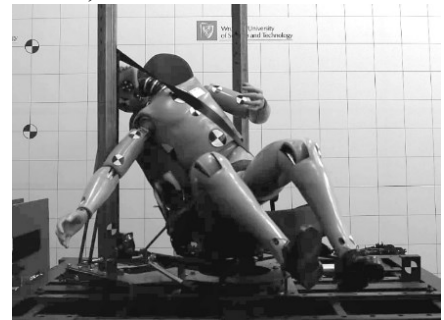


Autonomous and highly automated vehicles are set to revolutionize transportation in the coming years. With these technologies, passengers will no longer be confined to the traditional upright, forward-facing seating position throughout the journey. In the future, travel could become significantly more comfortable. Passengers might recline their seats, sit sideways, or even face backward, allowing them to work, rest, or sleep while on the move. These unconventional seating configurations are referred to as “out-of-position” (OOP) scenarios and are analyzed through crash tests and sled tests. However, a key challenge lies in the fact that current crash testing protocols and passenger safety standards are not designed to accommodate such scenarios. The standard assessment methods, which perform well for conventional seating positions, do not provide sufficient insight into the potential injury risks associated with these new seating arrangements.

Research conducted at the Vehicle Safety and Dynamics Laboratory of Wrocław University of Science and Technology has shown that out-of-position scenarios involve injury mechanisms that differ from those observed in standard crash tests. One notable example is the occurrence of whiplash injuries even in frontal collisions when the seat is reclined, a phenomenon previously associated only with rear-end impacts. Another concern involved the risk of lumbar spine injuries, caused by the abrupt collision of the pelvis with the seat base. Additionally, a new interaction mechanism between the seat and the occupant was discovered, referred to as the Pelvis-to-Headrest Transmission Effect. The analysis further revealed a non-linear increase in head injury risk depending on the seat recline angle and the severity of the collision impulse. Even small changes in these parameters led to a sudden spike in loading forces. In rear-oblique scenarios, it was also found that the dummy’s head often misses the headrest (Fig. 1), which significantly increases the risk of neck injuries. These findings demonstrate that traditional safety criteria are insufficient for evaluating non-standard seating configurations and highlight the need for continued experimental validation. In light of these observations and the limitations of current safety assessment methods, a new research program has been planned, aiming to:



Rys. 1. Rear-oblique collision

development of passenger kinetics and biomechanics models and assessment of injury severity in collisions involving non-standard scenarios and passenger positions.

The research focuses on four crash scenarios: frontal, rear-end, and both front-oblique and rear-oblique impacts. The experiments will be conducted at the Vehicle Safety and Dynamics Laboratory of Wrocław University of Science and Technology, using a sled test facility that allows for precise replication of collision impulses under controlled conditions.

The measurement system includes sensors that record accelerations, angular velocities, forces, and moments in the head, neck, chest, pelvis, and lumbar spine, as well as high-speed cameras that enable three-dimensional motion reconstruction. Based on this data, standard injury criteria will be calculated, including the Head Injury Criterion (HIC), which estimates the risk of head trauma, the Neck Injury Criterion (Nij), which assesses loads on the neck, the Brain Injury Criterion (BrIC), related to brain injuries resulting from head rotation, and the Neck Injury Criterion (NIC), used to evaluate the risk of cervical spine damage during inertial motion. In out-of-position (OOP) scenarios, however, the values of these indicators alone may not accurately reflect the actual injury risk. For this reason, sensor data will be synchronized with high-speed video footage, allowing for three-dimensional reconstruction of body segment motion and the correlation of numerical results with the observed biomechanical mechanisms.

The primary test dummy used in the project remains the Hybrid III, widely applied in homologation procedures and scientific literature. Its limited biofidelity will be complemented by selected tests using the Primus Biofidelic Dummy, which, due to its different construction, more accurately replicates human body biomechanics, particularly in non-standard seating configurations (Fig. 2). The use of the Primus dummy will enable comparison with Hybrid III results, evaluation of the relevance of current injury criteria, and provides data to support the development of Human Body Models (HBMs), which are planned to be incorporated into Euro NCAP protocols starting in 2030.

The project therefore addresses critical gaps in current passenger safety procedures and will provide essential knowledge for protecting occupants of autonomous vehicles in new, non-standard travel conditions.

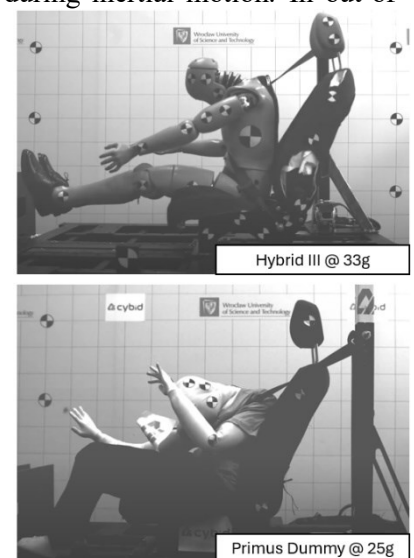


Fig. 2. Comparison of the Biomechanics of the Hybrid III Dummy and the Primus Biofidelic Dummy