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## SAFETY OF DRIVER AND PASSANGER IN FRONTAL CAR CRASH USING A NEW TYPE OF IMPACT ATTENUATOR

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**Abstract:** *The impact attenuator (IA), along with the seat belt and airbag, is an important device in ensuring the passive safety of motor vehicles. This refers to both current cars and racing or special purpose cars. The study investigates the benefits that a simple, cheap and easy-to-apply safety system can bring, as it proposes the use of water in a simple system that contributes to the absorption of a shock in a collision with a vertical wall. In this regard, the behavior of a mannequin in a frontal collision is monitored. Knowing the loads acting on the dummy, a theoretical check (based on a FEM model) and then an experimental one is made to see if the stresses occurring after the collision fall within the range suggested by current standards. The vehicle is seen as a structure that has an IA and a dummy using a seat belt. An innovative water-based IA solution is used. According to the criteria, the behavior of the mannequin was examined for a frontal crash of the car-driver/passenger system. The results obtained suggest the possibility of using water in a suitable assembly as a shock-attenuation system in the event of an accident.*

**. Key words:** *car; Impact Attenuator; safety system; seat belt; crash; (IA); shock; dummy*

### 1. INTRODUCTION

Passenger safety is, obviously, one of the main objectives of designers in the domain of cars and transport vehicles. Passive and active safety systems are constantly being developed and improved. This trend requires additional results and information obtained during the operation of vehicles, which can be acquired through a research on aspects related to passenger safety. Passive safety systems are crucial for reducing damage and bodily injuries to the driver/passengers in the case of a crash.

The seat belt is the first passive safety element noted and introduced into production by car manufacturers [1-3]. The impact attenuator (IA), another important element of passive safety, is the element that will be studied in this paper, in an innovative version. It has the role of absorbing shocks. In modern cars it is generally placed in the front bumper. AI involves high costs, as a result, solutions are sought for the realization of material dies that absorb the energy of the impact but also have low costs [4].

In the mentioned study, a nonlinear finite element model was used for the proposed attenuator. The average energy of the attenuator studied was 16,000 J, a value that represents an excellent solution compared to the standard recommended value of 7350 J (see the regulations of the FSAE), with 20 g average acceleration and maximum 40 g. Static compression was used in [5] for the testing of an IA. Plastic slices of polyurethane foam were manufactured to create an attenuator in [6] that managed to absorb 8800 J compared to the value of 6380 J that a classic attenuator using standard polyurethane can provide.

In [6], an effort is made to identify a design that, out of the various models now in use, has the best kinetic energy absorption capacity using numerical approaches. Aluminum and zirconium G350 are used to make the impact attenuator material. The simulation was conducted using frontal collision to determine the deformation and the absorbed energies. In [7–11], intriguing and affordable AI solutions are provided. The researchers' suggested solutions have been validated by experimental

verifications in tests carried out in accordance with standards [12–15]. In [16], the response of a roll cage installed on a SUPRA car was studied.

The research suggested, a best solution is recommended to provide safety in the event of an accident. The program that was used was ANSYS 18.1. It goes without saying that the materials used to create AI have a big influence on how they react to stress. In [17], for example, a CFRP composite was studied with the intention of using it in car design. The material is considered or the design of a monocoque chassis to meet the safety requirements set forth by Formula SAE. The investigation was performed using the FEM, and so the geometry and size of the chassis were optimized.

Additional tests made experimental confirmations for a Formula Student vehicle [18].

The goal of an IA is to guarantee a high rate of energy absorption during the time of impact. As mentioned in [19,20], there are medical considerations associated with the use of IA as shock absorbers. In the publication [21–24], a number of novel facets of IA computing and design are covered. Numerous numerical techniques have been created to represent driver, automotive, and IA systems [25–28]. Methods for IA design and optimization are described in [29–33]. In addition to problems with sudden changes in acceleration, the idea of acceleration energy is pertinent to the study of biological phenomena [34, 35].

Researchers and the automobile industry continue to place a high priority on driver and passenger traffic safety, i.e. [36–41]. Enhancing cellular solids' ability to absorb energy has been researched for use in automobile applications as a safety precaution [42, 43]. In [44–46], several design-related issues are addressed.

Determining the role of an IA and the pressures a driver experiences during a frontal collision is the aim of this study. For IA, three different materials with varying thicknesses were used to create two unique geometric variations. Therefore, the impact of 24 IA modifications on the dummy is examined. The complete system, including the driver, the car with the IA, and a safety belt, was modeled using

the FEM. Due to the early stages of the event, when demands are at their peak, the impact of the airbags was not taken into account. The goal was to determine whether the device could offer enough protection in the event of an impact during a race.

Many of the elements influencing the general behavior of the system are poorly understood. The Gibbs–Appell approach can be used to quickly obtain the external forces. The FEM model then makes use of these forces [47–58, 65]. Using the results, a racing car used in Formula Student competitions was designed and built.

They are used in many different devices, such as wearable technologies, haptic devices, artificial muscles, and state-of-the-art medical equipment, due to their agility, flexibility, and versatility. Nevertheless, complex biological systems have so far outperformed synthetic models. The challenges presented by this soft actuator are thoroughly covered in the specialized literature [59,60].

## 2.MATERIALS AND METHODS

IA's goal is to transfer the pressures of an impact to the body structure at high speeds without inflicting damage, and to minimize such damages if the vehicle is moving slowly, in order to save the driver's life.

In general, people are quite sensitive to different shock requirements from their surroundings. It is susceptible to mechanical shocks, acceleration, and shocks. In addition to having a detrimental effect on the driver's or passengers' health, strong accelerations and shocks that happen during a collision can occasionally be lethal.

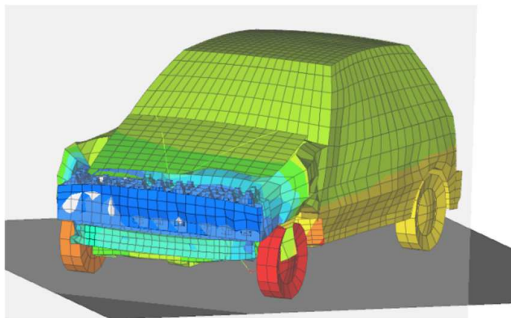
They helped model many real-world scenarios and develop extremely effective safety measures. The development of software and computation techniques has enabled the creation of virtual mannequins, from which several perceptive inferences and discoveries can be extracted.

From the standpoint of kinematics, dummies can be fairly precise and give very close-to-real values for kinematic parameters, especially accelerations. "Front impact dummies," "side impact dummies," and

"aerospace dummies" have the three different varieties. Men's, women's, and children's mannequins were customized for a range of situations and studies.

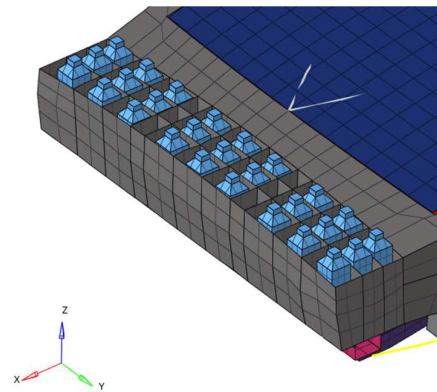
The specialized literature describes numerous of these dummies and their experimental performance under various shock circumstances. The research employs a standard adult mannequin, which is the typical height and weight of adult males in the United States. As a result, a major disadvantage—the absence of a genuine human body for testing devices and doing research to look at the consequences of various situations—can be eliminated. The subject of such an experiment would surely sustain serious damage or possibly die. One approach would be to use corpses, but the results were disappointing.

Below is the vehicle model used for the impact investigation that included water-based energy accumulators and a frontal dampening system.



**Fig. 1.** Car equipped with impact absorber and FEM model

A FEM model made with Altair Hyperworks is used to analyze the system. This model is used in a number of settings to see how the dummy responds to different potential situations. The explicit analysis type was developed using the Altair Hyperworks package's RADIOSS solver. The element type used in this study is CQUAD4, a shell element with six degrees of freedom and four corner nodes. These element types have been employed for most of the components of the model, except for the upper and lower arms of suspension that were simulated as CBAR elements. The resources used for the comparative analysis are shown in the document. Additional findings from [61–62,66] were helpful for modeling the overall structure.

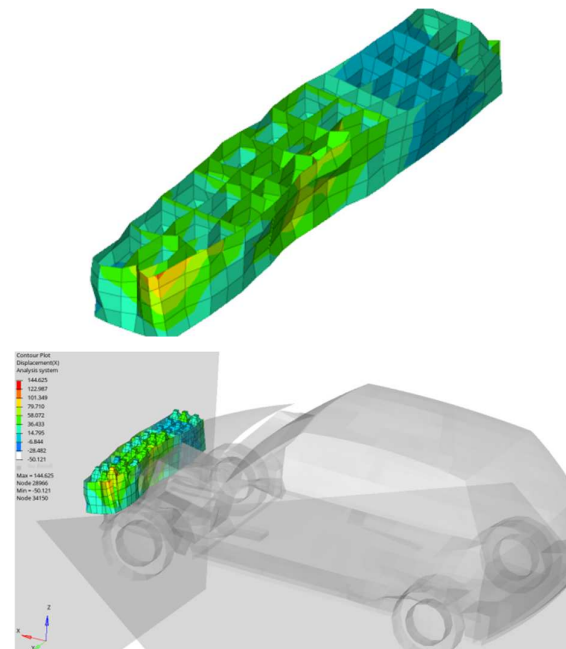


**Fig. 2.** A proposal for the impact absorber (detail)

The following type of material was considered:

- The dummy should be M1\_ELAST.
- M2-John-Zeril Card Image Material is used to suspend arms made of nonlinear steel. John-Zeril: The M2 card image is thought of as nonlinear rubber for tires. The material has a youthful modulus of 200 MPa and a poisson ratio of 0.49 for the linear zone.

Self-contact elements were employed to provide node-to-surface contact between the components using an image card TYPE7. We can learn more about the demands that emerge in such a system from these findings. For the vehicle with damping, the pre-collision velocity was 11.74440 m/s  $\cong$  42.28 km/h.



**Fig. 3.** The car after collision and IA (detail)

### 3. EXPERIMENTAL VALIDATION

Enhancing and validating the technical solution that successfully controls the risk and the occupant injuries is the primary goal of the experimental testing. To replicate actual collision conditions, a simulation of the impact between a car and a rigid barrier is run for this purpose. After the measurements, the kinematic parameters (acceleration, speed, and displacement) are obtained, and the likelihood of an injury occurring as well as the severity of occupant injuries are determined. A test range, which is available at Transilvania University of Braşov, is needed to conduct the tests. PicDAQ, a data acquisition system, is employed. During the experimental experiments, video samples are recorded using a Hi Spec 5 high-speed camera. It has the capacity to record at around 1400 frames per second. The gadget produces 1696 x 1710 high-resolution photos. Panoramic photos are taken with a DJI Phantom 3 Standard drone. It weighs 1216 g, can take off and land at a maximum speed of 5 m/s and 3 m/s, respectively. Operating temperatures for the drone range from 0 to 40°C.

The experimental experiments make use of two anthropomorphic test devices, the DD1 Prototype. With the head weighing 4.7 kg, neck 1.4 kg, upper torso weighing 20 kg, and lower torso weighing 12.6 kg, the dummy weighs 84.12 kg in total. The remaining weight is split between the lower limbs. A plastic frame measuring 1230 mm in width, 230 mm in depth, 160 mm in height, and 45 plastic water bottles make up the damping system (Fig. 4).



**Fig. 4.** Plastic frame of the damping system

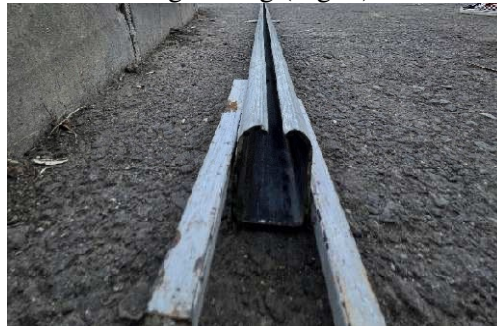
The height of the cushioning system is increased to 310 mm by installing the water bottles. The

device is made to minimize injury to the occupants and ease their displacement. Fig. 4 shows the designed cushioning mechanism. A car without IA colliding head-on with a rigid barrier at a speed of around 42 km/h was the initial test scenario. The second test scenario was a frontal collision at a speed of about 42 km/h between a vehicle equipped with an adaptive damping system (IA) and a structural barrier.



**Fig. 5.** Rigid barrier check

The rigid barrier is presented in Fig. 5. Guide rail: The rail is used to ensure a straight path for the vehicle during towing (Fig. 6).



**Fig. 6.** Guide trail

DJI Phantom 3 Standard drone was used to capture images. It has 1216 g mass, maximum speed of 5 m/s, and a landing speed of 3 m/s. The drone can operate at a temperature between 0 and 40°C (Fig. 7).



**Fig. 7.** Drone DJI Phantom 3 Standard

Two DD1 Prototype anthropomorphic test devices were used. The dummies were developed to study the kinematics of body movement in experimental tests. The device in Fig. 8 has a total mass of 84.12 kg: head 4.7 kg, neck 1.4 kg, upper torso 20 kg, lower torso 12.6 kg.



**Fig. 8.** Dummy (DD1 Prototype)

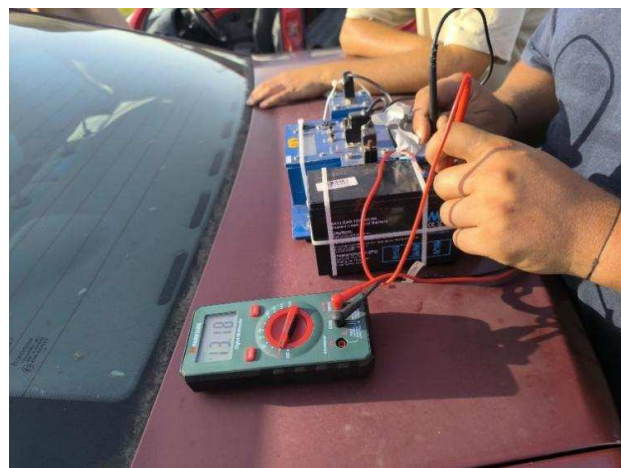
The pneumatic cylinder for brake actuation was fitted on the left side of the vehicle's front floor as the first step in the sequential installation of the braking system. For both cars, the technology was installed in a similar manner. The PicDAQ 5 data gathering platform was used to obtain the occupants' acceleration parameters. The placement of the dummies is shown in Figure 9.



**Fig.9a.** Position of the driver and passenger

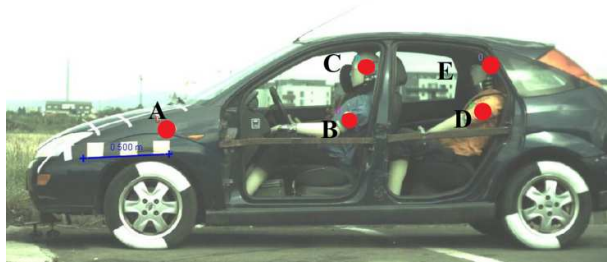


**Fig.9b.** Position of the driver and passenger



**Fig.10.** Checking the data acquisition platform battery with a multimeter

Two dummies were placed in the driver's seat and the back passenger seat, respectively, and the car proceeded. The vehicle was airbagged, and the dummies were fitted with three-point seat belts (Fig.10). The collision speed was approximately 42 km/h, and the impact angle was  $0^\circ$ . The towing system launched the vehicle. In order to replicate a real accident situation, the impact was triggered at a speed of about 42 km/h. The vehicle's collision speed will be determined by applying the mass point in A. The changes in their speeds throughout the collision will also be examined using the mass points B and C, which represent the head and chest of the dummy placed in the driver's seat. Similarly, the rear passenger's mass points D and E will be specified to track the dummy's movement dynamics over time, establishing the precise speeds and helping to provide a more thorough evaluation of the occupants' biomechanical behavior (Fig. 11).



**Fig. 11.** Identification of points where measurements were made



**Fig. 14.** Pre-impact phase



**Fig.12.** Car without IA



**Fig. 15.** Impact phase



**Fig. 16.** Post-impact phase



**Fig.13.** Car with IA

The results of a collision phases are presented in Figs 14-16.

Vehicles are put through thorough and precise evaluations that replicate actual frontal crash scenarios when a test program is rigorously implemented. Important information for enhancing automotive safety is gathered by means of rigorous vehicle preparation, accurate occupant simulation, and cautious equipment calibration and verification. The outcomes of these studies have a direct impact on improving road safety for all users by greatly aiding in the creation and optimization of protective devices.

The accidentology experiment described offers a thorough and precise insight of how cars and their occupants behave in a collision. Thorough preparatory techniques, such as using the braking system during the preliminary test and verifying the straight-line trajectory, guaranteed regulated and repeatable test circumstances.

Procedures were crucial to the experimental research process in order to eliminate uncontrolled variables and lower the possibility

of errors. The basis for further analyzes will be the establishment of regulated and repeatable test settings. By taking these preventive steps, the experiment was conducted as planned, enabling the collection of trustworthy data that will advance a thorough understanding of the phenomena under study.

The results emphasis the importance of the preparation phases for the overall experiment's validity and success.

Figures 17-19 show some of the experiment's findings.

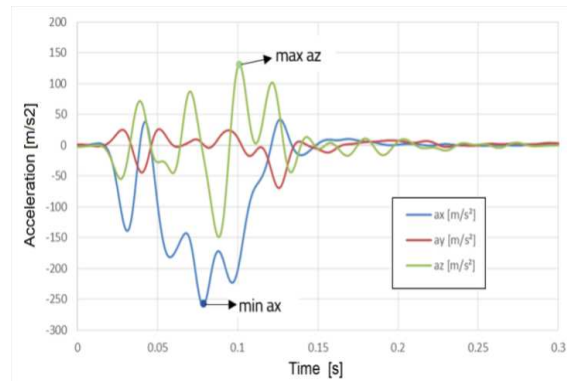


Fig. 17. Components of acceleration of chassis (point A)

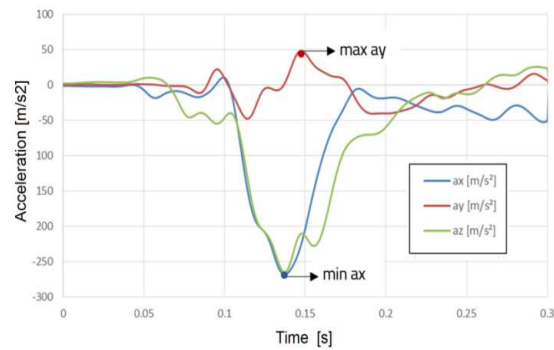


Fig. 18. Components of acceleration of the head (point C)

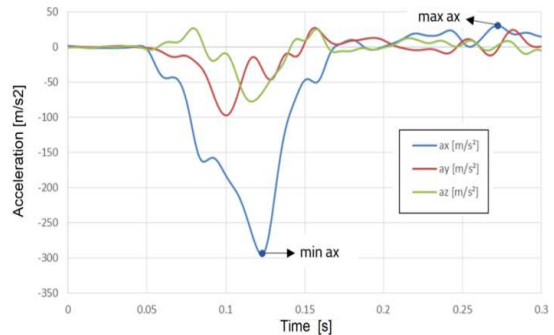


Fig. 19. Components of acceleration of the thorax (point B)

Table 1. The results o the two experiments

		Test 1		Test 2
Car body	Velocity[m/s]	11.67		11.74
	ax [m/s <sup>2</sup> ]	Min	-	-259.21
		Max	283.31	41.51
	ay [m/s <sup>2</sup> ]	Min	-17.09	-69.27
		Max	22.32	26.26
	az [m/s <sup>2</sup> ]	Min	-	-149.05
Max		124.65	131.28	
Head (driver)	Velocity[m/s]	11.28		11.45
	ax [m/s <sup>2</sup> ]	Min	-	-267.86
		Max	278.62	10.91
	ay [m/s <sup>2</sup> ]	Min	-65.21	-47.41
		Max	45.48	48.69
	az [m/s <sup>2</sup> ]	Min	-	-264.63
Max		306.32	25.98	
Thorax (driver)	Velocity[m/s]	11.44		11.46
	ax [m/s <sup>2</sup> ]	Min	-	-
		Max	316.39	294.696
	ay [m/s <sup>2</sup> ]	Min	-	-96.87
		Max	164.92	27.68
	az [m/s <sup>2</sup> ]	Min	-	-77.15
Max		127.10	21.90	
Head (passenger)	Velocity[m/s]	11.04		10.85
	ax [m/s <sup>2</sup> ]	Min	-	-340.31
		Max	475.32	7.52
	ay [m/s <sup>2</sup> ]	Min	-68.46	-77.44
		Max	23.91	11.73
	az [m/s <sup>2</sup> ]	Min	-	-174.36
Max		242.09	15.02	
Thorax (passenger)	Velocity[m/s]	11.33		11.26
	ax [m/s <sup>2</sup> ]	Min	-	-301.66
		Max	408.76	29.596
	ay [m/s <sup>2</sup> ]	Min	-	-141.03
		Max	176.02	42.89
	az [m/s <sup>2</sup> ]	Min	-59.93	-46.82
Max		50.81	83.56	

#### 4. CONCLUSION

The validation of the mathematical model demonstrated that there is a concordance between the simulated and experimental results, both for the vehicle and for the occupants (driver and passenger). The adjustments made by using fractions of the critical damping and by calibrating the time lags allowed a faithful representation of the system dynamics, highlighting both the influence of the occupants' position and the damping system on the vehicle's behavior. The analysis of the percentage errors confirmed a good correspondence between the simulated and experimental results, demonstrating the accuracy of the model in representing the system dynamics. For test 1 (vehicle-rigid barrier), the errors obtained were 2.3% for the vehicle, 15.3% for the driver and 9.5% for the passenger. In test 2 (vehicle with damping system - rigid barrier), errors of 9.6% were recorded for the vehicle, 17.2% for the driver and 10.1% for the passenger, maintaining the trend of lower values for the passenger.

The recalibrated intermediate fractions allowed a balanced representation between the two experimental tests, preserving the observed dynamic differences. The introduction of time lags was essential for synchronizing the simulated responses with the experimental ones, strengthening the validity of the model.

In conclusion, the mathematical model proved to be a robust tool for analyzing the behavior of the vehicle and occupants under various experimental conditions, providing a solid basis for future predictions and optimizations.

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### **Siguranta soferului si a pasagerului intr-un accident frontal cu utilizarea unui nou tip de attenuator de impact**

Atenuatorul de impact (IA), împreună cu centura de siguranță și airbag-ul, reprezintă un dispozitiv important în asigurarea siguranței pasive a autovehiculelor. Aceasta se referă atât la mașinile actuale, cât și la mașinile de curse sau cu scop special. Studiul investighează beneficiile pe care le poate aduce un sistem de siguranță simplu, ieftin și ușor de aplicat, deoarece propune utilizarea apei într-un sistem simplu care contribuie la absorbția unui șoc într-o coliziune cu un perete vertical. În acest sens, se monitorizează comportamentul unui manechin într-o coliziune frontală. Cunoșcând încărcările care acționează asupra manechinului, se efectuează o verificare teoretică (bazată pe un model MFF) și apoi una experimentală pentru a vedea dacă tensiunile care apar după coliziune se încadrează în intervalul sugerat de standardele actuale. Vehiculul este văzut ca o structură care are un IA și un manechin care utilizează o centură de siguranță. Se utilizează o soluție inovatoare de IA pe bază de apă. Conform criteriilor, s-a examinat comportamentul manechinului pentru un impact frontal al sistemului mașină-șofer/pasager. Rezultatele obținute sugerează posibilitatea utilizării apei într-un ansamblu adecvat ca sistem de atenuare a șocurilor în caz de accident.

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