Professional paper

TRANSPORTATION OF PATIENTS IN MEDICAL VEHICLES - PROBLEMS AND COMFORT SOLUTIONS

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ABSTRACT

Medical vehicles are produced based on cargo vans, transporters. Such vehicles, without adequate modifications, do not offer comfort necessary for transport of patients. Harmful body vibrations cause discomfort and can worsen the condition of the patient lying on the stretcher. The patient is not protected and cannot receive adequate care due to the vibrations. The research problem lies in the suspension of such vehicles, which is intended for the transport of cargo and is not adapted for the transport of sick and injured or hospitalized patients.

The experiences of patients when transported over long distances bring desperate stories. Severe bounces, vibrations, shocks, jolts and side-to-side rolling of the vehicle can not only cause secondary injuries to patients but can also affect the use of instruments and equipment in the vehicle. The paper presents the method of installing such a suspension in a medical vehicle. By replacing the old metal spring with an active air bellow, harmful vibrations are reduced and eliminated, thus increasing the comfort of transporting patients with medical vehicles.

KEYWORDS: medical vehicles, emergency vehicles, ambulance vehicles, medical suspension, vibration problem, air suspension

1. PROBLEMS AND SOLUTIONS

The problem of the comfort of medical and emergency transport

First, the desperate story of the wife who, in recent months, accompanied her husband several times in an ambulance to the Clinical Hospital Center - *KBC Rebro* (Gavranović Ž. PLUSportal, 2023.).

Those ambulances look decent from the outside. But the truth is that these means of transport are not even for transporting animals. It is so inhumane that I can characterize it as a crime against humanity. These are cargo vehicles, not passenger vehicles. The shock absorbers are not made properly, it knocks, you feel as if it will fall apart, you feel every hole in the road...Imagine what it's like to travel like that for people who, for example, have just been operated on. Inside there is one bed with a low sponge, the others must sit on chairs. When we were traveling, one of those chairs was walking left and right. My husband vomited from Slavonski Brod to Zagreb. How many of us can fit - that's how many of us are stuffed inside. All the passengers complain, all cry and cry, but no one has the courage to speak publicly. When we were walking back home, the woman who has no leg from the hip left the bed for my husband who was having pancreatic surgery, so he could lie down and stop throwing up. Otherwise, I don't know how he would get to Slavonski Brod. Even healthy people can't stand it. I, who am accompanying, cannot go to work the next day because I am recovering. - she told us about a difficult experience.

When asked by a journalist, the director of the Health Center in Slavonski Brod replied that the vehicles were not missing anything. All vehicles used meet and comply with the Croatian standard HRN EN 11789:2020 for A2 type vehicles and the Ordinance on the organization of medical transport activities (Official Gazette 72/19).

My husband is the first Croatian policeman. He spent six years fighting for this country, barely making it out alive. Now he got sick, he is 57 years old, he is not an old man... Fighting for this something of ours, you end up experiencing such suffering. They paint themselves, instead of investing all together in quality vehicles for longer distances. You can check the truth of my claims just by driving to Nova Gradiška and back. - concluded the patient's wife. If the profession respects all applicable norms and regulations, and patients still complain about this type of transport, it is necessary to check in more detail what it is about - is it an individual case, a complaint concerning the patient's personal condition and illness, or is it something that many patients experience, but are afraid to talk about. Likewise, it should be determined how much other factors - such as the fact that the section of the NG-SB highway is in extremely bad condition - influence this impression. If everything is fine with the vehicles, but they do not fulfil the basic task - safe and comfortable transport of passengers - then we should insist on changing the norms. In any case, ignoring inquiries and complaints is not a good way to solve this serious problem. Please help, how can I prove such a visible truth? My husband's health is destroyed in that transport, as well as other people's health. In January, we need to go to Zagreb again, where he will have an operation and the same day he goes back...he needs to lie on a thin sponge that destroys the kidneys and the entire intestine, and he had a difficult operation on his abdomen.

Looking on the internet for how an ambulance should be equipped for transporting patients, I came across your work (Mikulić, D., Muck D., Pakšec E.: Polytechnic and Design, 2022). I am interested, since you are experts in this matter, who are the authorized service technicians and who

can check and in what way the correctness of the vehicle? Realistically, a layman can verify this by sitting in it.
Link to the local newspaper where it was published: *https://plusportal.hr/politika/toliko-je-nehumano-da-moze-biti-nazvano-zlocinom-protiv-covjecnosti-51121?slide=1&fbclid=IwAR1EG7IpZCf7Leit7TNvFbsSH0llHr9hDdUU lOpzGq4TsxQBbNeDWmsqNE*

In this paper, relevant research is presented in accordance with the published article in *Polytechnic and Design* magazine. The two key components of medical transport are safety, care and comfort from the aspect of protecting patients from harmful vibrations. A suspension system for a medical vehicle is proposed, which should remove harmful vibrations transmitted to the patient and medical staff when driving on different road surfaces. With such a vehicle, the medical team has a greater potential to save human lives.
When transporting a patient in an ambulance, every second is important for his life. While the vehicle is in motion, the medical team must sensitively aid the patient, *Figure 1.* The general perception is that doctors try to save the patient using medical equipment. Accidental shock vibrations can be assumed to cause or aggravate patient injuries, especially if the shock absorbers are defective. Even inertial driving (acceleration, braking, rolling) can be dangerous for his life.

Taking care of the modernization of medical vehicles is one of the components of the continuous improvement of the quality of services of the *Croatian Institute for Emergency Medicine* (HZHM). The *Vehicle Standard* for a uniform vehicle fleet, the external appearance of vehicles for the performance of outpatient emergency medicine was adopted, as well as the adopted HRN EN 17898:2020 norm, which determines the general requirements for the design, testing, performance and equipment of medical vehicles that are used for the transport, treatment and care of patients. Considering the high annual intensity of the number of kilometres travelled, medical vehicles, especially ambulances, are rapidly becoming obsolete. The county institutes of emergency medicine are responsible for the provision of medical care, technical correctness and equipment of vehicles, which can initiate amendments to the standards regarding comfort.

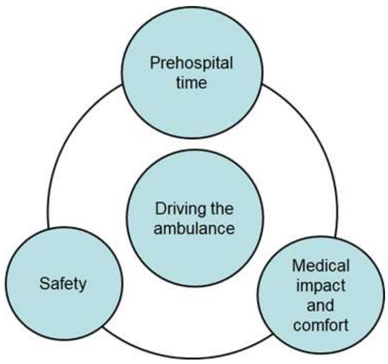

Figure 1. Medical transport components, safety, medical care and comfort

Papers (Klegraefe N. 2010; Graziosi J., Barber L., Wojcik M. 2010) present the results of extensive research into vibrations that occur in the patient care area. Research has shown that the vertical acceleration (acceleration/deceleration) experienced in the floor of the patient compartment often exceeds the limits that exist for healthy adults, which has adverse effects on patients. the authors deal with the generalization of vibration parameters of medical vehicles, giving physiological responses to harmful vibrations.

The problem of harmful vibrations in the patient during the short interval of transport to the hospital was highlighted. Accidental impact vibrations on the floor of the vehicle along the vertical axis, which are caused by obstacles on the road surface such as potholes or speed bumps, are the hardest to bear, and accelerations ranged up to 15 m/s^2 were measured, which falls into the category of extremely harmful to human physiology, because the accelerations are accompanied by forces (Newton's second law) that can cause injuries to the patient. In the lying position of the patient, bearing the vibrations is the most difficult, so the patient stretcher must be carried out carefully. When transporting baby incubators, the level of vibration and noise exceeds the recommended values, which are "very unpleasant" even for healthy adults. The results of research into the reduction of vibrations on the patient's body indicate the use of active suspension systems, i.e. air balloons to maintain a constant height of the vehicle, which is placed between the wheels and the body, and to reduce vibrations in the main stretcher.

Mechanisms used to limit the speed of traffic on roads include speed bumps or speed limiters, i.e. raised thresholds or raised pedestrian crossings (speed bump, hump) to impose speed limits in traffic-important places. The recommended speed limits for driving over the barriers are 20 km/h, 30 km/h or a maximum of 40 km/h. However, when the vehicle hits the barriers at an excessive speed, the passengers can suffer physical injuries. For example, by driving a bus at twice the speed limit (30 km/h) and hitting the speed limiter, passengers in the back seats can suffer injuries in the form of spinal trauma due to high accelerations. Even the courts invite experts to assess the cause of the passenger's injuries. Research results (Graziosi J. 2010, Janczur R. 2015, Brammer J. A. 2022), and references (Mikulić D. 2020, VB air Suspensions, 2022) allow a reasoned discussion and conclusions about the modernization of medical vehicles.

On Croatian roads there are speed limiters of different profiles and designs. Their height is up to 120 mm, which is higher than the European standard (75 mm). The most common is the trapezoidal or rounded section of the strut profile, 50 mm high and about 350 mm in base, laid across the entire width of the road. The speed limit for driving over a speed limiter is the maximum speed at which a passenger vehicle can cross the speed limiter without causing significant inconvenience to passengers, without damaging the vehicle or endangering traffic safety. Ambulances have their own routes to avoid the speed limiters. However, in urgent situations, searching for the shortest possible route is often not possible, so it is not possible to avoid speed bumps. When a vehicle's wheels hit a speed limiter at a speed limit of 40 km/h or faster, body accelerations can be extremely damaging, which is associated with noise and vehicle lift. Research shows that accelerations/decelerations on the rear axle are greater than on the front axle, which is important from the point of view of patient protection. Accelerations that can occur at excessive speed when crossing the barrier with medical vehicles (which have passive suspension) can cause pain or injury to the patient. Such vertical and angular accelerations of the vehicle are dangerous for the patient lying on the stretcher. A higher speed of the vehicle over bumps brings a higher risk of injuring patients. To eliminate the harmful vibrations of medical vehicles when moving on different types of bumps, it is not enough to provide a comfortable stretcher bed (ambulance stretcher), it is necessary to replace the mechanical suspension of the vehicle with an air suspension.

2. IMPACT OF VECHICLE VIBRATIONS ON HUMANS

Vibrations are mechanical oscillations of the system with smaller amplitudes. These are movements that are periodically repeated. Motor vehicles cause vertical and angular vibrations when moving. The vibrations are transmitted to humans through the body (seat, or stretcher if lying down). A person tolerates vertical vibrations up and down best, and angular vibrations are more difficult to tolerate. All mechanical vibrations of the vehicle can be observed in the coordinate system X, Y and Z. Of all the possible accelerations and displacements of the body (six: 3 linear and 3 angular), the most significant are accelerations in the direction of the vertical Z-axis, angular vibrations around the Y-axis (*galloping / pitching*) and angular vibrations around the X-axis (*rolling*).

Other movements are limited by the mechanical connections of the body. Longitudinal vibrations are structurally prevented, and transverse vibrations must not be allowed either. Thus, suspended masses have vertical and angular vibrations around the longitudinal X-axis and the transverse Y-axis. Vibrations are transmitted from the wheels and suspension to the body, passengers and cargo being transported. Vibrations also come from the engine, transmission and wheels. Intense vertical vibrations and angular vibrations cause discomfort and quick fatigue for passengers and drivers, which limits the time of safe driving. This is why vertical and angular vibrations are considered in passenger comfort analysis. There are two types of vertical vibrations on a motor vehicle,

Figure 2:

- low-frequency vibrations: 60-120 cycle/min (1-2 Hz) on the body
- high-frequency vibrations: 600-900 cycle/min (10-15 Hz) on the wheels

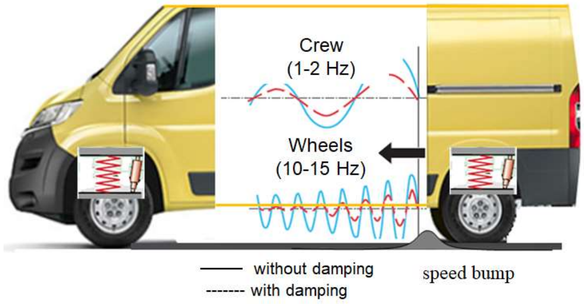

Figure 2. Low-frequency and high-frequency vehicle vibrations

Since childhood, the human body gets used to walking frequencies of 1-2 Hz (1-2 cycles up and down per second). Because of this, the vibration frequencies of the vehicle body are in the range of 60-90 cycle/min (comfortable-sporty driving), which speaks of the calmness of the ride. If the body vibrates at less than 60 cycles/min, the suspension is considered soft, which corresponds to a vibration time of 0.8-1.0 seconds. If the vibrations are higher than 90 cycles/min, the suspension is too hard and can cause damage to body parts. Low frequencies in the range of 0.1-0.65 Hz cause nausea (sea sickness). The impact of vibrations on the human body is quite subjective, from person to person. However, vibrations are professionally assessed quantitatively based on vehicle behaviour parameters: *frequency and amplitude of vibrations, speed and acceleration of vibrations.*

The permissible exposure of people to vibrations is prescribed by the ISO 2631 standard, and the EU directive 2002/44/EC defines the minimum safety and health requirements for workplaces. The medical team can have several interventions in a work shift, the professional exposure of which can be calculated and standardized. The exposure of the patient during transport to the hospital is one-time, of varying duration, however, due to the urgent care of the patient, harmful vibrations that may endanger his life should be avoided. Therefore, to protect the patient from injury, it is necessary to maintain the calmness of the vehicle, maintaining the frequency of vibrations and low displacement amplitudes. Practically, natural frequencies for cars are 0.8-1.2 Hz and 1.2-1.9 Hz for buses and trucks [9]. If the frequencies are within the indicated intervals, then the organism tolerates the vibrations well. The human body is sensitive to vertical acceleration at frequencies of 4-8 Hz, as well as to lateral accelerations up to 2 Hz, which should be avoided. Sensitivity to frequencies of 4-8 Hz is recognized as the resonance of the abdominal organs. As the frequency increases, the permissible displacement amplitude decreases (2 Hz/10 mm; 6 Hz/0.5 mm).

Most medical vehicles are designed so that the main stretcher with the patient is fixedly attached to the vehicle body. In the supine position of the body, bearing vibrations is more difficult, so the stretcher must be carefully designed to accommodate the patient, *Figure 3*. The patient is subjected to the same vibrations as the body of the vehicle. For a person in a lying position on a stretcher supporting the weight of the thighs, lower legs and feet, the resonant frequency is 3-3.5 Hz. If the patient's movement is limited by the body's constriction at the legs and shoulders, the resonance is shifted lower, to 2.5 Hz. Regarding vertical and angular displacements, the parameter values of the comfortable city, road or off-road driving program can be set. For example, the values of the vehicle's travel comfort can be assumed: the vehicle's own frequency 0.8-1.2 Hz; vertical acceleration, 0.65-2.0 m/s^2; angular acceleration around X and Y-axes, less than 1.5 (2.0) rad/s^2. Less permissible acceleration limits are associated with functions such as feeding in the vehicle, writing and the like.

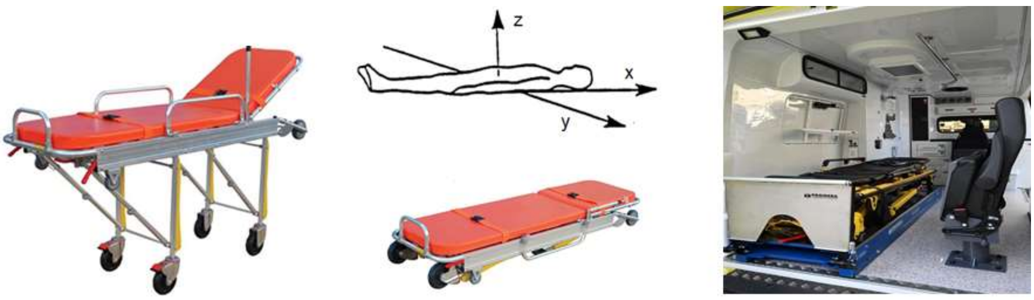

Figure 3. Main stretcher in a medical vehicle (*ambulance stretcher*)

3. TECHNICAL REQUIREMENTS FOR MEDICAL VEHICLES

The vehicle standard (NN 80/2016) describes the conditions that must be met by the medical vehicles of the outpatient emergency service in the Republic of Croatia in terms of general features, equipment and exterior decoration, partition wall between the patient compartment and the driver's compartment, openings on the medical vehicle, areas for entering/ removal of the patient, patient compartment, driver's compartment, equipment and interior decoration of the vehicle. Medical ambulances are built based on commercial vehicles with passive suspension, which are not directly adapted for transporting and rescuing patients. Conversion of such transporter-type vehicles into medical emergency vehicles entails mechanical processing and equipment in specialized companies and the issuance of a certificate by an authorized institution.

According to the HRN EN 1789:2020 standard, a medical vehicle is intended for the care and transportation of at least one patient, it is operated by at least two appropriately educated and trained employees. Three types of medical vehicles are defined:

1. Type **A** vehicle: patient transport vehicle, with its two subtypes; A1 – vehicle adapted for the transport of one patient and A2 – vehicle adapted for the transport of one or more patients
2. Type **B** vehicle: vehicle for transportation, providing basic assistance and patient care
3. Type **C** vehicle: intensive care unit equipped to transport and provide more advanced medical care.

All medical vehicles of the emergency medical service in the Republic of Croatia must meet the **B** vehicle type. This type of medical vehicle is intended to provide basic assistance and patient care, designed and equipped to transport, treat and monitor patients. Equipping and exterior decoration of a medical vehicle refers to additional equipment and devices that are installed on the basic model of the vehicle during its conversion into a medical vehicle. The patient loading/unloading area is located at the rear of the vehicle and must ensure safe entry and exit of patients.

The angle of introduction of the *main stretcher* (with a load capacity of 150 kg) is up to 16º, and in general the angle of introduction must be as small as possible. The maximum height of the floor threshold or the ramp/platform for loading the main stretcher, measured from the ground, must not exceed 750 mm when all the prescribed equipment is in the vehicle. The equipment and devices in the patient area must be placed and fixed to provide unhindered use and monitoring of the patient while driving, as well as the introduction and extraction of the main stretcher as required by the patient's health condition.

The *Vehicle Standard* does not recognize the technical requirements for vehicle comfort and safety to reduce unwanted vibrations during the transport and treatment of patients. In Art. 4, item 5 states the following: ***the suspension must be adapted to the transport of patients lying on stretchers and medical staff in the patient compartment***. Since the adaptability of the suspension to the transport of stretcher patients and medical personnel has not been further technically specified, additional advanced requirements for modernization of their suspension are considered in this research.

Requirements for the modernization of medical vehicles:

- maintaining a constant height of the vehicle from the ground (self-levelling, road, comfort)
- increasing and decreasing the height of the vehicle from the ground (highway terrain)
- raising and lowering the rear part of the vehicle
- side tilting of the vehicle

Maintaining a constant height of the vehicle from the ground, when crossing various bumps, is achieved by processed leveling of the body using the active suspension in a short time (*self-leveling*), which avoids the occurrence of harmful vibrations. For example, when the wheels hit an obstacle, the active air suspension levels the given height of the body, while the wheels are raised or lowered due to the change in the characteristics of the air suspension, as well as the mutual angular displacement of the front wheels in relation to the rear wheels and vice versa. In addition to regulating the maintenance of a constant height of the vehicle, such suspensions provide driving programs (*road, highway, off-road*) and additional practical possibilities of using the vehicle: easy access to the entry of the main stretcher and unhindered work with the patient. This means, the rear of the vehicle can be lowered towards the road to help wheelchairs get in and out. By lowering the suspension, the angle of the ramp is significantly reduced, a shorter ramp can be used, which makes it easier to bring in the patient, and tilting the vehicle to the side allows emptying the toilet tank.

4. PASSIVE VEHICLE SUSPENSION

The most used suspension in vehicles (M, N category) is the passive (classic) suspension, Figure 4. The suspension connects the wheels and the vehicle body. It consists of elastic, damping and up and down guiding elements. The main parts of the suspension are springs (coil or leaf), shock absorbers, guides and transverse stabilizers. Suspension has two primary functions, vibration isolation and keeping the wheels on the road without bouncing. The function of the transverse stabilizers is to limit the lateral tilting of the vehicle by increasing the angular stiffness, which improves the stability and controllability of the vehicle. Therefore, the passive suspension of the vehicle allows certain vertical and angular vibrations of the body, other movements are structurally limited.

Vehicles with a larger wheelbase and wheel track generally provide greater vehicle comfort and safety. Vehicle suspension determines the essential characteristics of a motor vehicle: *road comfort, road safety and operational safety of the vehicle*. Driving comfort of the vehicle can be achieved by a quiet ride, i.e. with moderate vibration damping. The static travel of the suspension in passenger vehicles is between 100 and 200 mm, which most closely determines the natural frequency of the suspension. The safety of keeping the wheels on the road without bouncing is achieved by stronger vibration damping, which ensures the stability of the movement. The performance of the passive suspension provides a compromise between these two opposing requirements. The operational safety of the vehicle depends on the strength of the suspension parts, so they are protected by the safety coefficient. The frequency and amplitude of the vibrations is linked to the elastic elements of the suspension (springs, air bag), and the regulation of the speed and acceleration of the vibrations is linked to the damping elements of the suspension (shock absorbers). The damping characteristic of the shock absorber can be *linear, progressive or degressive*. Comfortable driving requires degressive, while sporty driving requires progressive damping force.

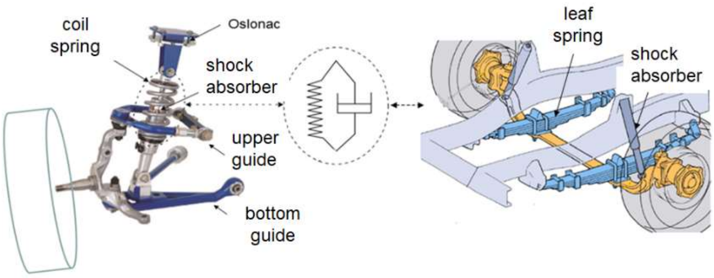

Figure 4. Passive suspension of motor vehicles, front and rear axles (Mikulić D., Motorna vozila 2020)

Passive suspension does not have the ability to self-level the height of the vehicle as well as change the height and slope of the rear part of the vehicle, which is required by an advanced medical vehicle. The passive suspension does not provide a sufficiently high-quality dampening of road vibrations, especially of the rear axle when the vehicle moves over various bumps, and therefore the safety of patients and the medical team. For this reason, on such vehicles, passive suspension is replaced with active air suspension or hydraulic-pneumatic suspension, which provide greater travel comfort and patient safety.

5. MEDICAL SUSPENSION

The suspension market offers an active air system for a medical vehicle. Such a suspension (VB air suspensions, 2022) includes air springs (cushions), gas shock absorbers, transverse stabilizers, height sensors, G-sensors and a control unit for maintaining a constant height from the ground, on bumps and struts, by coordinated leveling of body parts in a very short time, which isolates harmful vertical acceleration, angular acceleration (galloping and rolling) of the body. Management of the suspension in terms of raising, lowering the rear part of the body or other options is carried out via remote control. The platform of the vehicle can be raised and lowered when the vehicle is stationary, which allows easier entry/exit of passengers from the vehicle. The wheel displacement sensors that monitor the lift of the wheels while driving provide the control unit (ECU) with data for leveling the height of the body floor. Active air suspension provides road comfort and vehicle movement safety that classic passive suspension does not provide.

Medical vehicles are processed based on commercial vehicles of category N1, the maximum permissible mass of 3.5 tons. New vehicles can be ordered with active air suspension or modified for used vehicles with passive suspension. There is a large number of vehicles on the market for conversion into medical vehicles (make/model: *Citroen Jumper, Mercedes Sprinter, VW Transporter, Peugeot Boxer*, ..). As an example of the available data, the *Citroen Jumper* vehicle is shown, which is recognized for its universality of use. The modular platform provides customers with the option of choosing a configuration depending on their needs regarding the use and choice of power of the HDi 110, 130, 150 and 180 diesel engines. The front axle has an independent *MacPherson strut suspension* (coil spring and shock absorber) with a triangular lower guide. The rear rigid axle has independent suspension, longitudinal leaf springs and hydraulic shock absorbers.

In the market of medical suspensions, factory installation or equipment packages for replacing passive suspension with air suspension (kit equipment) are offered for all well-known brands of transporter or van type vehicles. Emergency Medical Services (EMS) - a specialized company for emergency assistance around the world (by road and air), in order to increase the safety and comfort of patients, use ambulances equipped with air suspension. In addition, to avoid sudden jerks when starting, the company decided to use only ambulances with automatic transmission. Among the most famous manufacturers of air suspension can be mentioned the companies *VB Air Suspension* (Netherlands) and *Glide-Rite Air Suspension* (Great Britain). For example, almost 90% of ambulances in the Netherlands are equipped with VB-Airsuspension. The VB air suspension concept offers options, from simpler (2C) to more complex (4C) variants:

1. *VB-air suspension 2C*, for the rear axle, with 2-angle height sensors.
2. *VB-air suspension 3C*, for the rear axle and semi-air suspension on the front axle.
3. *VB-air suspension 4C*, complete suspension system on the front and rear axles of the vehicle, wheels equipped with angular height sensors and acceleration G-sensors.

6. VIBRATION SIMULATION

In the article (Mikulić, D., Muck D., Pakšec E., 2022) a comparison of the vibration parameters of passive and air suspension was made through simulation, using the *Motion Study* module (*Solidworks*). The simulation was made for a planar two-dimensional vehicle vibration model in the longitudinal plane, with four degrees of freedom of movement (*half car model*, 4 DoF). Both with passive and with air suspension, accelerations as well as angular acceleration due to sudden excitation were simulated when the vehicle crossed a 50 mm height barrier, at a minimum speed of 20 km/h.

A comparison of the simulation results of the air suspension on both axles was performed in relation to the passive suspension. When the front wheels pass over the speed limiters, there is no significant difference between the classic and air suspension in terms of vertical acceleration values. At the transition of the rear wheels with air suspension, low peak values of vertical acceleration are achieved. Therefore, the permanent option is 2C air suspension for the rear axle only. The amounts of vertical and angular acceleration directly affect the quality of the ride. By increasing the speed of the vehicle over the speed limiter, more pronounced acceleration values are expected. The installation of gas shock absorbers or magneto-rheological shock absorbers (MR) can additionally increase road comfort and safety. With such shock absorbers, the damping force does not weaken during long-term driving, so there is no loss of damping force and safety of movement.

7. INSTALLATION OF AIR SUSPENSION

Figure 5 shows an example of the installation of active air suspension 4C on the front and rear axles in the *Citroën Jumper X250* vehicle. The elegant solution of the air bag and lever contributes to the compactness of the structure. The suspension control unit (ECU) manages the elastic and damping elements by regulating the parameters, both for self-levelling of the height and for driving programs. Based on monitoring the acceleration of the body, the damping intensity of the shock absorbers is adjusted according to the driving program (*road, off-road, highway*). The working pressure in the airbags changes progressively, from 9 to 13 bar, depending on the load (*empty, full*), maintaining the set frequency (1 Hz). The time it takes to raise and lower the body to a certain height depends on the vehicle's load. From the aspect of suspension modification, by replacing passive with air suspension, there is a slight increase in mass per axle (20-30 kg), which for N1 category vehicles has no significant impact on acceleration and speed.

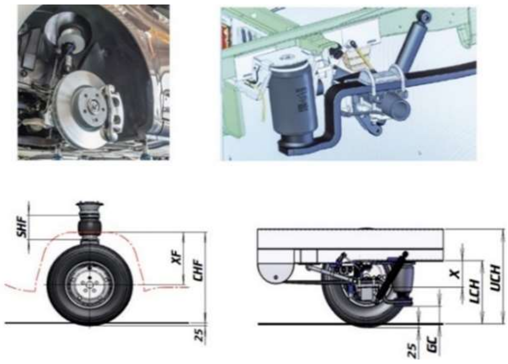

Figure 5. Installation of suspension 4C on front and rear axle (*Citroën Jumper X250*, 2022)

Air suspension 4C ensures:

- constant height of the vehicle regardless of the load (*self-levelling*), without harmful vibrations of *galloping* and *rolling*, with the possibility of adjusting the height of the loading threshold +/- 70 mm
- the driver can choose a higher level in addition to the normal constant height of the body (terrain), and the lower level is set automatically during fast driving (sport)
- the rear part is raised to the maximum height, for the vehicle to enter the ferry
- loading / unloading, the front axle is automatically raised and the rear one is lowered to the end, which facilitates loading or unloading of cargo.

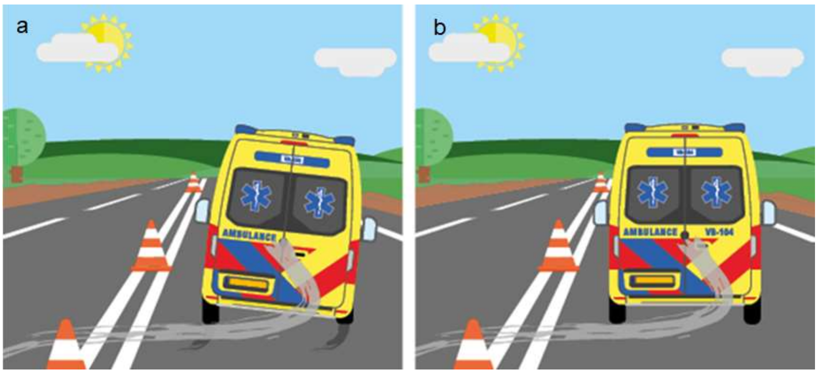

Figure 6. Medical vehicle: a) passive suspension - the vehicle leans (rolls), b) active air suspension, without harmful vibrations - the vehicle is stable and easy to control (*VB air suspensions*, 2022)

Air suspension 2C

Air suspension of the rear axle 2C offers a simpler and cheaper solution, although it does not provide complete self-leveling of the vehicle, there are acceptable values of vertical and angular accelerations,

Figure 7. This suspension design is suitable for medical vehicles and transport of patients sensitive to shocks from various bumps. As research shows, accelerations on the rear axle are higher than on the front axle, so it is a priority to install air suspension on the rear axle and thus eliminate harmful vibrations. The ECU unit of the suspension limits the vertical and angular accelerations of the centre of gravity of the vehicle and the rear part of the body, which contributes to the smooth running and stability of the vehicle. For example, the 2C suspension provides:

- constant rear axle sill height, regardless of load, 675 mm
- lowering the rear axle for loading or unloading cargo (kneeling), 65 mm
- raising the rear axle to enter the ferry, 45 mm.

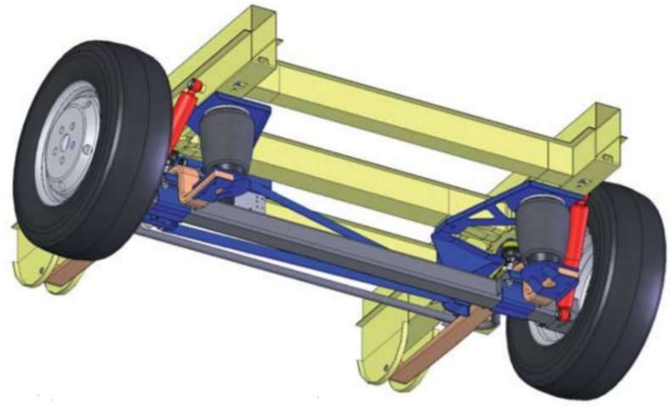

Figure 7. Air suspension 2C on the rear axle (*VB air suspensions*, 2022)

8. CONCLUSION

Problems of patient transport and solutions for modernizing the suspension of medical vehicles are presented. Air suspension is recognized for the high-quality equipment of medical vehicles and is therefore available, both when specifying the purchase of new vehicles and used vehicles. The least that is necessary when converting vans into medical vehicles is to install active air suspension on the rear axle and thus eliminate possible harmful vibrations that endanger patients and the work of the medical team.

It can be assumed that the responsible county employees when procuring medical vehicles, regarding comfort problems and complaints, will not heed these calls and demand the amendment of the requirements for regulating the comfort of medical vehicles and thus justify the trust of the public health institution. In the Republic of Croatia, there are manufacturers for the conversion of transport vehicles into medical vehicles, as well as accredited institutions for testing and examining the complete correctness of medical vehicles.

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