5.1 Types of experimental trials

Collision refers to the interaction between at least two vehicles, or the interaction between a vehicle and an object, which takes place during a specific period, which, moreover, is not present either before or after the collision. Contact between vehicles can be measured over time, called collision time or period. This is shorter compared to the observation duration of the other movement stages which take place over very long intervals. As soon as the bodies come into contact, the sudden mutual deceleration begins and, implicitly, their deformation.

The two stages, compression and relaxation, have different durations, but their sum is equal to the total collision time. In an uncontrolled impact, deformations do not occur uniformly, which results in a conversion of kinetic energy into other forms of energy.

Thus, the types of experimental trials will be presented separately below. They represent a certain segment of the world of road events. The establishment of the objectives is of great importance for the experimental simulation, which on the one hand can be perceived as validating the effectiveness of the protective measures regarding certain modes of road events. On the other hand, the purpose of the tests can be to verify the behavior of the protection system during the road event.

In the absence of intrusions, seat belts and airbag systems provide a non-lethal space, with minimal risk of injury, sufficient to protect the occupant.

Some test procedures use experimental frontal impact tests with fixed rigid or deformable barrier with partial or full coverage to evaluate the protection of the occupants and the movement limitation systems.

In the case of a side collision, it is difficult to avoid contact of the occupant with the elements inside the vehicle. Its protection is ensured only by the padding materials and the side airbag systems that limit the intrusion and remove the victim from the penetrated objects.

Correct conduct of behavior and deformation tests results from tests with fully equipped vehicles. In order to determine the movements and stresses of the contact points, as well as the possibility of injury, car testing uses anthropometric mannequins, representing passengers or pedestrians.

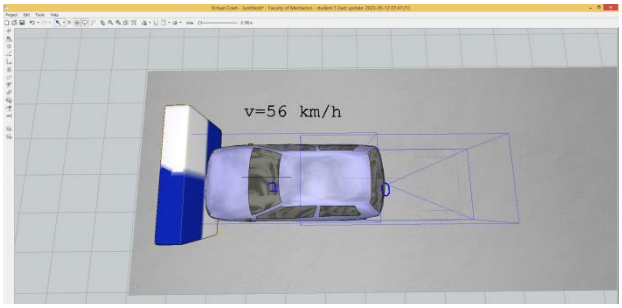


Fig. 5.1 Frontal impact with full coverage

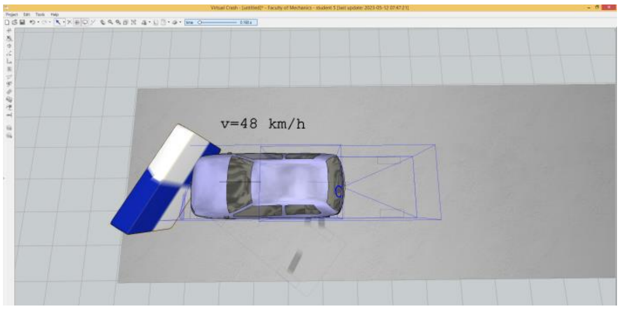


Fig. 5.2 Frontal impact with a rigid obstacle, arranged under an inclination of ±30˚

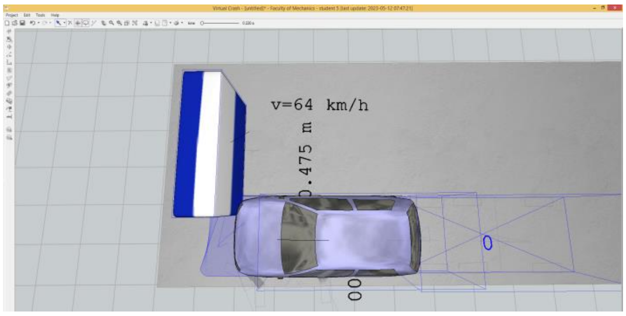


Fig. 5.3 Frontal impact with partial coverage 25%

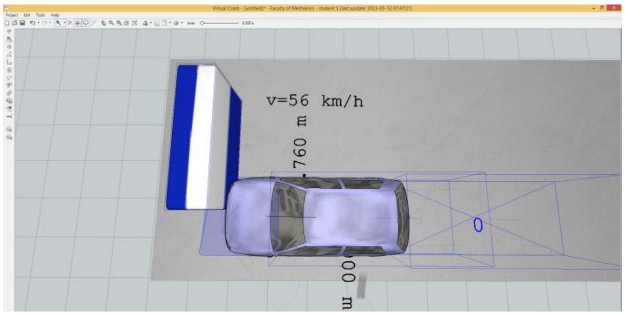


Fig.5.4 Frontal.impact.with.partial.coverage .40%

Test procedures - depending on the type of collision, it has been found that the safety performance of vehicles in a frontal collision cannot be accurately penciled in from a single crash test. Therefore, the establishment of the safety level must be carried out only after performing several frontal experimental tests: front collision with total overlap, with a fixed and rigid object, at the speed of 30-50 km/h, see figure 5.1; frontal impact with an inclination of ± 25-30°, and with a speed of approximately 30-48 km/h, see figure 5.2; frontal impact with partial overlap of 25%, on the left side of the vehicle, with an estimated speed of 64 km/h, figure 5.3; frontal impact with partial overlap of 40%, on the left side, with static barrier, non-deformable, at different speeds, starting from 40 to 56 km/h, see figure 5.4.

In frontal collision tests, according to ECE-R 94 regulations, the impact takes place, in the first stage, at a speed of 50 km/h, with a fixed barrier and the impact plane arranged at 0°, a plane which is provided with metal elements for not to allow the ASD (Anti Slide Devices) to slide in order to ensure the reproducibility of the tests. In the second stage, the crash test takes place at a speed of 56 km/h with a deformable barrier and a degree of coverage of 40% on the driver's side.

That is why the automotive industry, state institutions, universities and specialized magazines conduct experimental tests under more rigorous conditions. Many of these tests are limited by cost and not by the actual desired crash types or injuries. Frontal collision tests at a speed of 55 km/h with a rigid barrier contribute to the study of the behavior of small and medium-sized cars.

Due to the large mass and rigid structure, conditioned by the current test procedures, heavy cars constitute a significant danger to all other cars. For this reason, the experimental research methods used in the past to quantify the passive safety of passenger cars cannot be considered optimal.

These solutions strive to faithfully reproduce the conditions for producing a frontal impact, using complex testing methods, and the results obtained to be as convincing as possible in terms of the issue of reconstructing road events. As a result, the deformations of the resistance structure cannot be fully identified, so the characteristics of the stress loads will not always be well known.

These models must be made carefully so that they can be used in the process of investigating and reconstructing traffic events.

Multiple impact ranks second with 26.5-45%, after frontal impact, 43.6-55%. It leads to an increase in the percentage of serious injuries, noting that the most affected parts of the human body are the head, neck, chest and abdomen, respectively the upper extremities.

5.2 Experimental tests in real conditions

In this sub-chapter, the equipment, methods and parameters used in conducting the experimental tests are presented.

The experimental research, carried out in order to realize the collision scenarios, in circumstances close to reality, involved the completion of the following stages:

- establishing the objectives and the types and modes of collision;
- creating the mannequin and choosing the types of cars used;
- checking the operation of the measuring installation mounted on passenger cars;
- adoption, implementation of measurement equipment;
- preparing cars for experimental tests;

In order to ensure the most reliable results in the evaluation of the performance and qualities of the tested automobiles, usually the tests must be carried out in various combinations. Equipment that displays signals in real time according to specific requirements is preferred. The experimental researches included various scenarios, such as: simulation of collisions using computerized virtual technique, testing and evaluation of the female mannequin on its own construction stand, according to figure 5.12 position a, and according to figure 5.12 position b, experimental tests were carried out under dynamic circumstances (acceleration, speed, deceleration) through head-on collisions between two vehicles, using the test dummy placed in the driver's seat in the struck vehicle and the test pilot positioned in the driver's seat in the striking vehicle.


a b

Fig. 5.12 Simulation on the stand or polygon


Fig. 5.13 Marking of the test platform

In the preparation phase of the experimental tests, the necessary system for recording and saving the complete data is installed, they are composed of transducers, sensors together with the necessary wiring ensuring their protection and eliminating the possibility of interference with the normal operation of the vehicle. The vehicles are simultaneously equipped with backup sensors, transducers and computer technology dedicated to monitoring the relevant quantities in the dummy and the vehicles involved in the test. The platform intended for tests in real conditions, with its distinctive places, are signaled with distinctive elements, according to figure 5.13.

Devices used for real-world measurements include devices such as XsensMTi, DSD PicDAQ, MC-32S and transducers, which are installed and/or checked on vehicles before each individual test. In order to ensure the safe conduct of the tests and for the installation of the technical equipment for measurements and storage in the pushing vehicle, we decided to free up the right front and rear seats, as well as the fuel tank.

5.3 Necessary conditions for polygon tests

In order to guarantee experimental tests with maximum efficiency, various conditions had to be respected such as: accuracy, objectivity, speed of deployment, repeatability, economy and meteorological conditions.

For the evaluation of the performance of passive safety equipment and for a better understanding of the real behavior of the human body during a road impact, it is obvious that the tests need to be objective.

5.3.1 Propulsion of the cars involved in the tests

The test vehicle is in a static position on a horizontal concrete platform, the handbrake is engaged, the gearshift is in fourth gear, and the pushing vehicle is self-propelled. The test vehicle's fuel tank was drained and then filled to 2/3 capacity with water, while the push vehicle's tank was removed and the engine primed by priming the constant level chamber in the carburettor after has reached operating temperature.

5.3.2 Preparation of cars for experimental tests

In order to carry out the tests on the range, cars in good and very good technical condition were chosen. The most relevant technical characteristics of the vehicles were checked, including model, engine number, chassis, weights and performance, manufacturing aspects, tire wear, brake operation, suspension and wheel geometry. Any dimensional deviations were corrected to comply with the recommended technical values, and the external appearance of the body was completely restored, figure 5.14.

The use of mannequins constitutes the reproduction of a mutual physical conditioning, known a priori, between the occupants and the environment of their appropriation, resulting in the production of mechanical injuries or traumas, which means that the purpose of all measurement chains is to record the parameters of actions such as: displacement, speed, acceleration, force and the quantities derived from them. Also, like the tires, the dummy was marked with a series of dots, numbered sequentially.

5.3.3 Setting up and preparing the space for the experimental tests

The following technical aspects were taken into account for the construction of the place intended for the experimental real collision tests, figure 5.16, and to ensure a fluent and coherent strategy of the collision test scenarios:

- ensuring the markings and the start and end place of the collision test;
- ensuring access, evacuation, intervention to and from the active surface intended for experimental tests;
- places of protection intended for intervention for unforeseen situations.

5.9 Microelectromechanical systems

A relatively modern technology globally, microelectromechanical systems radically transform the construction and performance of inertial sensors, being also known as MEMS (Microelectromechanical Systems) [58, 76, 80, 223].

They are designed as electronic resonators and are fabricated in a quartz or silicon body

[224, 322, 323].

M - micro, due to very small dimensions and manufacturing technology (< 1 mm).

E - electro, indicating the use of the electrical and/or electronic domain.

M - mechanical, describing the spatial transformation of the components, in which the movement is converted into variations of an electrical quantity or the electrical quantity executes the update of the position of an element.

S - systems, solving issues related to hermeticity, modularization, calibration, mechanical or noise stability, and others.

Fig. 5.23 MEMS System

They consist of components, either electronic or non-electronic, performing functions such as data capture, processing and display of electrical signals or automatic regulation, according to figure 5.23. The IMU inertial measurement device is shown in figure 5.24. The magnitudes generated by the inertial unit can be influenced by the electromagnetic field, which is why a ±15 V voltage source has been added.

The change in the posture of the occupants is tracked using the Xsens MTw system [90, 316, 317], which has two fundamental elements: the software component and the hardware component [318, 319, 339, 340].

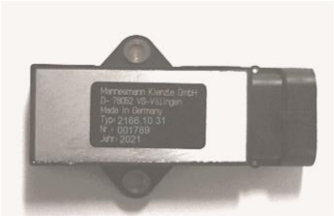
Xsens is an inertial sensor that is used in experiments, it weighs 52 grams and its dimensions are: 61L x 60W x 28 mm thick and can measure: accelerations in three directions of its own reference system up to ± 5 g and angular motion relative to its own frame of reference, magnetic field change, and can display the spatial orientation of the transducer relative to a landmark as well as the attitude of the transducer given by roll, pitch, and yaw motion. Through the MT Manager software for analysis, the measured or stored data can be presented in the form of graphs at the same time as the animation of the position of one or more modules, as shown in figure 5.25.

Fig. 5.24 Inertial unit of measurement

5.10.3 Accelerometers

The sensitive element in the structure of the acceleration transducer, figure 5.28, provides a mechanical quantity (displacement or force).

As a result, this mechanical quantity must be converted into an electrical quantity with the help of the conversion element in order to be recognized by the adapter. The combination of the



a

Fig. 5.29 Acceleration transducer

sensitive element with the conversion element has only a functional character, thus forming a single constructive component, figure 5.29 a.

5.12 Processing of measured data

In this section, the operations for memorizing, storing and processing data are analyzed, figure 5.35.

To separate the measured values from disturbing signals, filters are used that cut the signal with high frequencies, low-pass, low-frequency, high-pass filter. For the signals measured during experimental collision tests, it is defined according to the frequency class of the channel CFC (Channel Frequency Class) indicating the filtering frequency.

The most used filters are the BUTTERWORTH, TSCHEBYSCHEFF and BESSEL filters.

5.12.1 Technique for video recordings

The stress measures recorded on the dummy are indicators of the severity of occupant injuries and provide crucial information about the impact of road incidents. In the experiments, the cars involved are photographed before and after each collision. The analysis of the interaction between the interior space and the body of the mannequin, is carried out with the help of high-speed filming, figure 5.36.

Fig. 5.36 High speed video camera PHOTRON SA3

In laboratory conditions, the lighting installation required for the high-speed filming technique consists of four fixed units positioned on the tracked object, which are equipped with LED bulbs. Figure 5.37 shows the location of the video cameras for the real collision experimental tests, as follows: 1 - high-speed camera PHOTRON SA3; 2 - Samsung ES95 digital camera; 3 - Canon EOS 350D camera; 4 - Panasonic A2-DC video camera; 5 - canon XH-A1 video camera.

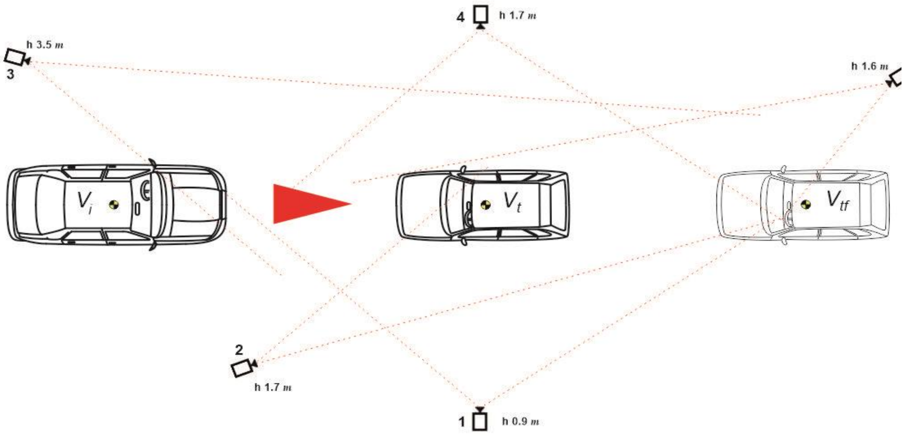


Fig. 5.37 The arrangement of devices for video recording

5.12.2 The computer system used to process and interpret data

The processing and interpretation of data obtained from experimental trials is not a simple matter. The interpretation of the data obtained from the measurements is carried out with the help of modern acquisition systems and electronic data processing. For this purpose, the system described in figure 5.38 was created, which includes components such as the MC-32S system, DSD, XsensMTi and NANO33IOT, in combination with a Laptop equipped with an i7 processor, with a nominal frequency of 3.41 GHz, 32 GB of DDR3 RAM memory, a 3TB hard drive, and a PHL273V7 LED monitor. During the tests multiple variables were subjected to verification and evaluation, these being: the position of the material point located in a coordinate system; linear/angular velocity as well as accelerations; the demands that acted on the test dummy. The duration of injury during a collision is relatively short, being of the order of milliseconds, while the maximum impulse and kinetic energy are equal, before and after the collision, and the duration of the impact is relatively short, not exceeding 0.25 s.

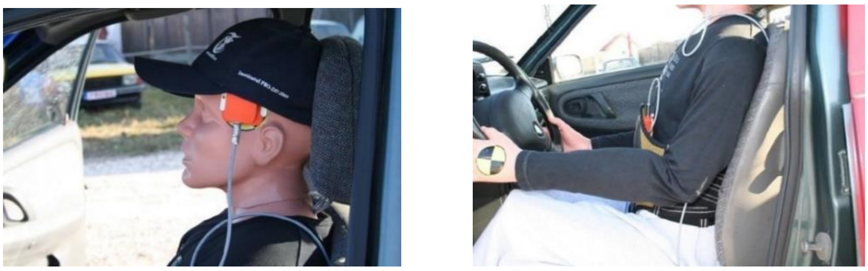


Fig. 5.39 XsensMTi Sensors

The conditions can be extended, depending on the possibilities and performances in which the laboratory tests are carried out or those in real controlled conditions. The rotation of body segments are classified as large deformations and can exceed 180°.

5.14 Conclusions

Technical-scientific investigations involve close dependence between theoretical analyzes and experimental research.

In order to carry out the analyzes of the experimental researches, measurement facilities were formulated and made specific to the procedures applied to the observation of the quantities subject to control, highlighting some issues regarding the assimilation of artificial intelligence applications in the structure of the systems of surrogate anthropomorphic devices. The content of the chapter clearly shows the program and methodology of experimental research, the technique and tactics of measurement, memorization, processing and interpretation of data, calibration of transducers and channels intended for measurements. Under these conditions, the various types of apparatus and installations controlled by processors, intended for measurements in experimental research, were described, making known the significant elements, their mode of operation and their efficiency.

6

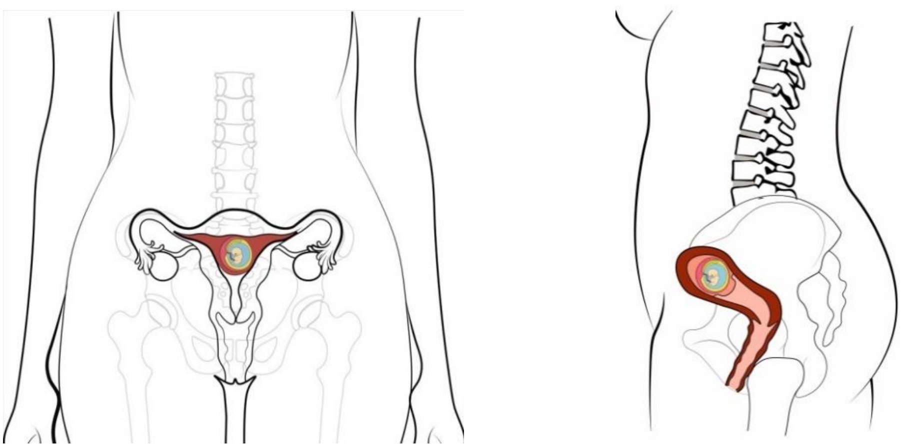
Presentation of the proposed solution for the anthropomorphic-dummy device

The traumas frequently found in pregnant women involved in road accidents are characterized by the rupture of the placenta, uterine injuries and injuries to the pregnancy, embryo or fetus as the case may be. Partial or total rupture of the placenta in the area of the utero-placental connection is the main cause of pregnancy loss

In order to analyze the possibilities of mechanical loading of the abdomen in general and of the uterus-embryo complex in particular, a proprietary constructive analysis solution was designed and realized. This solution equips a mannequin, we can say minimally invasive, for gathering information about the forces and accelerations applied directly to the abdomen with a pregnancy of up to ten weeks, in different impact scenarios and systems to limit the movement of the driver's body.

6.1 Presentation of the proposed solution. Elements of human anatomy

The anatomy of a pregnant abdomen with pregnancy in the embryonic period of 8-10 weeks is presented in figure. 6.1.



a **b**

Fig. 6.1 Anatomy of the abdomen with pregnancy

The focus is on the constructive solution practically realized and implemented on the mannequin, but also on the simulations of frontal collision cases with full coverage, when the uterus can be stenosed (narrows) in the direction of application of the stress or in the transverse direction you will suffer an aneurysm (a expansion).

Constructively, the author had in mind that the proposed and realized solution should comply with the anthropometric configuration so that the stress loads load as realistically as possible the pelvic ring-uterus-embryo nucleus complex 8-10 weeks, for the investigations to highlight, with a high degree of accuracy, the potential risk of pregnancy loss as a result of placental damage.

6.2 Realization of layered uterus shell capsule membrane

The execution of the outer membranous casing was made using the technology of obtaining landmarks through fused additive manufacturing, namely Deposition Modeling (FDM) technology, which offers the possibility of obtaining unique elements, with various dimensional shapes in an extremely small range, in relation to the technique used until recently to their realization.

The practical realization of the embryo's shell took place at the 3D printing center of the Transilvania University in Brașov INNO3D and for the configuration of the uterus we collaborated with a private company from Stuttgart, FRG. Both 3D printing units have a Cartesian device displacement system for extruding the material, which is also the most common type, figure 6.3.

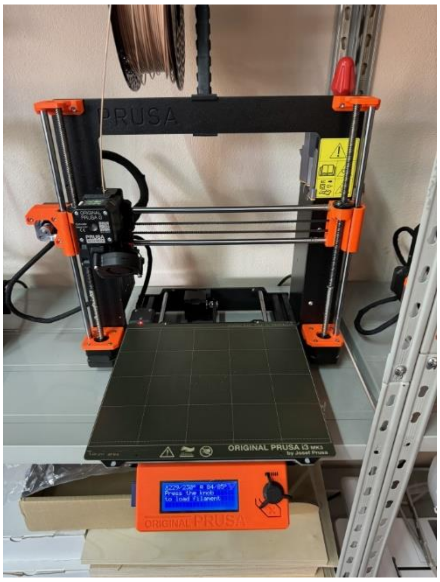
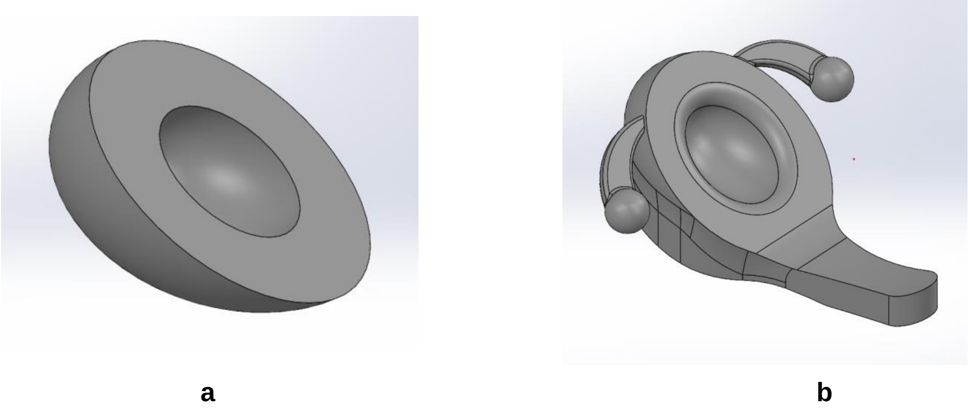


Fig. 6.3 Cartesian system 3D printer

6.2.1 Additive fusion manufacturing steps

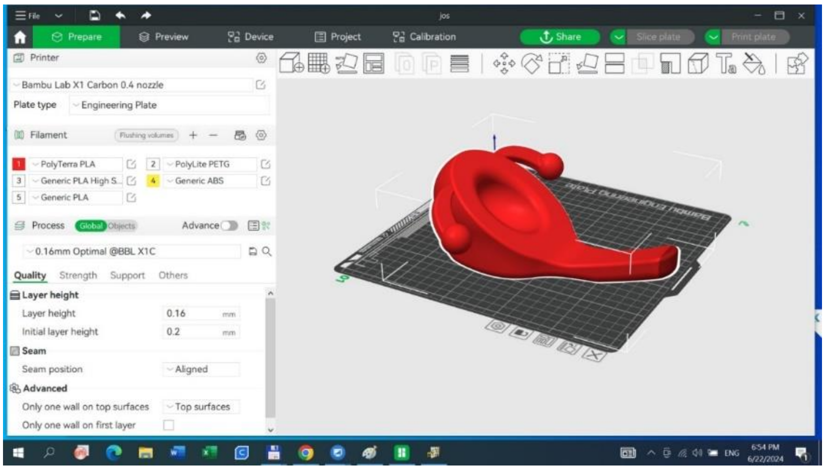
Figure 6.4 illustrates the initial housing design in SolidWorks, detailing how to join and the volume intended for the IMU.



a b

Fig. 6.4 CAD model of the box in SolidWorks, in STL format

b) the CAD model is transferred in STL format directly from SOLIDWORKS to the printer, figure 6.5 and 6.6



Printer
Bambu Lab X1 Carbon 0.4 nozzle
Plate type: Engineering Plate

Filament
1 PolyTerra PLA
2 PolyLite PETG
3 Generic PLA High S...
4 Generic ABS
5 Generic PLA

Process: Global / Objects — Advance
0.16mm Optimal @BBL X1C
Quality | Strength | Support | Others

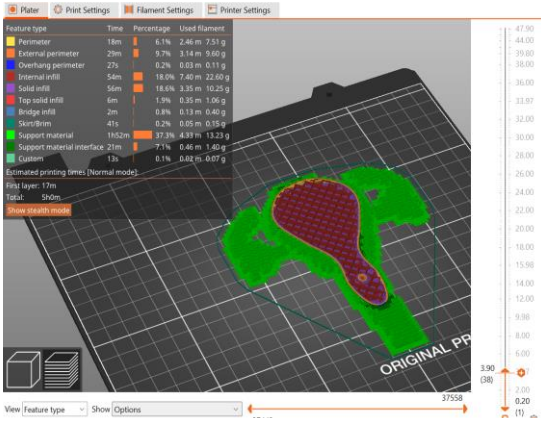
Layer height
Layer height: 0.16 mm
Initial layer height: 0.2 mm

Seam
Seam position: Aligned

Advanced
Only one wall on top surfaces: Top surfaces
Only one wall on first layer: ☐

Fig. 6.5 The model for printing the lower part of the uterus

c) the model imported into the processor module of the printer is ready for the Slicing conversion, of sectioning according to horizontal parallel planes of the reference system, figure 6.7, a process carried out in the Bambu Studio v1.8.4.51 program, during which the trajectories traveled by the extruder device are also generated , to create each layer, figure 6.8.



Feature type	Time	Percentage	Used filament
Perimeter	18m	6.1%	2.46 m 7.51 g
External perimeter	29m	9.7%	3.14 m 9.60 g
Overhang perimeter	27s	0.2%	0.03 m 0.11 g
Internal infill	54m	18.0%	7.40 m 22.60 g
Solid infill	56m	18.6%	3.35 m 10.25 g
Top solid infill	6m	1.9%	0.35 m 1.06 g
Bridge infill	2m	0.8%	0.13 m 0.40 g
Skirt/Brim	41s	0.2%	0.05 m 0.15 g
Support material	1h52m	37.3%	4.33 m 13.23 g
Support material interface	21m	7.1%	0.46 m 1.40 g
Custom	13s	0.1%	0.02 m 0.07 g

Estimated printing times [Normal mode]:
First layer: 17m
Total: 5h0m
Show stealth mode

Fig. 6.7 Slicing conversion, sectioning by horizontal parallel planes

For the execution of the elements, a rectilinear infill with a density of 12% was chosen. Rectilinear infill is a common adoption in 3D printing due to its balance between structural stability and efficient use of material. This type of infill consists of parallel lines that intersect at regular angles, giving the desired strength and elasticity and minimal material consumption.

d) the actual realization of the elements by the successive addition of layers using more elastic materials such as: FLEX tube and TPU-thermoplastic polyurethane, on the printer's own support, figure 6.7, with the help of the BambuLab P1S program; at this stage, the paths of overlapping layers and solidification of the material are generated.

e) In the post-processing stage, I deburred, removing the excess material, and manually finished the contour surfaces of the elements in the final shape, improving their surface quality, figure 6.10. The finished items did not require resin impregnation or UV treatment.

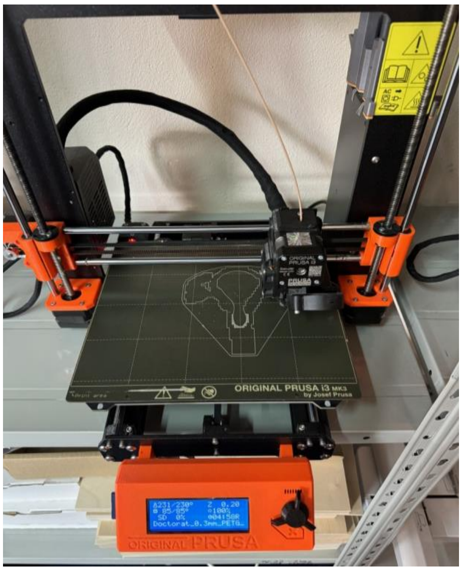


Fig. 6.8 Trajectory of the extruder

6.3 General characteristics of the proposed solution

Along with the deformation of the lower torso, the uterus is also deformed and in the area of the placenta, the mechanism of traumatization of it through crushing and even rupture is outlined. Abdominal deformations were measured at the outer level of the shell (epidermis) of the mannequin with the help of a belt specially designed and made practically in order to solve the objectives of the thesis, which consists of five IMU NANO33IOT units, arranged at equal distances along the length of the horizontal abdominal arch of approximately 39 cm, see figure 6.15.

Fixing the mannequin in the seat is done with the help of a three-point safety belt, and the back and seat of the seat are adjusted at 45° from the horizontal and vertical respectively, figure 6.16.

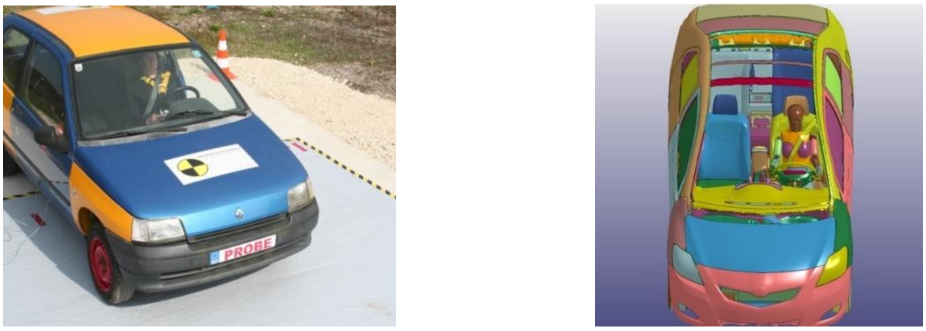
The real and the virtual car prepared in order to carry out the experimental tests for real frontal collision and in the laboratory, and the mannequin equipped with the solution conceived, designed and made by the author, is presented in figure 6.18 position a, and for the virtual tests with the mannequin configured from the base of LS-DYNA data, the FEM structure of the vessel, being presented in position b.

6.4 Constructive characteristics of the device-dummy used

6.4.1 Anthropometric characteristics

The configuration of the abdomen with load is important for optimal knowledge of the interaction with the seat belt, steering wheel, airbag or dashboard during a collision.

For this purpose, a medical specialty collaboration was carried out with the Cotarcea Smărandița Obstetrics-Gynecology Medical Office Craiova, with the progress of pregnancies for a sample of 21 pregnant women being monitored, Annex 3. In the case of each person, a series of measurements were performed to characterize the size of the abdomen with pregnancy on during three test sessions performed at 3, 6 and 8 weeks of the embryonic period of pregnancy.



a b

Fig. 6.18 Car-dummy system for research: experimental-a, virtual LS-DYNA-b

6.4.2 Construction of the proposed solution for the uterus-embryo complex

The creation of the prototype model took into account the anthropometric information of a female human subject up to 8 weeks pregnant, previously described, without the need for changes to the pelvis or abdominal envelope, figure 6.14, position a and figure 6.11, position a.

Several constructive solutions have been designed, made and tested in terms of viscoelasticity, inertial characteristics, behavior under stress in different places and directions of the abdomen. In this context, two identical models of the uterus, with fluid, and materials of different stiffness were used, without the mobility of the embryo sensor inside it being possible, figure 6.19 position a. The proposed uterus is made by layering with additive fusion, a developed method in paragraph 6.2, from two parts: uterus casing and double membrane capsule, adapted to the development of the dummy components, shown in figure 6.10. These elements represent a positive factor in the analysis, they are necessary but raise problems of biofidelity or repeatability of the tests but also the measurement of meaningful variables that can be best correlated with the risk of injury or even pregnancy loss. Thus, the uterus with pregnancy including the fetus and the umbilical cord but without the trophoblast was created in the first stage, and for future solutions this element will be added, if the test results prove the need to include it.

a b

Fig. 6.19 Tested uterus models: a - different materials and b - cylindrical shape

The implementation of the constructive solution uterus with load on the mannequin, is carried out by arranging it in the sagittal plane, having the lower part at the level of the sacral spine vertebra S1 and the upper part of the uterus positioned at the level of the L4 vertebra of the lumbar spine following an inclined line with an angle of up to 30°, figure 6.20.

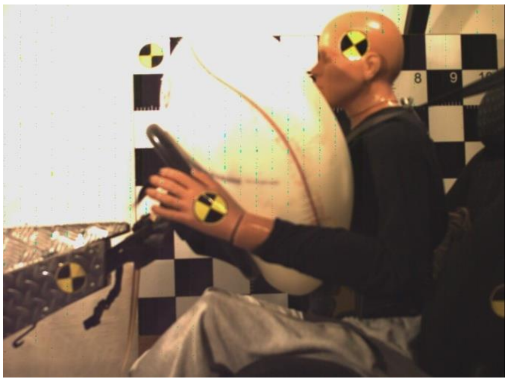


Fig.6.22 Airbag-abdomen contact tests

6.4.3 Experimental tests on the stand

The investigation of the risk of abdominal trauma of the driver during the collision was carried out by means of collision tests with a speed of 4 and 6 m/s. Spinal acceleration was measured.

The direct stress analysis of the abdomen was performed under laboratory conditions on the bench using an impactor for constant compression of 16%. Along with measuring the compression of the abdomen and the speed of application of the stress, the triaxial acceleration was measured at two points at the level of the lumbar spine, and at the level of the outer border of the abdomen at five points. The pressurization of the airbag cushion was analyzed through experimental tests on the stand so that its lower part comes into contact with the upper torso at the level of the sternum appendage or 75 mm below it, figure 6.22. It is noted that the phenomenon of sinking into the seat of the chair can be simulated in experimental laboratory conditions with mannequins if the seat belt is positioned at a high level above the navel or by the sharp inclination of the seat back relative to the vertical and implicitly of the back of the mannequin.

We notice the accentuation of the influences on the uterus with the change in the position of the spine in the sagittal plane in response to contact with the steering wheel sector or the airbag cushion.

6.5 Conclusions

The chapter analyzes and presents the main stages for obtaining components by additive fusion on 3D printers.

In order to carry out experimental research, an economic but high-performance constructive solution was proposed for the uterus-embryo complex, the latest generation software was used for the modeling-simulation of the phenomenon.

The technical and IT equipment for the experimental investigations is mostly carried out by the author of the thesis in collaboration with teaching staff from the Transilvania University of Brașov and the University of Craiova.

To carry out the manufacturing process through FDM additive fusion technology, a dedicated software package was used that allows the significant reduction of the activities program, generating a general picture of perspective regarding the mechano-thermal resistance of the filaments adopted to make the components.

Due to the possibilities of choosing from a polyform variety of technological features, the chance of achieving the landmark in the conditions imposed by the author is maximum.

CAPITOLUL 7

Comparative analysis of theoretical and experimental data

7.1 Establishing the coordinates of the center of mass

Taking into account what was presented in the previous chapters, namely the fact that some of the measuring devices are directly dependent on the coordinates of the center of mass, we carried out an analysis of them regarding the correct position to identify the possibilities of placing the measuring equipment in order to eliminate mounting errors and location of the equipment.

To establish the longitudinal, transverse and vertical coordinates of the center of mass, the centr_gr subroutine was used, obtaining the following characteristics:

7.1.1 The vertical coordinate

To run the subroutine in order to establish the vertical coordinate of the center of mass, the values obtained experimentally for the car prepared for the purpose of the frontal collision tests were used.

Figure 7.2 shows the load fluctuations on the vehicle axles in relation to their angle of inclination. The determined values for m (charge fluctuation) are displayed gradually according to the figure. It is observed that in each vehicle loading scenario (no load, partially loaded, fully loaded) m fluctuates proportionally with the lift of the vehicle. Based on the measurements, the characteristics were drawn with the origin at the intersection of the coordinate axes of the system where the abscissa is the lift of the car tg and the variation of the measured mass m on the ordinate. mf the mass fluctuation distributed on the front axle and ms the mass fluctuation distributed on the rear axle were noted. With the lower index 0, the empty vehicle was noted, figure 7.2, index 2 corresponds to the mass of the car loaded with two people, identical for index 5, which corresponds to a load of five people and luggage. The feature provides an easy determination of the m data, which is taken into account to determine the height of the center of gravity.

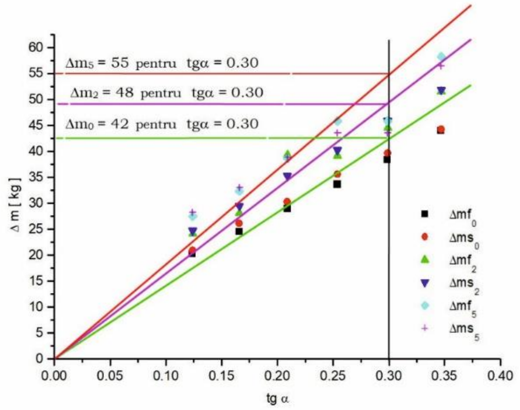


Fig. 7.2 The position of the center of mass relative to the load

7.2 Stress analysis of the manikin protected with seat belt and airbag cushion

7.2.1 Chest loading at T12-L1 rib level

The study of the kinematic behavior of the dummy in the frontal collision follows the time variation of the components of the resultant motion, velocity and linear acceleration. The variation of the accelerations of the thorax, at the level of the T12 node, of the driver analytically established by virtual modeling of the impact, are included in publications of the injury standards [105]. For the synchronization of the IMUs it was agreed that the longitudinal axis should be referred to as the y-axis

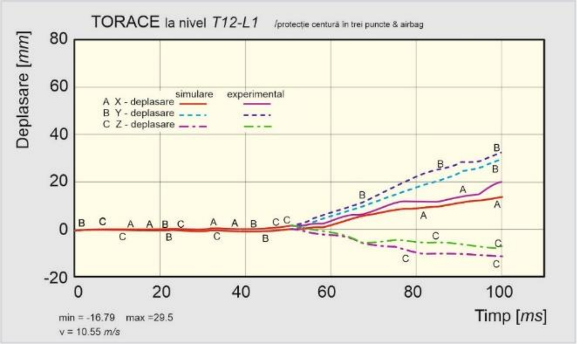


Fig. 7.5 Variation of displacement components

The linear movement of the chest on the x, y and z axis is shown in figure 7.5. Note that the maximum of 30.0 mm is achieved at 100 ms, on the longitudinal axis y.

Movements in the direction of the z-axis are lower, which details the type of collision and the process of tools for limiting the movement.

The maxima of the velocity components reach the value of 11,982 mm/ms, along the y-axis, at the time instant of 85 ms, figure 7.6. Obtaining low x- and z-axis velocities is due to the fact that the x-axis movement is restricted by the seat belt and airbag and the crash mode.

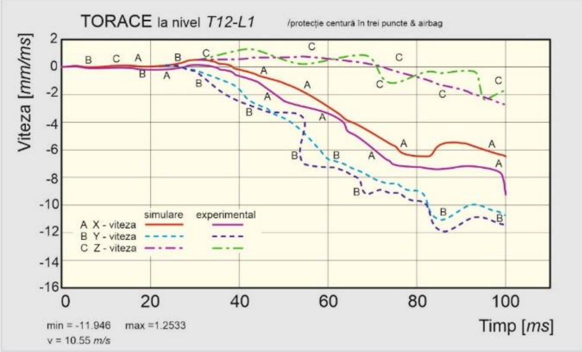


Fig. 7.6 Variation of velocity components

As a result of the virtual reconstruction of the collision, the fluctuations of the x, y and z triaxial accelerations measured at the T12 vertebra were illustrated.

In the given conditions it is observed that the longitudinal acceleration, on y, reaches high values. Thus, the value of the acceleration of the chest at the level of the T12 rib was measured to be 30 g at the time of 70 ms, figure 7.7.

FMVSS regulation No. 208 limits the maximum acceleration for the thorax to 60 g. We find that this acceleration limit is not exceeded, in which case the severity of injuries in the thoraco-abdominal area will be moderate. The same regulations provide a maximum value of 1000 for the CSI chest severity criterion, so that it is compatible with survival.

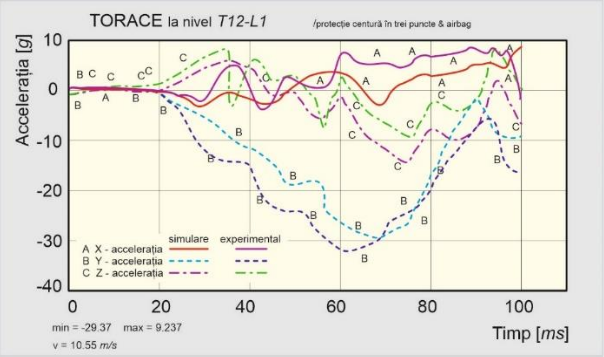


Fig. 7.7 Variation of acceleration components

Correct positioning of the driver behind the wheel and the use of the seat belt together with the airbag cushion, in the case of a frontal collision with full coverage, for the speed of 39 km/h, it follows from figure 7.8 that there are no traumas to the T12-L1 abdominal area that would put life in danger. The calculation program generated and recorded the value for the CSI index as 191, which is well below the limit imposed by the experimental crash test regulations..

Fig. 7.8 CSI value

7.2.2 Pelvic Ring stresses

The position of the pelvis given by the components of the linear movement on the x, y and z axis graphically displayed in figure 7.9. The range of motion of the pelvis is 35,907 mm, observed at 100 ms, along the longitudinal axis.

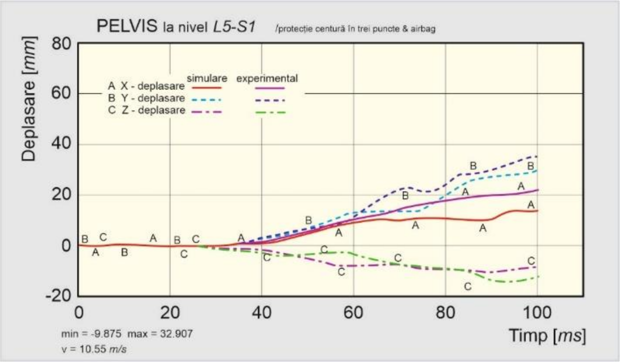


Fig. 7.9 Variation of displacement components

The movement on the other axes, x and z, is reduced, being justified by the mode of the collision and the limitation of the movement by the passive safety devices.

The maximum velocity in magnitude of 5,873 mm/ms is identified for the longitudinal axis y, at the time 100 ms of the simulation, figure 7.10.

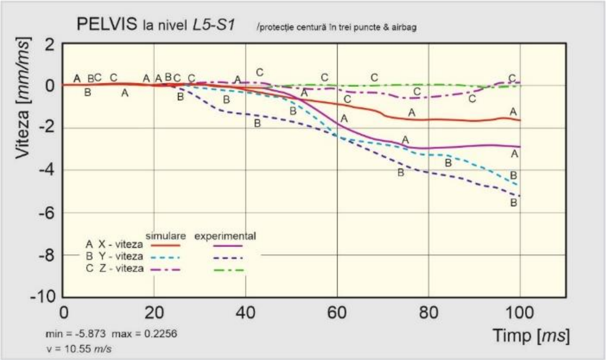


Fig. 7.10 Variation of velocity components

The linear velocities in the direction of the x and z axes are relatively low, being justified by the manner of the collision investigated, respectively by fixing the dummy in the seat with the three-point safety belt with the ventral strap and over the shoulder, so that the pelvis can still slide by diving under the belt, so his free movement is not completely stopped.

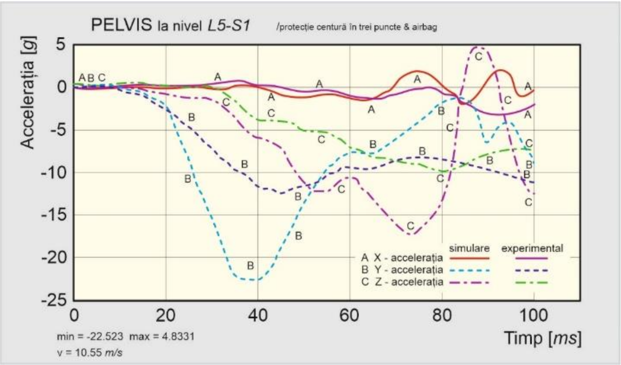


Fig. 7.11 Variation of acceleration components

The triaxial components of the linear acceleration, on x, y and z measured in the articulation of the L5-S1 lumbosacral vertebrae of the mannequin are shown in figure 7.11. Important values appear along the longitudinal component of the acceleration, the y-axis.

The maximum longitudinal acceleration, measured inside the pelvic girdle at L5-S1, is 22,523 g at 38 ms.

For the velocity measured in the left and right coxo-femoral joint, a maximum of 11.75 mm/ms was observed at the time of 100 ms in the longitudinal direction, and the acceleration along the x, y and z axes, recorded 34 g at the time of 32 ms, for the femur from the side right.

7.3 Stress analysis of the manikin protected by the seat belt

7.3.1 Loading of the thoraco-abdominal area at the T12-L1 rib level

The movement is presented in the following, together with the speed, figures 7.13 and 7.14, in which the longitudinal movement up to 19.3mm and the speed after the same trajectory with the maximum value of 10.132mm/ms are found for the moment 100 ms.

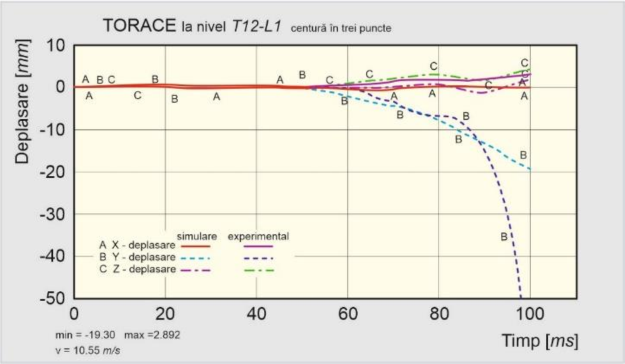


Fig. 7.13 Variation of linear displacement

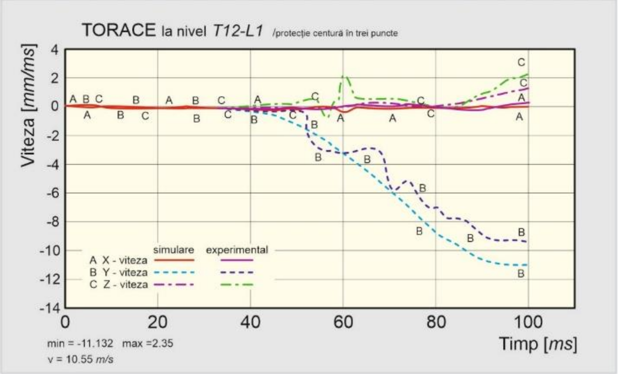


Fig. 7.14 Variation of linear velocity components

During the experimental tests, the acceleration variations were also measured, on x, y and z, at the level of the driver's torso, finding that the transverse acceleration reaches a maximum of 19.8 g for the time instant 100ms, see figure 7.15. Even if only the seat belt was used without the airbag, the maximum limit according to FMVSS No. 208 for acceleration was lower, which means minor injuries to the abdomen.

FMVSS norms No. 208 and CMVSS 208 provide a maximum value of 1000 for CSI to be compatible with survival.

The peak y-acceleration is reached after 85 ms from the onset of impact, with significant variations in the x-axis acceleration, according to Figure 7.19. Between 52-57ms, the longitudinal acceleration peaks at 16g, much higher than the transverse acceleration.

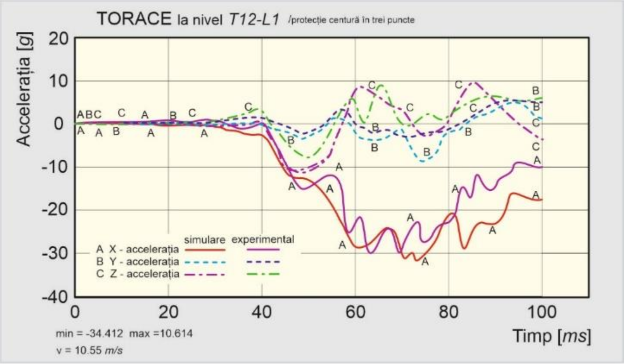


Fig. 7.15 Variation of linear acceleration components

In conclusion, the absence of systems to limit motion induces significant changes in position, velocity and acceleration in the longitudinal plane as a result of the manikin's pelvis moving freely without constraints.

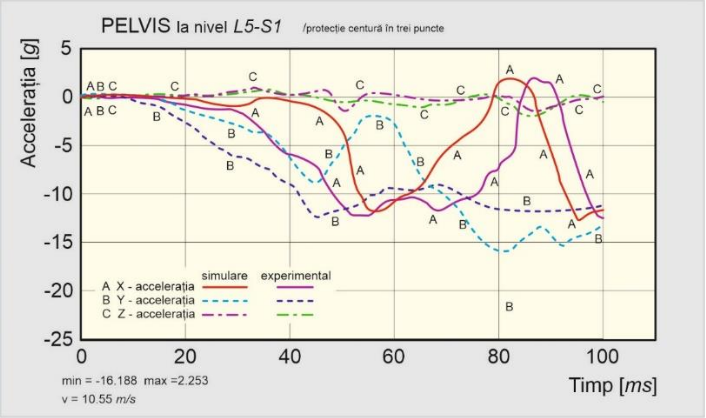


Fig. 7.19 Components of linear acceleration

7.4 Conclusions

For the location of the devices and apparatus in the system for measuring the variables of interest directly dependent on the position of the center of mass, its coordinates had to be determined in the longitudinal, transverse and vertical planes.

For this purpose, a Turbo Pascal program was formulated and developed for determining the position of the center of mass. The program uses constant values of total vehicle mass, front/rear axle mass, wheelbase and dynamic radius of the wheel resting on the scale platform. From the keyboard, the values for the lift height, and the mass of the front/rear axle corresponding to the lift height, depending on the case, are entered, finally generating the characteristics for establishing the coordinates of the center of mass in relation to the transported load.

The analysis of the information obtained from the experimental frontal collision tests at different speeds with the proposed technical solution was carried out covering the abdominal area in general and the pregnant uterus in particular for the situation when the dummy is protected by the seat belt and the airbag cushion, figures 7.5-7.12 inclusive determination of the CSI index figure 7.8 and the situation when the dummy is protected only by the seat belt, figure 7.13-7.20 including the estimation of the CSI index figure 7.16.

The graphical presentation of the results in figures 7.1-7.20 are part of the theoretical information of the analytical model regarding the seat-mannequin-protection system system, and analyzed by comparison with the experimental results.

The study of the rendered curves highlights the differences between the values of the quantities obtained by calculation and the quantities obtained experimentally but which fall within the research errors, which means that analytical modeling and virtual simulations as well as real tests are confirmed as correct which studies can achieve details of the dynamic behavior of the manikin in the case of the side impact of the car.

Conclusions, Original contributions, Proposals for the future

The activity of the automotive industry globally is guided by the requirements of transportation and the need to protect drivers, passengers, outside participants and the environment. The paper presents a methodical analysis regarding the protection of the occupants in general and the driver in particular.

For the evolution, the car manufacturers are based on the study of the definite requirements of the genuine market eliminating the dimension and the excessive performances in favor of the improvement of the stability on the move, the increased comfort of the trip and the increase of the safety in the road traffic

The automobile, being an indispensable locomotion unit, must ensure some conditions, such as good road holding and maneuverability, fault-free operation, cheap operation, interior comfort, and protection during road accidents. Improving the level of comfort and the active and passive safety of automobiles is an essential principle in the evaluation of manufactures, compared to market requirements and competition offers, a context in which the analysis of all information is indispensable in making decisions. Traffic safety legislation must be strictly observed. Intense competition to attract and maintain market share must be crucial in the conception and design process. Some treaties give the European Union important, well-defined responsibilities in order to reduce the number of road traffic incidents. We can say that the protection of the road system is complemented by the long-term rigorous application of traffic safety regulations.

Information regarding safety issues is essential for the organizational research activity in this sector, as well as for estimating the performance of the measures ordered. For this purpose, information on automobile safety performance and injuries must be well organized.

Thus, the passive safety of the car has an important weight, which increases from year to year. The constant objectives of car manufacturers are: speed, low price, high comfort, safety, so all the information beneficial to the assumption of some decisions must be accepted. The possibilities offered by the new technologies to achieve the desired safety are numerous in laboratory conditions, which, however, must be confirmed by real situations.

Analyzing the evolution of passive safety systems, it can be seen that through the continuous improvements brought to the devices for limiting movement (seat belts, airbag systems, seats, head restraints) and their components, the development of the adaptive airbag cushion with multiple pressurization has been reached. This was made possible with the introduction of microprocessors for the control and command of pyrotechnic capsules, pressure generators and headrest position.