# RELATION BETWEEN ACCELERATION, INTRUSION AND PASSENGER LOAD IN LATERAL COLLISIONS - RESULTS FOUND THROUGH NON SOPHISTICATED SIMULATION MODEL

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## ABSTRACT

A one-dimensional, four-mass model was used to investigate tendencies of several parameters on passenger acceleration in a motor vehicle struck from the side. The passenger is represented as a single mass. The parameters are the speed, the rigidity of the external structure of the striking and of the struck vehicle, the hardness of the interior door cushioning, the thickness of the door, and the distance between passenger and the interior door cushioning upon initiation of the collision.

## INTRODUCTION

Until now, little attention has been paid to the lateral collision, in comparison with the work done with frontal collisions (1). There are several reasons for this:

1. The frontal collision is the most common type of accident, with the highest rate of injury. The focal point of such study, however, could now well shift to the lateral collision, especially in view of improved safety belt application.

2. Due to the small path of deformation, the possibilities of reducing loads on the passenger are less favourable than with the frontal collision. The possibilities which do exist are very expensive.

3. The definition of the lateral collision is more complex than that of the frontal collision.

4. The knowledge of vehicle characteristic values is necessary for mathematical simulation. These values are, however, only available to an insufficient degree.

Precisely because the possibilities for reducing the dangers of a lateral collision are limited, it is necessary to optimize the coordination of the most important parameters. First of all in this regard, one may gain basic knowledge of the relationship between lateral rigidity, intrusion, and loads on the passenger.

The basic relationships and the necessary direction of future effort have become apparent in the simple vehicle model for simulation of the lateral collision described below.

## DESCRIPTION OF THE MECHANICAL MODEL

The accident situation investigated is shown in Fig. 1. The striking vehicle has the velocity $v_0$, and the struck vehicle is standing still. The longitudinal vehicle axis of the striking vehicle intercepts the center of gravity of the struck vehicle, as well as the resulting impact force. The two vehicle longitudinal axes are positioned perpendicularly to each other.

Fig. 2 shows the simulation model. The entire mass $m_f$ of the frontally-striking vehicle is supported over a massless spring with a modulus of elasticity $C_F$. In addition the constant braking force $F_{RF}$ is effective over the tires. The mass of the laterally-struck vehicle is included in $m_S$, with the exception of the mass of the door, $m_t$. The door mass $m_t$ is supported directly against the vehicle mass over a spring with modulus of elasticity $c_S$ combined with a damper. The distance between the exterior metal door surface and the interior door cushioning is indicated by $d_o$. The interior door cushioning has modulus of elasticity $c_p$. The passenger is simulated by the single mass $m_J$, which is located at distance l from the interior door cushioning. The movement of the passenger's head is not considered in the construction of this model. The passenger support due to seat friction is simulated by the constant frictional force $F_{JS}$. The struck vehicle is also supported over a constant frictional force $F_{RS}$. All springs have a linear path of force characteristic. The modulus of elasticity of all springs during expansion is greater than that during compression by the factor of 100. Nearly fully plastic behavior is thereby simulated. The model is suitable as well for simulation of a lateral impact onto a rigid obstacle.

## CHOICE OF THE PARAMETER VALUES

A special problem is involved in determination of the spring modulus of elasticity, especially for the vehicle side and for the interior door cushioning, since there are only a few investigative results available in this area (2), (3). Side rigidity is in modern vehicles closely related to vehicle mass. For this reason, three vehicle masses (L = light, M = medium, S = heavy) were used, with equal frontal and lateral rigidity in each case. By means of combination of vehicle masses "light against heavy", or "heavy against light", the influence of various lateral rigidities can be investigated in spite of the predominant influence of the mass. The value for the thickness of the door is likewise linked to the mass of the vehicle. The parameter values choosen are given in table I.

| Vehicle | Mass [kg] | Characteristic of front and lateral Structure $C_F, C_S$ [$10^5$ N/m] | Width of Door $d_0$ [cm] |
|---|---|---|---|
| L | 870 | 6.1 | 10 |
| M | 1100 | 7.7 | 15 |
| S | 1400 | 9.8 | 20 |

| | | | |
|---|---|---|---|
| Distance between | | | |
| Passenger and Door - Padding | $l$ | [cm] | : 2, 5, 8 |
| Cushioning of Padding | $c_P$ | [N/m] | : 7, 10, 13 |
| Velocity | $v_0$ | [m/s] | : 7, 10, 13 |
| Friction | $F_{RF}, F_{RS}$ | [N] | : 7000, 8800, 11 200 |
| Mass of Door | $m_t$ | [kg] | : 5.5 |
| Value for Damping | $\varphi_t$ | [NS/m] | : 2000 |
| Coefficient of Seat-Friction | | | : 2.0 |

| | | |
|---|---|---|
| ILM TU-Berlin | Values of Parameters | Table I |

RESULTS OF CALCULATION

Fig. 3 shows the typical progress of the acceleration, velocity, and path of the single masses with respect to time. The maximum value of passenger acceleration was selected for evaluation of the results. The variation of the parameters has revealed two essential limiting qualities for the magnitude of the passenger acceleration: the relationship of frontal and lateral rigidity, and the rigidity of the interior door cushioning. Fig. 4 shows the passenger acceleration with respect to the penetration depth of the door for the various vehicle mass combinations. The further parameter values are $v_0$ = 13 m/s, $c_p$ = 7 · $10^5$ N/m, and l = 5 cm. Clearly apparent is the rise in acceleration with decreasing lateral rigidity of the external structure. If the light vehicle with its low lateral rigidity is struck by three different heavy vehicles, then the value for $a_J$ doubles from the most favourable combination "light against light" up to the most unfavourable combination "heavy against light". With the heavy vehicle, the value of passenger acceleration increases only about 20% from the most favourable to the most unfavourable combination.

Although the mass influence predominates over the influence of lateral rigidity, one can see by means of analysis of the course of time-dependent curves that the level of acceleration for low rigidity results from the fact that the passenger is directly struck by the only slightly delayed front of the penetrating vehicle.

Fig. 5 shows once again all combinations of masses for three different rigidities of the interior door cushioning. One can see that only for the "light against heavy" and "light against medium" combinations does the passenger acceleration remain under 40 g, also for the smallest value given here, $c_p = 7 \cdot 10^5$ n/m. For the most unfavourable combination "heavy against light", the value is 50% greater and increases with greater cushioning hardness up to almost 75 g. Although the absolute numerical values may scarcely be compared with the usual limit values, the tendencies are recognizable. Fig. 6 shows how soft the cushioning would have to be for the most unfavourable combination "heavy against light" in order to maintain a value of acceleration comparably as favourable as for the most favourable mass combination. The necessary deformation path of the cushion then becomes 8 cm when the rigidity is $3 \cdot 10^5$ N/m.

The other parameters such as distance between passengers and cushioning, velocity, and door thickness show the expected, if considerably lesser, influences on the course of the collision. Only when the distance between passenger and cushioning is zero and the passenger takes immediate part in the comparatively low vehicle acceleration, do especially low acceleration values result.

## SUMMARY

The calculations with the simple model for investigation of lateral collisions have resulted in the following:

The most favourable loading values result when the lateral rigidity is sufficiently great to prevent the direct collision of intruding vehicle parts upon the passenger with barely reduced velocity. The thereby increasing relative velocity between vehicle and passenger and possible load peaks would have to be compensated for by means of a thick and relatively soft interior door cushioning. The other parameters have considerably lesser significance.

It must be borne in mind that the movement of the head itself was not simulated in these investigations. The basic findings of this investigation should be examined by means of a more sophisticated model which also allows for the evaluation of head movement and loading.

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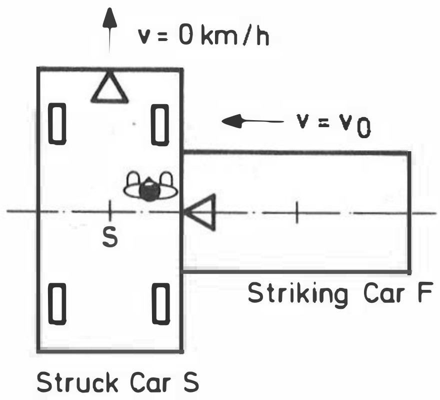


Fig. 1: Situation of Impact

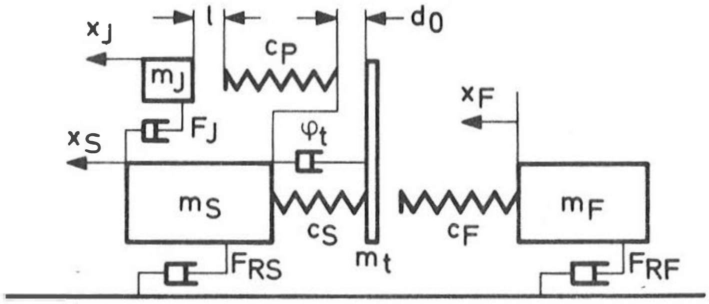


Fig. 2: Mechanical Model

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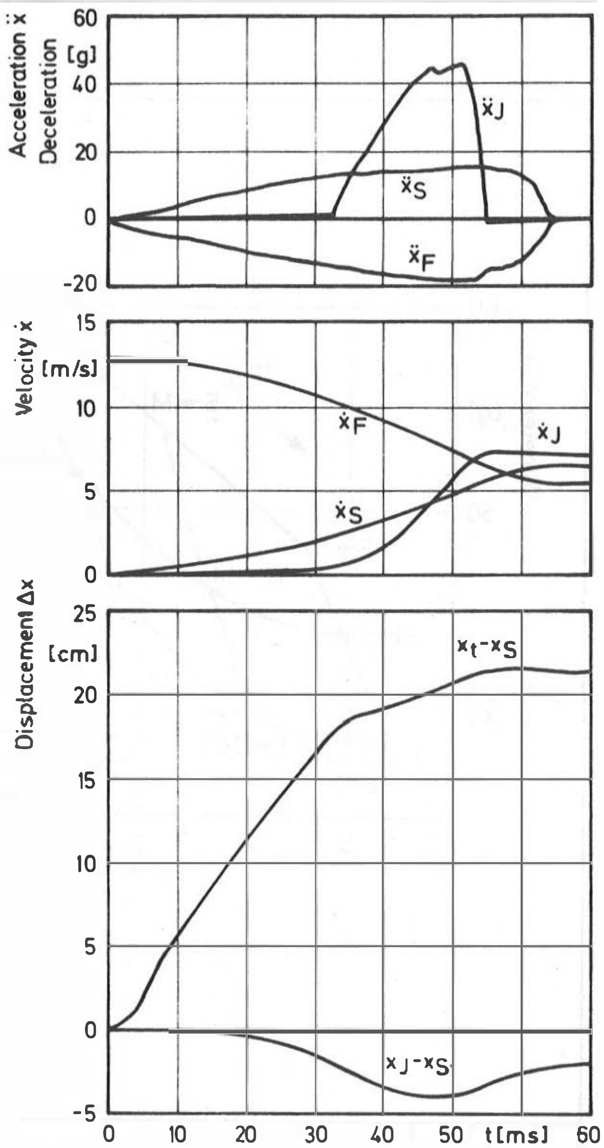
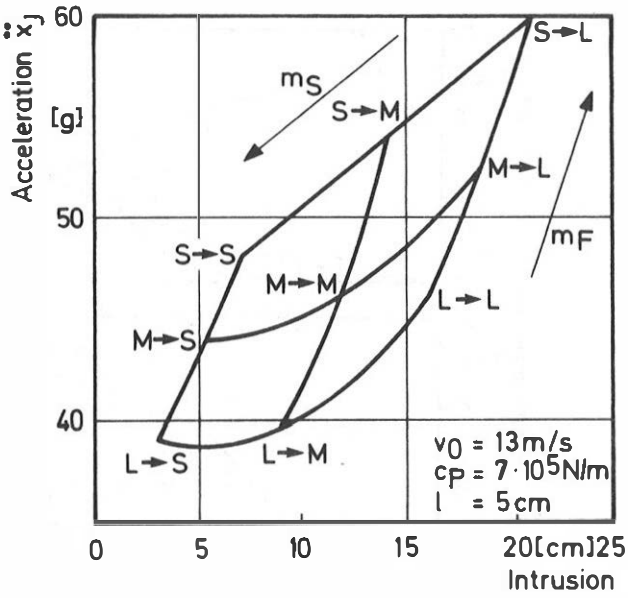



Acceleration, Velocity and Displacement depending on Time

Fig. 3




| ILM TU-Berlin | Passenger Acceleration depending on Intrusion andMass-Combination | Fig. 4 |
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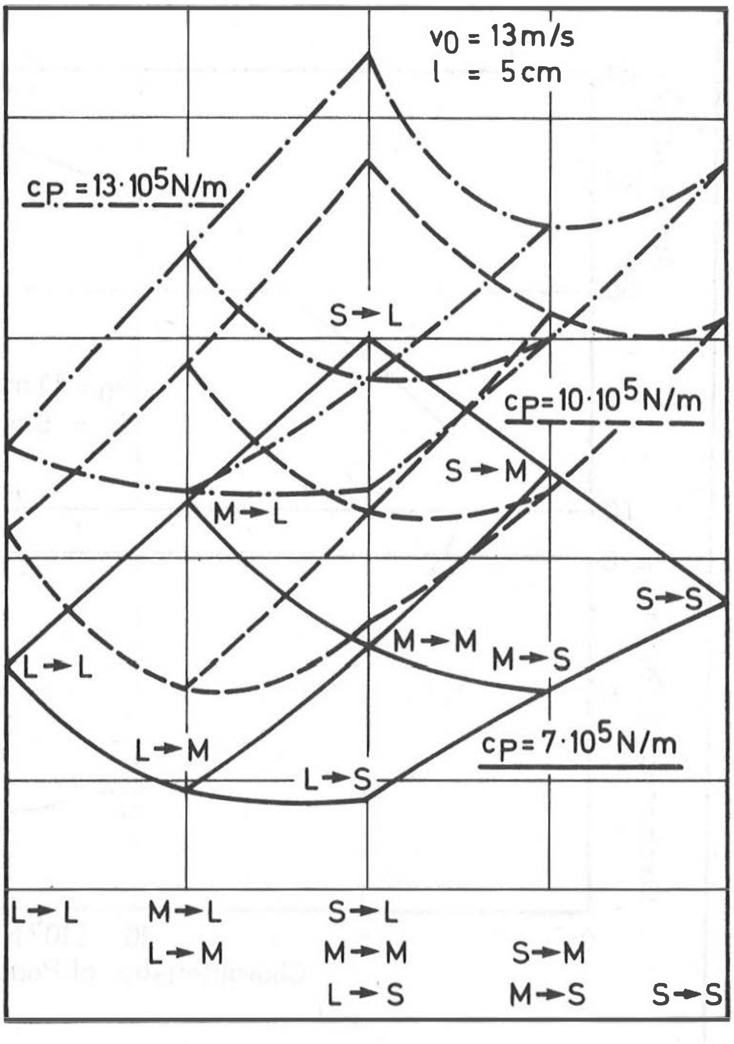


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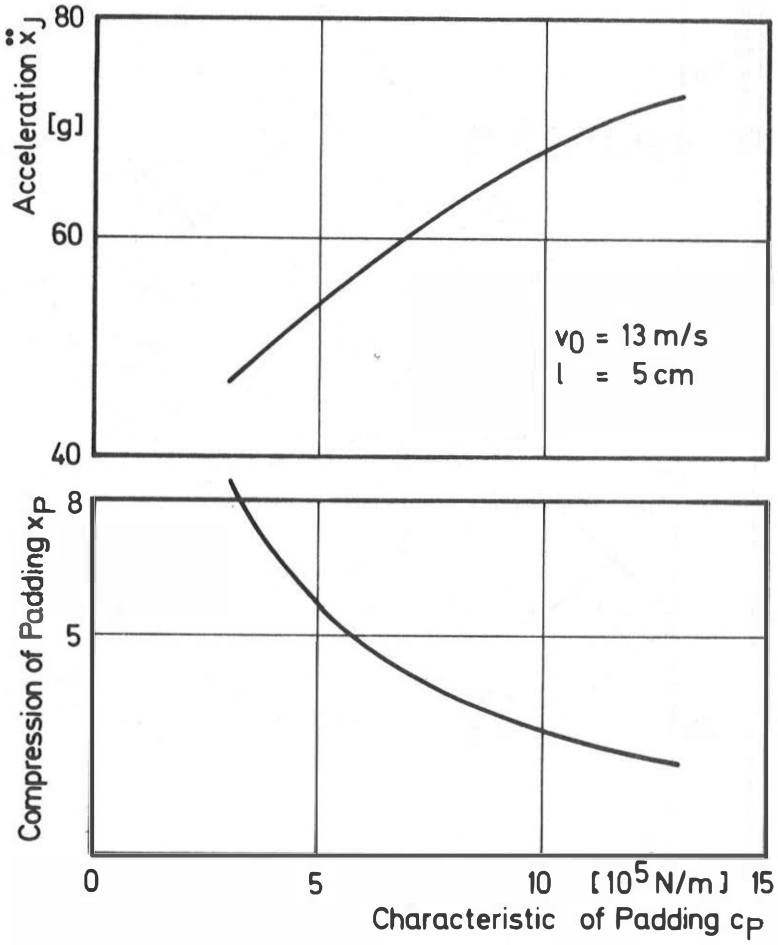
| ILM<br>TU-Berlin | Passenger Acceleration depending on Mass-Combination and Padding-Characteristic | Fig. 5 |




| ILM<br>TU-Berlin | Passenger Acceleration and Compression depending on Padding-Characteristic | Fig. 6 |
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