ADVANCED ENERGY ABSORBING COMPONENTS FOR IMPROVED EFFECTIVENESS OF LOW MASS VEHICLE RESTRAINT SYSTEMS

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ABSTRACT

Given an adequate structural design, low mass vehicles can exhibit a level of passive safety comparable to their heavier counterparts, even in frontal crashes against vehicles twice their mass. The high car mean acceleration levels (50 g) and Δv (20 m/s) observed in such collisions demand for an optimisation of their restraint systems. It has been shown in earlier tests that especially the distance between chest and steering wheel, which is defined by ergonomical constraints, is insufficient in a low mass vehicle under these crash circumstances. The steering wheel must therefore yield during the crash, preferably through an energy absorbing mechanism. The belt system must in return allow for an increased forward displacement of the occupant without intolerable belt force levels.

Optimisation of the key components of such a restraint system is solvable only with the extensive use of computer simulation in combination with single component tests and sled experiments. A restraint system meeting the occupant protection requirements is presented. In sled tests, a collision with a Δv of 77 km/h was simulated, yielding tolerable injury protection criteria for the Hybrid III 50 % dummy.

LOW MASS VEHICLES (LMV) are expected to have a rising significance in future urban traffic concepts, since they generate less pollution and also require less space. Such a development will only take place if the passive safety level of LMV's is comparable with the standard encountered in conventional cars. An aggravating fact is that, at least in the early phase of the introduction of LMV's, these vehicles will most likely collide with heavier cars and not - as assumed in almost all of today's testing standards - against one of their kind [APP72].

If the structural stiffness of a low mass vehicle lies slightly above the stiffness of its heavier counterpart in a frontal collision, the integrity of the passenger compartments of both vehicles can be preserved. This has been shown in earlier publications [KAE95]. In a frontal collision between a compact car with a mass of 1200 kg and a low mass vehicle (600 kg), both cars moving at a speed of 14 m/s (50 km/h), the smaller car will experience a Δv of approximately 20 m/s. Since there is only a limited deformation zone available in the LMV, high car mean acceleration levels are to be expected in addition to the high Δv. A small part of the crushing zone of the larger car will also be available for the deceleration process of the LMV, thereby extending the crushing zone of the LMV to a tolerable length [NIE93]. Early tests with a very stiff LMV structure crashed against an Audi 100 have shown that the larger car could even absorb practically the whole kinetic energy of the LMV without danger to its own passenger compartment. In order to achieve the lowest possible car acceleration level for the LMV, however, a deformation of about 300 mm of the LMV's front structure is allowed in a design currently under development in our working group.

The collision circumstances described above require, in addition to an adequate structural design, a highly optimised restraint system. Especially for the driver's chest, the ride-down distance must be increased to prevent a contact between the thorax or abdomen with the steering wheel rim. The protection criteria can only be met if such an additional space is provided, e.g. by a deformable or retracting steering column. The characteristics of the steering column, the airbag, and the belt system must be adapted to each other, thus creating an optimisation problem. We will outline the methods used for such an optimisation as well as discuss the obtainable results in sled tests.

BASIC CONSIDERATIONS

COLLISION CIRCUMSTANCES - Figure 1 shows, schematically, deceleration pulses during an impact on a rigid barrier with an initial velocity of 15.5 m/s for a LMV in comparison to a typical compact car. Deformations in this example would be in the range of 300 mm for the LMV vs. 800 mm for the Compact Car.

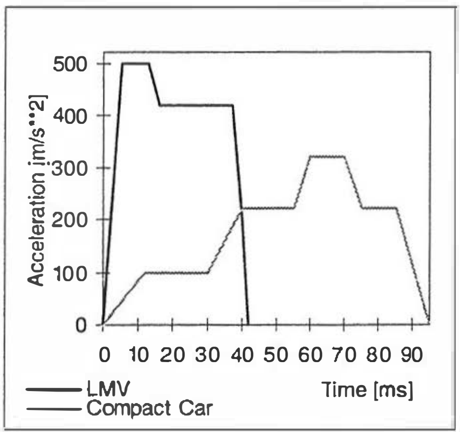

Figure 1: Schematic representation of the deceleration pulses of a typical Compact Car and a LMV against a rigid barrier at 15.5 m/s (56 km/h).

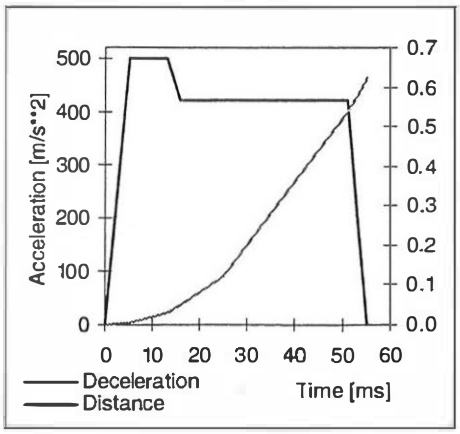

Figure 2: Estimated deceleration pulse and distance traveled by the center of gravity of a LMV during a frontal collision against a car with twice the mass of the LMV, both cars at a initial velocity of 14 m/s.

A collision against a car with a higher mass and only slightly lower structural stiffness (both cars with an initial velocity of 14 m/s) will yield deceleration levels in the same range (between 40 and 50 g), but the duration of the pulse will be significantly longer, since the LMV, due to its low mass, experiences a total change in velocity of about 20 m/s. The total ride-down distance for the LMV (the sum of the deformation of the LMV plus the amount of deformation space provided by the larger car) is 600 mm in the example shown in Figure 2.

OCCUPANT RIDE-DOWN DISTANCES - Using the estimates for the crash pulse shown above plus the interior geometry of the car, the theoretically available ride-down distances for the driver of a LMV can be derived.

In an ideal environment, the occupant would be rigidly coupled to the car at the beginning of the collision, and would thus only experience the deceleration of the car structure, which rarely exceeds tolerable levels. In reality, an initial time delay of 15 - 20 ms before any restraint system becomes effective cannot be avoided. During this time, the body picks up speed in relation to the car. In a LMV, the consequences of this effect are much more serious, since car decelerations rise much faster due to the stiff structure, e.g. the occupant (with no restraint systems active) moves relative to the car with a velocity of 6.2 m/s after 15 ms as opposed to 0.9 m/s for the compact car example in Figure 1. The displacement of the occupant is 40 mm vs. 8 mm. These considerations clearly show that, by providing some additional space in the car interior, some of the disadvantages of the LMV can be alleviated.

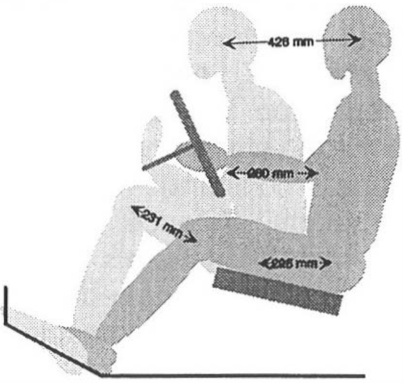

Figure 3: Available deceleration space for the driver (50 percentile HIII Dummy) of the LMV currently under development. Initial (dark gray) and maximum forward (light gray) position during the crash..

DEFORMABLE STEERING COLUMNS - Deformable or actively retracting steering assemblies have been discussed by [HOR91], [POH77], and others. However, such systems were primarily intended to counteract a possible intrusion of the steering column and to prevent or soften a head or chest contact in cars with no airbag [GLO74]. In addition to this, the steering column of a LMV must act as a restraint system component in itself, e.g. absorb energy and help to make sure that all of the available deceleration space is used as effectively as possible.

An actively retracting steering column, either pyrotechnically or mechanically activated, requires no force interaction between the driver and the steering wheel. While fulfilling its purpose of providing more free space in front of the driver, it does not help much to absorb the driver's kinetic energy. The airbag, still in the inflating process while the steering column retracts, must be larger and more aggressive to guarantee its effectiveness. Such systems have been implemented in production cars.

A passive system, where the steering column is compressed under the reactive forces from the airbag or directly by the occupant, can be constructed in a way that it helps to absorb energy [HOR91]. The deformation occurs only after the airbag is inflated and already in contact with the driver, thus allowing more of the available ride-down space to be effectively used by the restraint system. Figure 4 shows the basic parameters that have to be taken into consideration.

The mass and geometry of the impacting body are those of the 50-percentile Hybrid III dummy. Since the airbag inflation process is concluded before the torso is in full contact with the airbag, the properties of the gas generator can be neglected for a first approximation. Only the initial volume and pressure, and the (pressure dependent) outflow of gas through the exhaust vent(s) and the airbag fabric are taken into account. The deformation element, finally, is defined by the available deformation distance x_d and the force level F_d at which deformation occurs (the element has purely plastic properties and exhibits rectangular force-deflection characteristics, e.g. it is stiff until a defined force is exceeded, whereupon deformation starts and the reactive force remains constant). The maximum deformation distance is limited by geometrical constraints of the cabin interior; in the example discussed here, about 100 mm can be obtained.

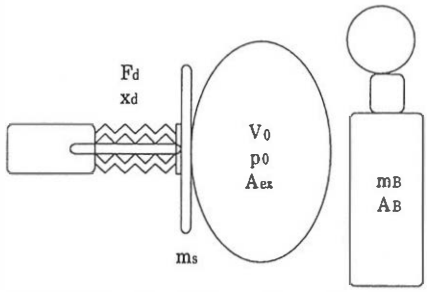

Figure 4: Basic parameters of a the combination of a passively deforming steering column with an airbag: Force level F_d and useable length x_d of the deformation element, mass m_S of the steering wheel (including airbag module and moving part of the steering axle), initial volume V_0, initial pressure p_0, and exhaust orifice area A_{EX} of the airbag, mass m_B and cross-sectional area A_B of the impacting upper part of the occupant's body.

The force exerted on the steering wheel support is dependent on the momentary pressure in the airbag, which (if exhaust vent properties are given) depends mainly on the velocity of the torso relative to the steering wheel and the area of the airbag already in contact with the torso. This force reaches its maximum in an early phase of the deceleration process, where the torso has made full contact with the airbag but still moves with a high velocity. It is therefore essential that F_d is lower than this maximum. Otherwise, the deformation will not occur before the airbag is fully deflated and the torso (or the head) makes contact with the rim. Such a contact is to be avoided.

BELT SYSTEM - The use of a belt system is essential if occupant protection criteria are to be met in a collision as described above. A conventional 3-point belt system will generally not allow an occupant forward displacement further than the position shown in Figure 3 with tolerable belt force levels, unless a webbing with a very high elongation factor (e.g. 25 %) is selected. A more efficient way to provide additional elongation is the use of belt load limiters. Such devices have already been discussed in the 70's [WEI78], [WAL76], [KEI74]. Although a number of different designs were patented, these devices have never found wide acceptance, probably since they were considered obsolete through the introduction of airbags. In view of the demands for further optimisation of the restraint systems in frontal impacts, load limiters have been investigated [NIL95] and introduced again recently in some European cars, e.g. [REN95].

The difference between a soft webbing material and a stiff webbing plus load limiter is depicted in Figure 5. The latter is preferable since belt forces are built up more rapidly, thus preventing the increase of relative velocity between occupant and vehicle at the earliest possible point in time. The energy absorption capabilities of the two systems are comparable up to a relative elongation of 14 %.

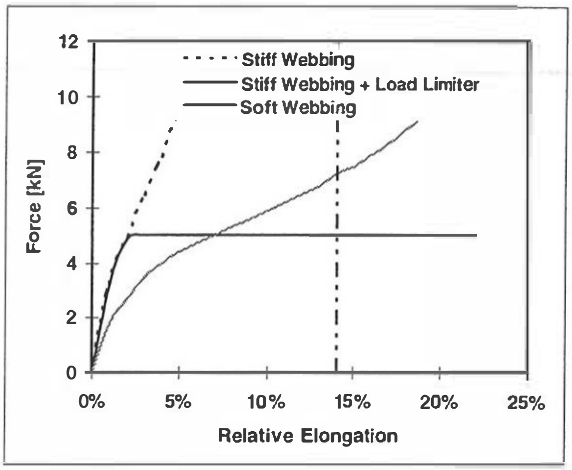

Figure 5: Typical Force-Elongation curves for a stiff (5%) and a soft (22%) webbing elongation factor, and a stiff belt coupled to an ideal load limiter. The vertical line shows the point where both the soft webbing and the stiff webbing with load limiter have absorbed the same amount of energy (0.6 kJ per meter belt length).

EXPERIMENTS AND MODELS

BELT LOAD LIMITERS - Various ideas for the construction of belt load limiters have been presented and evaluated [WAL80],[BEZ79]. The use of such a device in an experimental environment proved to be difficult, because most of the available devices did not offer the required pullout of 300 mm for the shoulder belt part. Moreover, they depend on force-limiting parts such as torsion rods, whose characteristics are difficult to alter without effort, e.g. for parameter variation experiments. It was therefore decided to use the principle shown in Figure 6. A stainless steel strip with thickness d is pulled over a rotating rod with radius R in the direction of the large arrow. The energy is converted into heat through plastic deformation of the strip. The force limiting level is defined by width, thickness and the material properties of the steel strip, and the rod radius R. Any length of pullout can be achieved. For the experiments, stainless steel with a thickness of 2 mm was used. The maximum pullout was 400 mm.

The mass of the steel strip plus belt attachment hardware is ~ 0.6 kg. During the crash, this mass has to be accelerated to the relative velocity of the occupant in a very short time. A dynamic overshoot to a load level about 20 - 30 % higher than measured in quasi-static tests must therefore be taken into account.

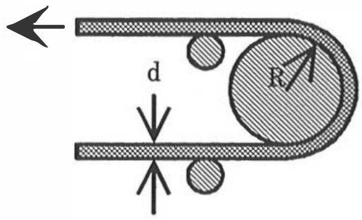

Figure 6: Principle of the force limiting device:

The dynamic behaviour of a belt segment coupled to a load limiter was explored using a pendulum impactor. The pendulum, featuring a cylindrical shape (r = 85 mm), impacted a loose belt segment of 1.24 m length at a speed of 7.1 m/s. For reasons of symmetry, two load limiters were connected to each end of the belt segment. The acceleration of the pendulum and the steel strips were measured as well as the belt forces at both ends of the segment (Figure 7). The force-elongation curves were obtained through integration of the pendulum acceleration. A pullout of 38 mm (left) and 35 mm (right) was observed at the load limiters. Accelerations of the steel strips were in the range of 1000 - 2000 m/s².

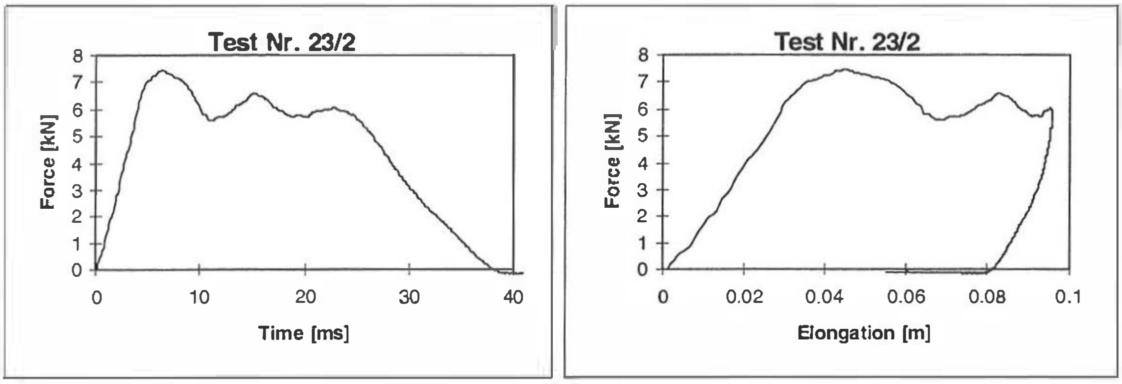

Figure 7: Belt force vs. time and belt force vs. elongation for a belt segment (length 1.24 m, 8 % characteristic elongation) connected at both ends to a load limiter (5.9 kN static test load level). The belt segment was hit by a pendulum impactor at 7.1 m/s (equivalent mass: 35.3 kg). The overshoot at the beginning of both curves is caused by the forces necessary to accelerate the steel strip and attachment hardware.

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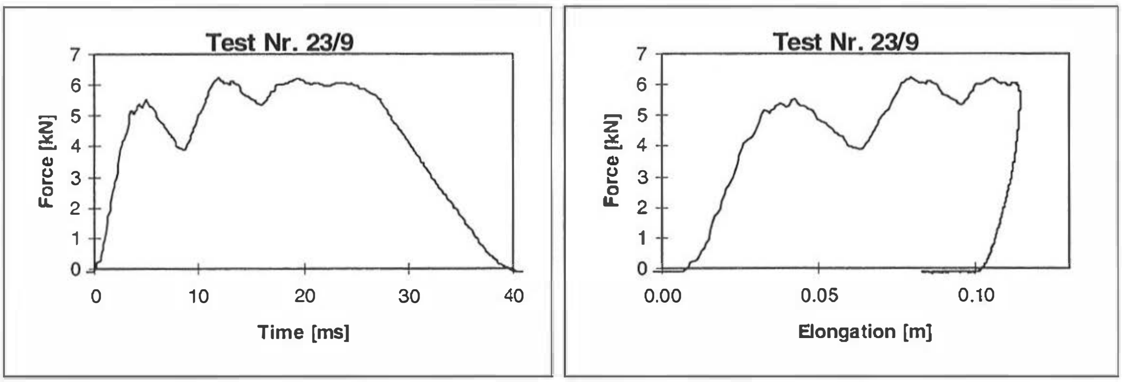

Figure 8: Improved load limiter (static test load level: 5.25 kN) with first 30 mm of the steel strip cut narrower. The overshoot at the beginning is a little over-compensated. By varying the width of the steel strip over its length, arbitrary force-elongation characteristics can be obtained.

TORSO IMPACT EXPERIMENTS - As mentioned above, matching the characteristics of the steering column deformation to those of the airbag is crucial for an improved effectiveness of the restraint system. An experimental setup where the parameters of these two components can be studied isolated from the influence of the other parts of the restraint system, e.g. belts, seat, knee bolster, was therefore conceived. Body block impactor tests are used widely to asses the properties of the steering assembly and are also part of the legislation (e.g. FMVSS 203). For the evaluation of a steering column-airbag system, such tests with an unarticulated body block which only marginally resembles the shape of a human torso were considered too inaccurate. The chest, neck, and head of a Hybrid II (Part572) dummy were therefore used. The abdomen of this torso was filled with foam (DOW 82-35-2) in order to provide enough cross-sectional area between torso and airbag. The total mass of the torso is 26.8 kg. In its centre of gravity, an attachment was added that allows hooking the torso to an accelerated pendulum. A pendulum impactor's final speed normally depends only on its initial height, which is at maximum twice its length; by coupling an additional weight of 350 kg at a distance of 0.8 m from the pivot (pendulum length = 3.5 m), the speed can be increased up to 18 m/s when equipped with a dummy head only and 13 m/s when equipped with the torso. When the pendulum reaches its lowest point, the torso is mechanically decoupled from the pendulum and impacts the airbag in free flight on a horizontal trajectory.

The steering column is constructed using an axis guided through a deformation element (precrushed aluminum honeycomb) and held by a translational ball bearing. The assembly was mounted on a steel rig that allows variation of the steering column angle and height. An open airbag module[1] with an inert gas generator was fitted to the steering wheel. The airbag inflation was performed using a blower (300 m^3/h at 450 mBar (7.5 kW)) connected to the airbag through a flexible pipe (Ø ~50 mm).

Three impact tests were performed using a 35 l Eurobag and five tests using a 64 l full-size Airbag. Steering wheels and airbag modules were taken from the production series for German cars. Impact speeds, steering column elevation angles, airbag exhaust vents, and deformation elements were varied. Dummy chest and head accelerations, steering column acceleration, and airbag pressure were recorded. In addition, the impacts were captured at 1000 frames/s on 16 mm film. The tests using the 35 l Eurobag showed that, at an impact velocity of 6.0 m/s, the chest will hit the lower part of the rim even with low force levels of the deformation element. These tests will not be further discussed, since the 35 l bag does not offer the energy absorption capabilities required by the severe collision circumstances mentioned above. The results of the other five tests are summarized in Table 1

[1] The sled tests presented in this study were sponsored through a collaboration with PARS GmbH, Alzenau, Germany. The steering wheels and airbag modules used here were production types manufactured by MST GmbH, Aschaffenburg, Germany; the airbags were modified with respect to their exhaust vents.

No	Angle [°]	Def. Force [kN]	Speed [m/s]	Head/Chest max. Accel. [m/s²]	Deformation [mm]	Comments
1	30	1.5	6.1	110/313	110	contact with rim
2	30	1.5	6.1	50/255	110	contact lower part of rim
3	15	1.1	5.0	81/98.7	109	original orifice Ø 60 mm
4	15	1.0	5.0	68/84	108	two orifices Ø 42 mm
5	15	1.1	5.0	58/80	108	two orifices Ø 42mm

Table 1: Five tests were performed using a 64 l airbag. The exhaust vents in the last two tests were altered in a way that they would not interfere with the steering wheel rim. Their total area was kept constant. The lower steering column elevation angle in tests 3..5 demands a lower force level of the deformation element.

The head and chest accelerations measured in these tests were far below the levels encountered in a real crash situation, because the dummy torso, once it has been decoupled from the pendulum, experiences no further acceleration, whereas in a real situation, forces introduced by the car deceleration (in the range of 400 - 500 m/s^2) still act on the torso. This could - in theory - be compensated for by increasing the mass of the torso by a factor of 40, or by increasing its initial velocity. The former is obviously unpractical, whereas the latter would lead to an unrealistically high force being transmitted by the airbag onto the steering column. The velocity was therefore selected in a range which was expected to coincide with the relative velocity of the occupant vs. the inflated airbag in a real crash situation. No direct conclusions should therefore be drawn from the observed accelerations to protection criteria in a real situation.

MATHEMATICAL MODEL AND OPTIMISATION OF STEERING COLUMN AND AIRBAG PARAMETERS - In parallel to the experiments, a mathematical model of the impact test has been developed using the 3-D rigid body program MADYMO (Version 5.1.1) for the torso and the steering column assembly and the FE-Module of the same program for the airbag. The inflated airbag mesh was generated by a pre-simulation of the inflation process, defining a gas generator with constant mass flow similar to the blower used in the experiments. The 50 % Hybrid II MADYMO dummy database was modified by removing the lower body parts and the lower arms, and by adding ellipsoids in the chest region for a better representation of the contact area between airbag and torso. Preliminary runs, using the geometry, material properties, and exhaust orifice definition of the 64 l airbag, showed that for steering column deformation thresholds above 1.5 kN, a contact torso-steering wheel was to be expected. Stiffer deformation elements were therefore never used in the tests.

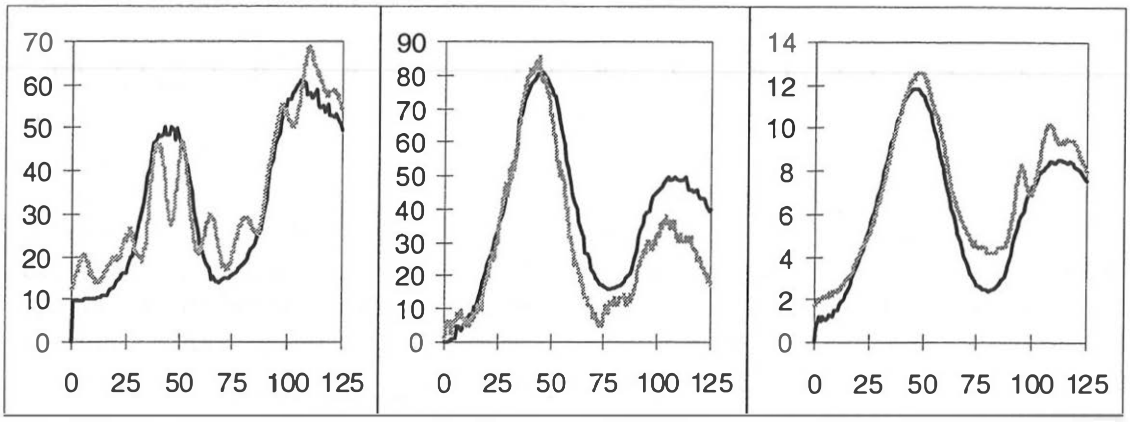

Figure 9: Resulting accelerations [m/s^2] vs. time [ms] of the head (left) and chest (center), and airbag gauge pressure [kPa] vs. time [ms] (right) measured in test no. 4 (gray) and simulated (black). The correlation is satisfactory.

After completion of the tests, the mathematical model was validated using the measurement results of tests 4 and 5. A good correlation was found between experiment and model. The characteristic twin-peaked shape of the curves in Figure 9 clearly shows the effect of the moving steering column: After the torso has made full contact with the airbag (t = 40 ms), the force exerted on the deformation element exceeds the threshold and the column begins to move. Accelerations decrease due to this movement, and increase again as the deformation space is used up. By varying the deformation threshold and the exhaust orifice area, the shape of these curves can be brought to an optimal point where both peaks have approximately the same height and the gap in between is as small as possible, thereby guaranteeing a continuous deceleration at the lowest possible level. Since the values obtained in these experiments cannot directly be linked to injury protection criteria, further optimisation is difficult since no target functions are available. The model parameters and set-up were therefore copied to the simulation model of the complete restraint system for further optimisation.

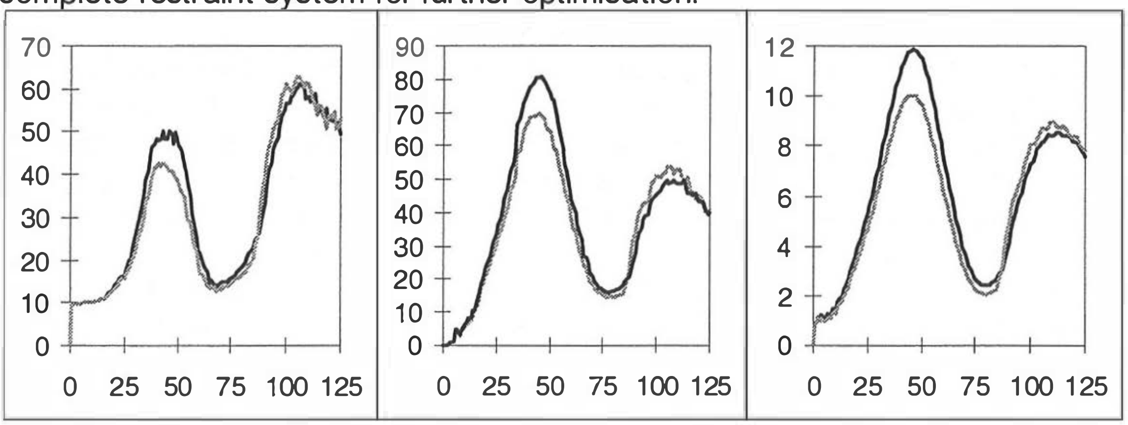

Figure 10: Resulting accelerations [m/s^2] vs. time [ms] of the head (left) and chest (center) accelerations, and airbag gauge pressure [kPa] vs. time [ms] (right) for two different configurations. Increasing the airbag exhaust orifice area and decreasing the deformation threshold yields a lower initial peak (gray curves). A value of about 30 cm^2 exhaust orifice area and 800 N deformation threshold were selected for the optimised curves (gray).

OPTIMISATION OF THE COMPLETE RESTRAINT SYSTEM - In parallel to the experiments and simulations described above, a mathematical model of the complete driver restraint system for the LMV currently under development in our working group was developed using MADYMO (Version 5.1.1). Several hundred simulation runs were performed, in order to find optimal settings not only for the airbag, steering column, and shoulder belt system parameters but also for those of the lap belt, seat pan, knee bolster, and foot pan. A complete description of this modeling and optimisation process is beyond the scope of this paper; we will discuss only the parameters of the upper body restraint system here.

Steering column deformation threshold [kN]	3
Shoulder belt char. elongation [%]	8
Shoulder belt load limiter level [kN]	5.5
Airbag exhaust orifice Ø [mm]	50
HIC	568
Head acceleration (3ms) [m/s²]	597
Chest acceleration (3ms) [m/s²]	480
Sternum compression [mm]	45

Table 2: Optimised restraint system parameters and theoretically obtainable occupant protection criteria values results for the upper body restraint system.

Earlier studies [KAE95] have shown that the parameters for the upper body restraint system have only little influence on the measurements of the lower body parts, and vice versa. Table 2 outlines the parameter values found after the optimisation process. These values represent a local minimum found in the parameter space during optimisation; to obtain these results in a sled test would require all the restraint system components and other experimental parameters (e.g. deceleration pulse) to work exactly as modeled, which can rarely be achieved. In a real test, the results will invariably be higher than this minimum.

SLED TESTS AND MODEL VALIDATION - In a series of 5 sled tests, the performance of the systems discussed above was evaluated. The experiments were performed on a hydraulically accelerated sled (HyGe principle) at the test facility of PARS GmbH, Alzenau, Germany. A test rig implementing the interior geometry of the driver position in a LMV was constructed. The rig has a very stiff structure, thus simulating the case where, in a real crash situation, no cabin deformation or intrusion would occur. The parameters for the belt load limiters, the steering column deformation threshold, and the airbag exhaust orifices were selected according to Table 3. For practical reasons, always the same type of airbag module, gas generator, and steering wheel was used. In tests S001 - S003, the effective exhaust orifice area was about 30 % less than specified, since the orifice was - unintendedly - partly obstructed by the steering wheel rim.

Test No.	S001	S002	S003	S004	S005
Max. sled acceleration [g]	47.5	48.5	47.9	49.6	52.0
Δv [m/s]	21.4	21.4	21.5	21.6	22.1
Shoulder belt load limit [kN]	5.9	6.2	5.25	5.9	6.2
Steering column threshold [kN]	3	3.5	3.1	3	3.9
Airbag exhaust [mm]	Ø 60	Ø 60	Ø 60	2 x Ø 42	2 x Ø 36
HIC	949	916	999.5	1232.1	1059.7
Head acceleration [g]	71.8	67.1	76.2	71.8	79.1
Chest acceleration [g]	64.6	64.8	63.7	66.3	67.7
Sternum compression [mm]	51.0	47.7	48.2	46.9	49.1
Shoulder load lim. pullout [mm]	200	200	235	227	177
Steering col. deformation [mm]	110	112	113	110	112

Table 3: Upper body restraint system parameters and measurement results for the sled tests

Results are summarized in Table 3. The injury protection criteria were considerably higher than predicted by the (unvalidated) model. However, only the chest acceleration was slightly above limits in all tests. The head injury criterion was exceeded in two tests, while all other criteria were well within limits in all experiments.

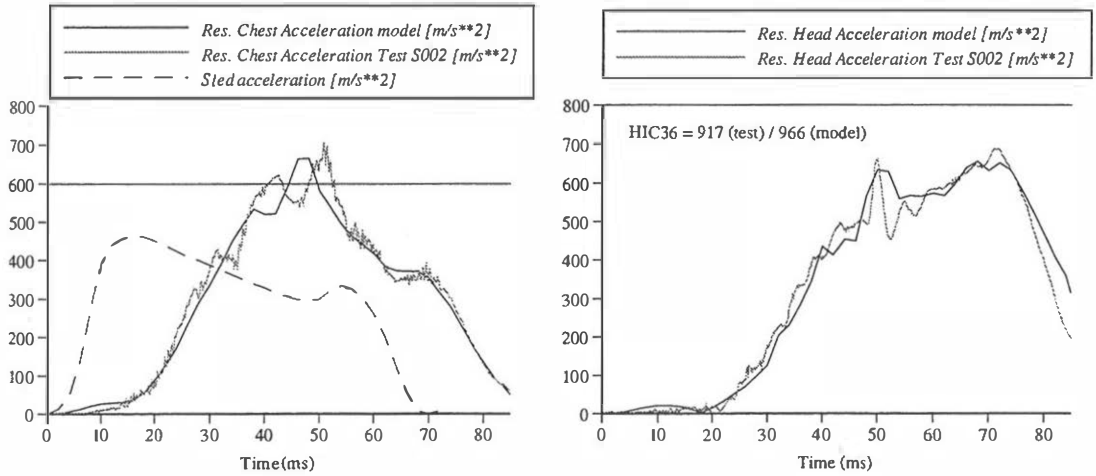

Figure 11: Head and chest resulting accelerations measured in test no. S002 (gray) and in the model (black).

While the steering column deformation element was always compressed to the maximum, pullout of the shoulder belt load limiter was below the predictions. Some 300 mm would be necessary for the dummy torso to exploit the full ride-down distance. The belt forces measured during the tests were considerably higher than expected; this caused the high chest accelerations. The MADYMO-model of the sled setup was validated by the results from the sled experiments and including the findings from all component tests. The correlation between model and experiment is satisfactory, as shown in Figure 11. Further simulations with the validated computer model show that the load limits could be lowered to 4 kN and the airbag exhaust vent area could be increased by about 10 % with no danger of a head contact to the steering wheel. In a followup series of two sled tests, these parameters were applied to the restraint system, yielding much better results as shown in Table 4.

Test No.	S006	S007
Max. sled acceleration [g]	51.2	49.6
Δv [m/s]	20.5	20.5
Shoulder belt load limit [kN]	4.5	4.0
Steering column threshold [kN]	3.5	3.5
Airbag exhaust [mm]	2 · 42	2 · 44
HIC	686	480
Head acceleration [g]	58	58
Chest acceleration [g]	59	61
Sternum compression [mm]	39	47
Shoulder load lim. pullout [mm]	280	340
Steering col. deformation [mm]	112	60

Table 4: Restraint system parameters and results of the last two sled tests.

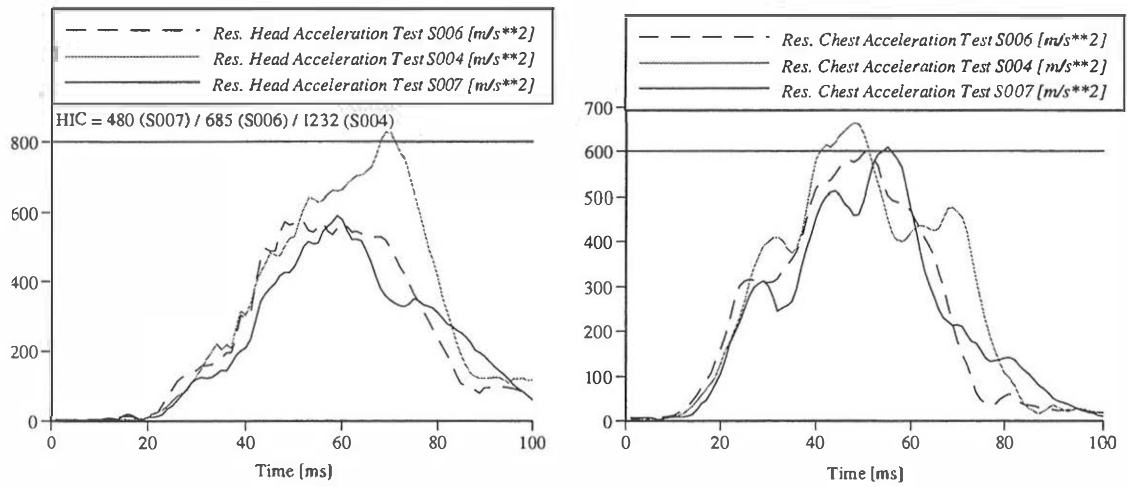

Figure 12: Head and chest resulting accelerations measured in tests no. S002, S004, and S007. The restraint system parameters varied only slightly between the first two experiments. In the last test (S007), belt load limiter levels were lowered to 4 kN, and the airbag exhaust vent area was increased. The stiffness of the restraint system is now adequate. A defective steering column in test no. S007 caused a contact of the chest and the steering wheel rim, which explains the peak in the corresponding chest acceleration curve.

CONCLUSIONS

The development of restraint system for low mass vehicles that could meet occupant protection criteria even at a Δv of 21.5 m/s (77.4 km/h) and car mean deceleration levels of 400 - 500 m/s^2 has been shown to be feasible. These results can only be obtained if the conventional belt and airbag system is augmented by additional devices that help absorb the occupant's kinetic energy and provide more effectively useable ride-down space. Such single devices have already been investigated or even produced. However, an adaptation of load limiters (especially with respect to pullout), airbags (exhaust orifice area) and steering columns (available deformation space, threshold) to the specific situation encountered in low mass vehicles as well as an investigation of their complex interactions is mandatory.

Further optimisation and tests are needed in order to lower the injury protection criteria values, and to investigate the performance of the restraint system with respect to different occupant sizes and weights, e.g. 5th to 95th percentile drivers.

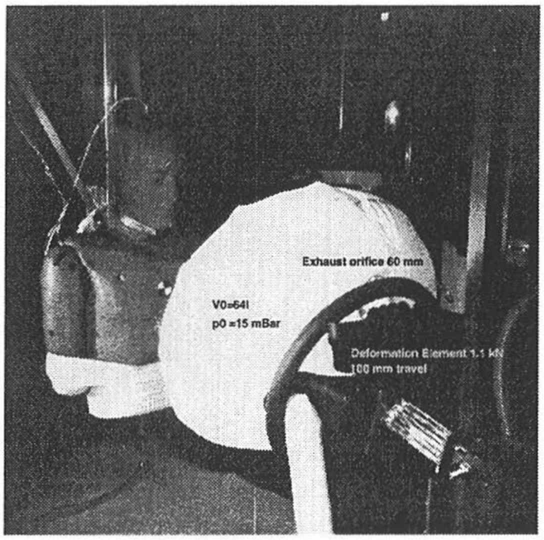

Figure 13: Experimental setup for the torso tests. The vertical position of the dummy torso was selected such that the prolonged steering axis would intersect with the dummy neck. This coincides with the seating position and the expected airbag contact position as shown in Figure 3. The exhaust orifice (Ø 60 mm) is partly covered by the steering wheel rim, thus reducing the available exhaust area by about 30 %.

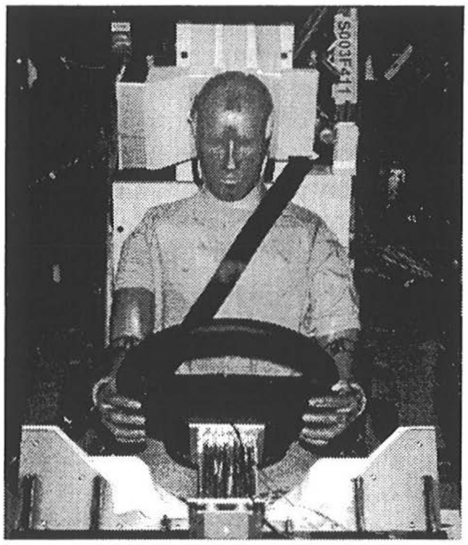

Figure 14: Sled test rig and 50 % Hybrid III dummy pre test S003. 3.1 kN threshold for the deformation element (bottom center) and 5.25 kN for the shoulder belt load limiter (top right) were selected.

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