EVALUATION OF PROTECTION CRITERIA BY COMBINING RESULTS OF COMPUTER AND EXPERIMENTAL SIMULATION WITH RESULTS OF ACCIDENT INVESTIGATION

by

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ABSTRACT

Nowadays, limit values of mechanical quantities which are measured with dummies are used as passenger protection criteria during development and design approval tests on vehicles. These limits are based mainly on experiments with animals or corpses.

A method which shows a direct relationship to real accident phenomena is applied to validate the biomechanical limit values which, up to now, are only roughly or partly known. In this method, correlations between passenger stress values and the severity of injuries in real accidents are determined for passengers wearing safety belts in frontal and lateral collisions on the basis of Equivalent Accident Characteristics by experimental tests, simulation calculations and statistical evaluation of carefully documented real accidents. The relationship between the severity of injuries and the mechanical load thus obtained enables the relevant dummy protection criteria to be determined in a simple manner while taking into account predetermined injury criteria (e.g. AIS 3). It becomes clear that the method for the validation of protection criteria presented here can be extended in depth (with regard to the method) as well as in latitude (with regard to other types of accident) by the combination of

- experimental and computer simulation and of
- real accident data.

INTRODUCTION

Up to now, the method used in evaluating measures for improving the crashworthiness was to demonstrate a reduction of dummy

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loading in experiments. Conclusions deduced from these, can, however, only be of a qualitative nature since:

- experimental tests are, as a rule, only carried out for a certain range of accident severity (e.g. frontal barrier impact with v_{impact} = 50 km/h), in order to be able to make comparisons

  and

- the legally prescribed protection criteria /1,2/ are only defined by their limits (e.g. Head Injury Criterion HIC = 1000) (Fig. 1).

Present-day biomechanics research involves, apart from aims such as the explanation of accident mechanisms or the development of realistic dummies, the definition of suitable injury criteria according to type and severity, as well as the determination of corresponding protection criteria. In this, the limit values, which are mainly based on component tests on living animals and human corpses, characterize the probability of a certain injury (Fig. 2).

With respect to the state of knowledge achieved at present, this still being unsatisfactory, however, the conclusion was reached that two aspects must be taken into account in all cases:

1. the living human being, and
2. the real accident situation.

This state of affairs is largely respected in the relation between the severity of injuries of human occupants of vehicles and the mechanical loads on mathematical passenger models as will be described in the following contribution, in which the causal relationship between the real accident events and computer simulation as based on experiments is established.

THE METHOD OF EQUIVALENT ACCIDENT CHARACTERISTICS

This method, which is applicable to all imaginable types of accident, as long as these can be simulated on a computer, has already been described in /3/ and /4/. In /5/ and /6/, first results concerning frontal and lateral collisions were described, so that only the essential aspects of the method are to be explained here (Fig. 3).

The dummy loading , DL, determined by simulation, is compared to the injury severity AIS (Abbreviated Injury Scale) on the basis of the Equivalent Accident Characteristics, which describe the severity of certain types of collision.

EXPERIMENTAL AND CALCULATED SIMULATION. It would be financially impossible to carry out tests for determining the dummy loading through the whole range of realistic accident severity, so we must limit ourselves to a few such tests, which then, however, form the basis for the calculated simulation. The load on the mathematically described vehicle occupant is determined in the case presented here using the TUB mathematical models ICMF+) for frontal collisions and ICMS+) for lateral collisions, only frontal collisions being considered in the following.

In order to adapt the computer model, acceleration-time curves of sled- and crash tests carried out by the VOLKSWAGENWERK AG are used as a basis, in that computer results, also in the form of acceleration-time curves, are fitted to the experimental results by suitable variation of the model parameters.

Calculations in the realistic accident severity range are based on the assumption of various initial conditions.

THE EQUIVALENT ACCIDENT CHARACTERISTIC describes the accident severity and combines all the values relevant to loading and injury. Since these are used as a basis for comparison both in simulation and in the field of real accidents, (Fig. 3), the possibilities of application of certain elements are limited due to accident data which cannot be specified. For this reason, in a frontal collision, the speed change Δv is still given as a criterion, although we know (e.g. from /7/), that the mean cell-deceleration has an influence on the accident severity and thus on the dummy loading, which is by no means unimportant. In addition to this, the intrusion could also be a relevant accident severity parameter.

ACCIDENT ANALYSIS. The investigation of accidents is based on approximately 9000 analyzed car-to-car collisions, the material being obtained from the HUK-Verband. For frontal collisions without offset, we have a total of 318 cases of occupants wearing safety belts, partly from the above-mentioned source and partly from additional accident research material obtained from the Unfallforschung MHH/TUB (Accident Research Organization - College of Medicine, Hanover/Technical University,Berlin). From this material we deduce the dependence of the injury severity

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+) ICMF/S: Insassen-Crash-Mechanik-Rechenmodell für Frontal-/Seitenkollisionen (Occupant-Crash-Mechanical-Calculating Program for Frontal/Side Collisions) on the Equivalent Accident Characteristic.

THE RELATIONSHIP BETWEEN THE DUMMY LOADING AND THE SEVERITY OF THE INJURY is determined by the elimination of the Equivalent Accident Characteristic (Fig. 4). The limit curves given indicate the scattering encountered in the accident analysis. This is due, on the one hand, to the limitation of the accident characteristics to "accessible" parameters, and on the other hand, to a larger extent, to the scattering of the "internal" parameters, such as age and constitution of the passengers, their position before the accident, vehicle-specific characteristics, intrusions, among other factors. The scatter described by the upper and lower limit curve embraces 90% of all cases in our evaluation, which will be described in more detail later, and can therefore be regarded as very wide.

SPECIAL FEATURES OF THE METHOD AND POSSIBILITIES OF IMPROVING THE PROCEDURE

The difference of this method to others lies in the fact that it does not have the determination of the human limits of tolerance as its aim, but that it opens up the possibility of correlating dummy loading values to the severity of injury of injured vehicle occupants, this correlation even being possible particularly in the subcritical range.

The method of Equivalent Accident Characteristics described here differs from the biomechanical procedures which have become known recently in the following aspects (Fig. 4):

1) A fundamental factor in the simulation process is computer simulation and extrapolation with the aid of mathematical models;
2) The experimental simulation is merely of a supporting nature;
3) Determination of the Equivalent Accident Characteristics as a criterion for the accident severity and as a link between simulation and accident occurrences.
4) Statistical preparation and utilization of as wide a range of accident material as possible;
5) Presentation of the relationship between the severity of the injuries and the dummy loading.

PROBLEMS AND POSSIBILITIES OF SOLVING THEM. When one looks more closely at this list of characteristics of the method presented, one can already recognize the weak spots; these can be reduced, however, at least in part:

As stated above, this method in its present form can be used for all kinds of accident. However, if computer simulation is not possible for reasons of model characteristics, essential advantages of the method are lost (at the Institut für Fahrzeugtechnik only two-dimensional models are used in all cases). Yet even when using two-dimensional simulation models, some questions relating to the representativeness of the simulation of the accident occurrences remain unanswered. The following points should also be mentioned:

- only a few tests are available, especially in the higher accident severity range;
- modelling of only one occupant (in accordance with the 50% dummy) and of only one specific vehicle (geometry of vehicle interior and safety belt system, seat construction etc.);
- as opposed to a real accident situation, one assumes a non-deformable occupant cell in the simulation;
- at the moment a head/steering wheel impact cannot be simulated;
- to what extent does the dummy represent the occupant as regards motion sequence?

Work is being carried out at the moment to try and find a solution to the problems indicated here as regards the simulation models, but at the same time one should not fail to mention that it is proving very difficult to provide appropriate test data. Limitations are placed on any attempt to assimilate the motion sequence of the modelled and mathematically described occupant on the one hand and the human occupant involved in the accident on the other hand by the fact that, using the occupant simulation model, the data obtained from the tests are used for calculation on the basis of the dummy used. By analysing carefully documented accidents, with regard to points of impact of the occupant, and comparing the simulation calculation, however, insight could be gained into the future design of dummies.

But even accident analysis as a whole entails problems which can exert an as yet largely unknown influence on the results:

- limits to the number of accidents which can be evaluated, especially within the higher accident severity range;
- reliability of information concerning estimation of speed and the independent and unambiguous determination of the degree of severity of injury;
- method in which multiple injuries are compiled (OAIS or ISS);

- magnitude of the influence of unknown occupant- and vehicle-specific parameters;
- statistical processing of the accident material available:

  a) arithmetical mean value for each group of characteristic classes

  b) introduction of a discrete distribution function according to the AIS-scale and correction of the inhomogeneous accident data.

Whereas a solution of the points first mentioned will have to remain to be solved in the near future by introducing new actual accident data, a satisfactory solution of the problem of the statistical preparation is emerging at present. Processing of the accident material obtained is characterized by the following method /6/ (Fig. 5):

- presentation of individual injuries in relationship to the Equivalent Accident Characteristic,
- division into characteristic classes of equal size,
- probability distribution and distribution function for each characteristic class,
- correction of the accident data by application of a discrete distribution (binomial distribution),
- retransformation, and
- presentation of the severity of the individual injuries as a function of the Equivalent Accident Characteristic.

The form of presentation achieved in this manner now contains only statistical quantities which characterize the qualities of the injury/characteristic relationship (mean value curve, 5% and 95% limit curve).

In order to illustrate the process described above in more detail, the last step, i.e. the elimination of the accident characteristic, is to be carried out according to the method used in determining the relationship between the injury severity and the dummy loading. Figure 6 shows the comparison of the results obtained from the accident data, which are subject to some degree of scatter, and the simulation calculation, each calculated dummy loading value (here HIC) being classified under the corresponding discrete AIS distribution. By introducing a level - here, for example at HIC = 1000 - the probability distribution of the degree of injury severity for a certain dummy loading can easily be determined and illustrated in an easily understood manner (Fig. 6).

PRESENTATION OF THE RESULTS

The discovery of the aforementioned problem complexes will not, however, cause this promising method to be abandoned at the stage which has now been reached. On the contrary, the necessity, but also the possibility of improving the method and of solving those problems which can be overcome should be pointed out here. In order to counteract the impression that the installation of the EAC method has only lead to the uncovering of problems, the results obtained up to data are to be presented in the following:

In Figure 7, the dummy loading HIC obtained by computer calculations, and the severity of individual injuries AIS_{head} for a frontal collision are compared as a function of the speed-change Δv, in accordance with the schematic representation given in the description of the method (Fig. 4). By eliminating the characteristic Δv, the correlation of the results of the simulation calculation and of the accident analysis is obtained. The relationships between the injury severity and the dummy loading are given for the thorax and for the pelvis in Figure 8.

With the aid of these relationships, protection criteria and load limits can be shown in a simple manner:

By assuming a tolerable injury level of AIS 3 and
a tolerance level of AIS 6

for the human being, we obtain the appropriate protection criteria and loading limits, which are interesting on the one hand for their relationship frontal collision-lateral collision and on the other hand for their relationship to the protection criteria valid at present (Table 1).

It can be observed in lateral collisions that the head only tolerates a fraction of the load which would be tolerated in a frontal collision. The application of the present-day protection criterion (HIC = 1000) corresponds to the tolerable injury level in a frontal collision, whereas in a lateral impact, even the tolerance level would be far exceeded.

In the case of the thorax, the protection criterion (SI = 1000) is obviously too high even for frontal collision, since a distinctly lower SI value corresponds to the injury criterion.

Finally, in the case of the pelvis, the injury criterion and the protection criterion (60 g) for frontal collisions correspond. In the case of a lateral impact, much higher values (120 g) are obviously permissible with present-day dummies.

Dummy loading	Injury severity	
Frontal collision	AIS 3	AIS 6
head HIC	930	1.635
chest SI	500	990
pelvis max a_{res} (g)	59	74
Lateral collision	AIS 3	AIS 6
head HIC	205	425
chest SI	435	625
pelvis max a_{res} (g)	123	142

Table 1: Correlation between Dummy Loading and Degrees of Injury Severity for Frontal and Lateral Collisions

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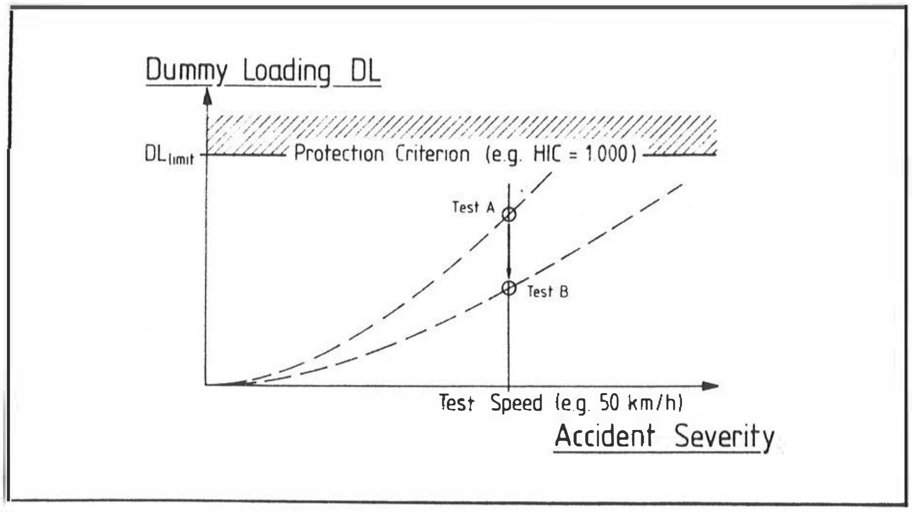


Fig. 1 - Results of Tests for Assessment of Safety Measures of Motor Vehicles

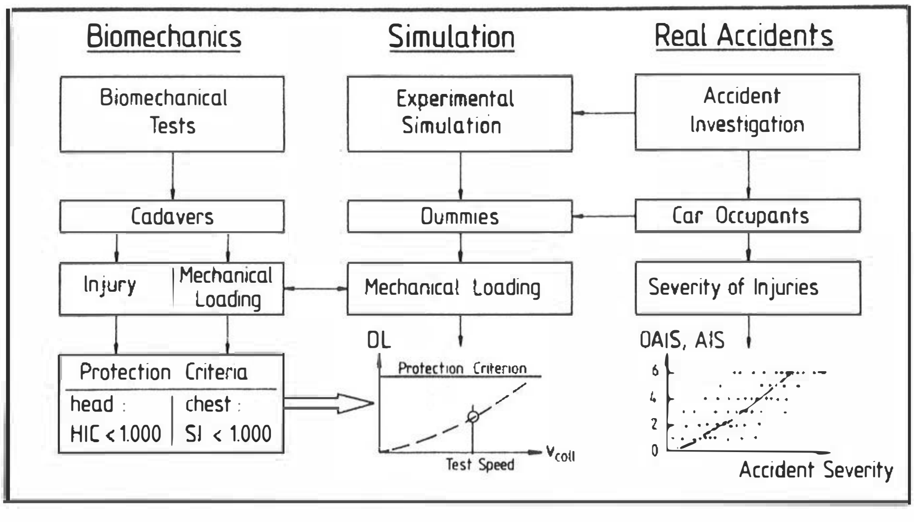


Fig. 2 - Determination and Application of Dummy Protection Criteria - Actual Situation

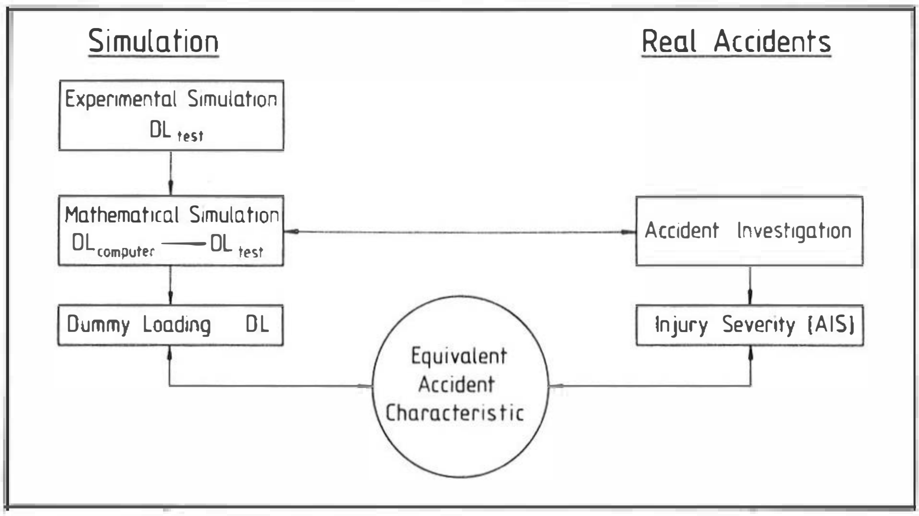
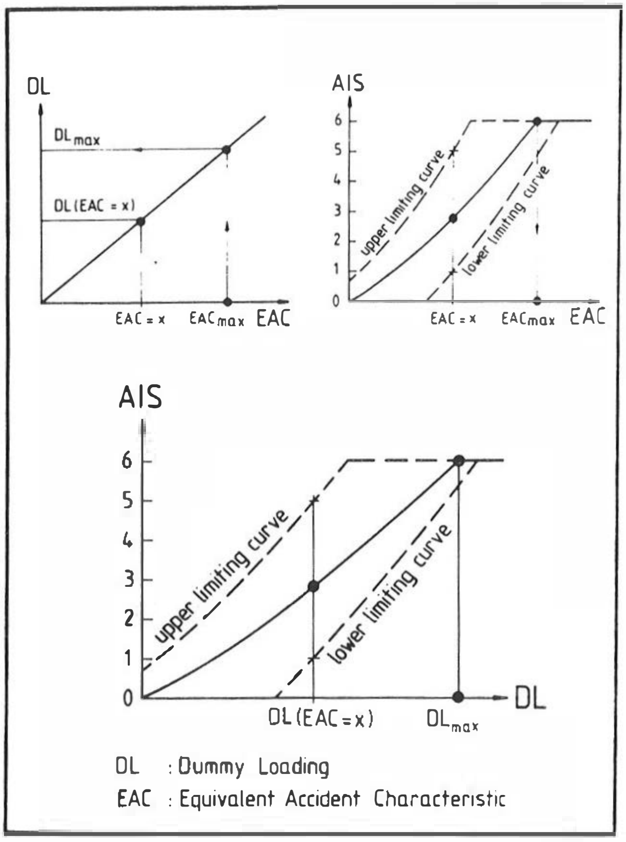


Fig. 3 - Equivalent Accident Characteristic - the Connection of Simulation with Real Accident

Fig. 4 -

Relation between Dummy Loading and Injury Severity Evaluated by Elimination of EAC



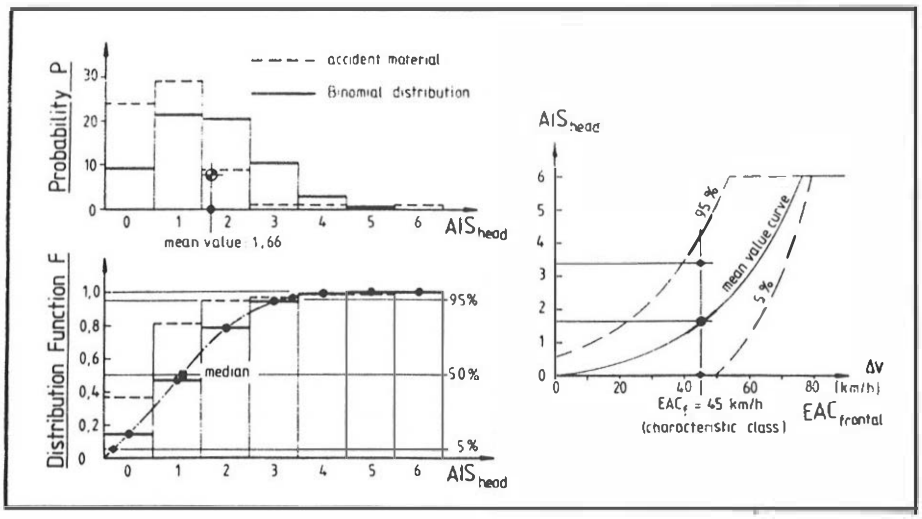


Fig. 5 - Distribution of Injury Severity and Adaptation by Use of Binomial Distribution

Fig. 6 -

Distribution of Injury Severity at HIC = 1.000 (head, frontal car coll.)

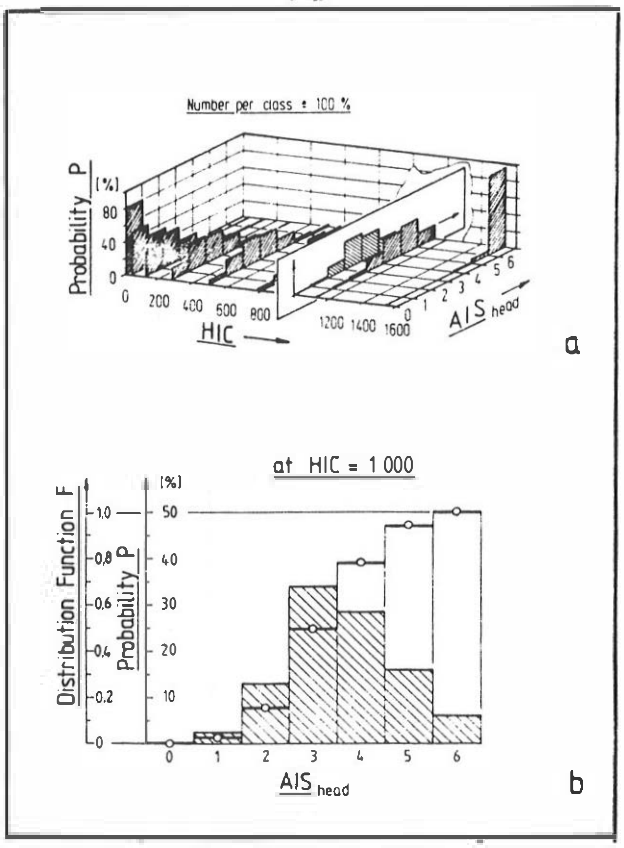


Fig. 7 -

Dummy Loading and Injury Severity (head) - Frontal Car Collision

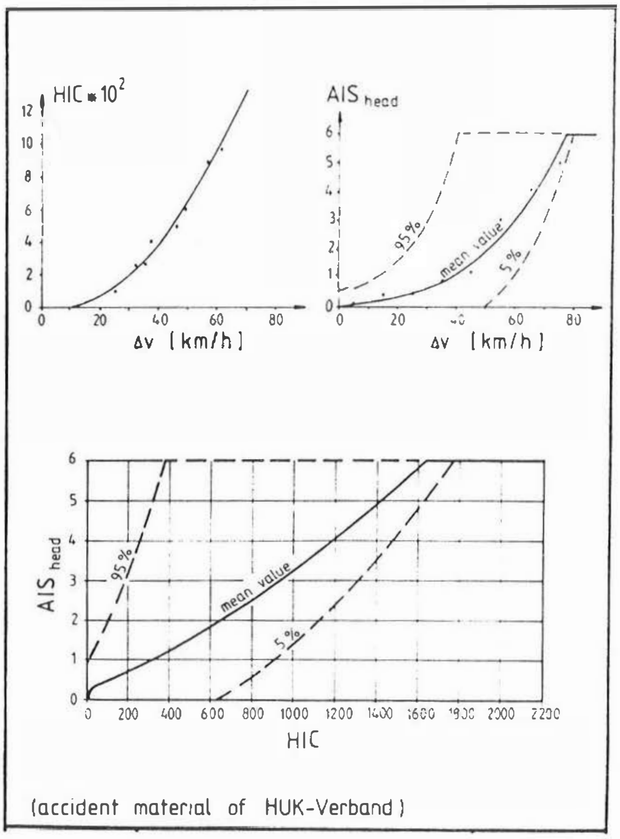


Fig. 8 -

Dummy Loading and Injury Severity (chest and pelvis) Frontal Car Collision