AIR-BAG PROTECTION OF THE TRAIN DRIVER DURING A COLLISION

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ABSTRACT

The objective of this study is to improve the protection of the train driver in case of a collision with a truck stopped at a level crossing. This is a contribution to the efforts carried out to develop European standards in the field of railway safety, in collaboration with the French railway company (SNCF). Research has been conducted by this company for several years on train passive safety, focusing on structural collapse and achieving a good level of prediction for the deceleration sustained by the occupants. Now, research is looking at interior fitting aggressiveness that affects the severity of crash injuries.

Keywords: Injury Criteria, Air Bags, Sled Tests, Hybrid III, Finite Elements Models.

EVEN IF TRAIN ACCIDENTS are less frequent than road accidents – in France, the ratio of fatalities is about 1 to 70 – their impact on public opinion is spectacular, due to the large number of victims at one but also to an extensive coverage in the press. Moreover level crossing train collision with heavy goods vehicle is one of the most frequent cases of train accidents, according to the European statistical study performed by ERRI [ERRI, 1997]. In order to minimize the consequences of such collisions, the French railway company has decided to perform specific biomechanical studies for train occupants [Leveque, 2001]. Currently, no restraint device is available in the train driver cabin, which can lead the driver to be projected against the desk structure and cause him considerable injuries in case of a frontal collision. The general objective of this work was to look at the feasibility of protecting train driver with restraint systems developed for the automotive world. The approach used in this work consisted in transferring the biomechanical knowledge acquired in the automotive field to the railway domain and adapting protection devices to the specific conditions to which train drivers are exposed. Injury risk was evaluated in several configurations: 1) no restraint device, as it is currently the case in trains; 2) seat fitted with a 3 point belt restraint system and a headrest; 3) car driver air bag fixed on the instrument panel.

METHODOLOGY

Sled tests and numerical simulations were carried out at the Biomechanics and Human Modelling Laboratory of INRETS [Chevalier, 2003]. In the experimental approach, the train driver environment was reconstructed on a test sled on which a Hybrid III dummy [Denton, 1994] was submitted to a deceleration corresponding to a reference accident (half sine pulse with 10 Gs plateau). Driver kinematics and injury risk were evaluated from 2 high speed video camera recordings and physical parameter measurements.

A computer simulation with a finite element model of the driver and its environment complemented the experimental approach. A digital dummy was positioned in the virtual mock-up in the same way as in the real sled tests; contacts between the dummy and its environment were also defined.

Fig. 1 - Comparison between unbelted real and virtual dummies kinematics (one frame every 50 ms). Calculations done with Radioss ® finite elements code.
Simulations were performed using Radioss® and Pam-Crash® FE software by applying the pulse of the crash test to the virtual sled: Pam-Crash was used for belted dummy simulations and Radioss for the unbelted case. The available outputs consist in dummy kinematics and mechanical loadings - such as acceleration, force, deformations, strains – of dummy and equipment. Simulation calculations such as dummy response and kinematics were compared with sled tests measurements and video camera recordings: the results underline a high correlation, validating the model. An example of unbelted real dummy and virtual dummy kinematics is shown in figure 1.

**RESULTS**

Sled tests as well as numerical simulations emphasize the particular injury risks to chest, legs and neck: biomechanical criteria often exceed the limit values as it is shown in table 1 which allows the comparison between the results of two sled tests: the first one is an experimental test with an unbelted dummy; the second one was performed in the same conditions, in terms of speed and sled pulse, but with a belted dummy. There is no interaction between the head and any element of the environment but the neck is subjected to successive movements of flexion and extension with values of mechanical moments which can be high. As demonstrated in a second study, femur protection can be improved with a 3 point belt restraint system: when the dummy is belted, forces applied on femurs decreased (see table 1).

<table>
<thead>
<tr>
<th></th>
<th>Experimental Test with unbelted dummy</th>
<th>Experimental Test with belted dummy</th>
<th>Limits values 96/79/EC DIRECTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest deflexion</td>
<td>84 mm</td>
<td>79 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>Chest Acc. (3ms max)</td>
<td>94.3 g</td>
<td>41.5 g</td>
<td></td>
</tr>
<tr>
<td>Neck: Extension Moment</td>
<td>37.2 mN</td>
<td>45 mN</td>
<td>57 mN</td>
</tr>
<tr>
<td>Head Acc (3 ms max)</td>
<td>37.3 g</td>
<td>40.6 g</td>
<td>80 g</td>
</tr>
<tr>
<td>HIC</td>
<td>200</td>
<td>297</td>
<td>1000</td>
</tr>
<tr>
<td>Femurs load</td>
<td>10 kN</td>
<td>4.5 kN</td>
<td>9.07 kN (0&lt;t&lt;10 ms), 7.58 kN (t&gt;10 ms)</td>
</tr>
</tbody>
</table>

**Table 1 - Biomechanical criteria measured on a real dummy in sled tests**

However the chest injury risk remains important, resulting from the short distance between the driver and the desk and because the seat rotates forward due to the belt forces applied to the backrest (figure 2). An important limitation for seat belt could be the reluctance of the driver to wear it. Moreover injury risk is higher for the neck and the head when the seat is equipped with a belt device.

This is why another option studied consisted in reducing the chest impact with a car driver air bag fixed on the desk. A model of the bag and the inflator was elaborated and validated with drop tests [Hong, 2003] as follows: first of all, the velocity between the upper torso of the dummy (without restraint system) and the desk was evaluated from high speed video analysis. The drop tests were performed by impacting the inflating air bag with a body block submitted to similar kinetic energy (figure 3a). Forces, acceleration and pressure measurements allowed the adjustment of the input
parameters of the air bag model (figure 3b) by comparison between the calculated and measured values. Figure 3c shows the comparison between the real and digital body blocks velocity.

![Image](image1.png)

(a) Drop tower test  (b) Virtual drop test  (c) Impactor Velocity

**Fig. 3 - Drop tests performed (a) to validate an air bag model with the FE code Radioss ® (b) and comparison between measured and computed impactor velocity (c)**

The tuned air bag model enabled testing by means of computer simulation of the effect of parameters such as position of the bag on the desk, orientation and inflating time on the level of protection afforded. The protection had to be achieved while preserving visibility and ergonomics criteria. The optimal configuration identified by simulation has been tested with a sled test. (figure 4).

![Image](image2.png)

**Fig. 4 - Comparison of experimental sled tests with air bag against virtual (one frame every 50 ms)**

Test and simulation results underline a significant decrease in injury risk to the chest, as it is shown on figure 5. Values of biomechanical criteria for neck and chest are also lower, compared with sled tests without air bag (see table 2).

![Image](image3.png)

**Fig. 5 - Comparison of the driver chest deflexion with and without air bag**
Table 2 - Biomechanical criteria measured on a real dummy in sled tests with air bag

However the mechanical loadings applied to the legs remain high due to an impact with the desk structure: a possible improvement would consist in the addition of cushioning materials to reduce the aggressiveness of the impacted surface.

CONCLUSION

When a collision occurs between a train and a heavy goods vehicle at a level crossing, the train driver is exposed to a high injury risk. Consequently, after such a collision the driver is unable to help the passengers for the evacuation of the train. The identification of the injury causes and the effectiveness of protection devices have been addressed in an approach mixing experiments and simulation. The injury risk is quite high with a regular train seat without restraint device because the train driver is unbelted. Thorax, abdomen and femur loads are quite high. The implementation of a car air bag allows the damping of chest impact and the addition of cushioning materials could be a possible improvement to reduce the aggressiveness of the impacted surface by the legs.

The estimation of the injury risk was obtained with the Hybrid III dummy but no local injury risk assessment is possible for the abdomen; for the head, HIC is designed to estimate skull fractures, especially when there is direct contact between the head and another object, but there is no criterion to evaluate diffuse brain injury risk. It would be useful to adapt crash test dummy and biomechanical criteria to railway situations, especially to evaluate the risk of abdominal injuries.

Several parameters were fixed in this study: only the seated position of the driver was assessed; the influence of the size of the driver on the kinematics was not analyzed: in all the tests, the driver substitute was a 50th percentile.

The technologies and methods developed for the passive safety improvement in the automotive world can be used for the protection of train occupants with limited adaptation. It is now time to carry this research to European level and come up with specific recommendations for trains: regulatory and acceptability issues must be addressed before the implementation of restraint systems in trains.

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