MISFUNCTIONS OF SAFETY BELTS UNAVOIDABLE AND AVOIDABLE INJURIES

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PROBLEM

The effectiveness of safety belts has been demonstrated in numerous papers, firstly in the "classical" investigation of Bohlin (1), recently e.g. by Danner (2). Bohlin shows an average reduction of injury frequency of 48%, see Fig. 1. Danner found about the same average injury reduction. For severe head injuries he found even a 75% reduction, in contrary for cervical spine injuries an increase of 21%. Bohlin's injuries are related to all impact types, Danner's only to frontal impacts. A change and reduction of injuries has also been stated on the basis of a comparison of 100 frontal collisions with and without belt usage (3), see Fig. 2.

The aim of this paper is to discuss factors affecting the seat belt performance in frontal collisions, the most frequent and severe collision type. In-depth analyzed accidents are investigated with respect to the observed misfunctions of the belt system. Misfunctions, probably affecting the belt efficiency, may be caused by the construction of belts, the handling of belts, or by reasons induced from "outside". This classification enables furthermore to distinguish between unavoidable and avoidable "belt-specific" injuries (4, 5), whereby it is out of discussion that these injuries are mostly on lower or at least equal AIS level than the injuries of non-belted occupants in comparable accidents. The corresponding probability was given by Beier (6) in the order of 99%.

THE STRUCTURE OF THE SAMPLE

Our sample consists of altogether 255 belted occupants. The accidents were investigated from 1972 up to now on the scene by multidisciplinary teams* in Berlin and in Hannover and its environs. Criterion for the inclusion of an accident is that at least one occupant of the car - belted or not - is injured.

The distribution of the involved belted occupants to the impact directions is given in Fig. 3:

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frontal impact	160 occupants
side impact	60 occupants
rear impact	17 occupants
rollover, top, roof	12 occupants
other	6 occupants
	255 occupants

For describing the accident severity and the representativeness of the frontal collisions in Fig. 4 115 out of the 160 occupants, the accumulative frequency of the velocity Δv is shown and compared with results of Hartemann et al (7) and of Walz (8, 9). The 50% value is 32 km/h. Fig. 5 demonstrates the scatter of the injury severity versus Δv. At the same speed change of 12 m/s equivalent to 43 km/h extreme cases could be observed, fatal as well as lower injury severity.

This paper deals only with the 148 injured three point belted occupants of frontally impacted cars. Dropping the AIS 0 and AIS 1 injured occupants, only 38 occupants remain. They were divided into two groups, occupants wearing 3-point-static-belts and 3-point-automatic-belts (ELR, emergency locking retractor) respectively (see Fig. 3):

frontal impact, AIS $\geq$ 2:	
3-point-automatic-belt	22 occupants
3-point-static-belt	16 occupants
	38 occupants

BELT MISFUNCTION TYPES

The extreme scatter of Fig. 5 shows that the figure of Δv is insufficient to demonstrate "car related collision severety". The type of crash pulse (high or low deceleration level), specific collision conditions (e.g. intrusion, overload), and specific conditions of the occupants (e.g. size and age) influences the OAIS at the same Δv. Furthermore, scatters of OAIS are primarily related to the way of seat belt effectiveness in single cases. High or low belt effectiveness can be caused by a poor seat belt design as well as through wrong belt handling by the user.

Parameters, negatively influencing the effectiveness of the belt system, can be called "Misfunctions of Belt Systems". The following classification seems to be possible:

1. Design misfunctions (see Fig. 6)

   - belt geometry (e.g. lap belt angle)
   - belt characteristics (e.g. belt broke)
   - length of the buckle part
   - film spool effect
   - stiffness of seating
   - mounting of the seat

- characteristics of the dashboard in the knee contact area
- intrusion of the steering column

2. Handling misfunctions (see Fig. 7)

- seating position forward**
- belt slack in the lap or shoulder belt**
- position of the lap or shoulder belt**
- inclination of the back rest

3. Induced misfunctions (see Fig. 8)

- velocity level
- intrusion
- overload
- tear out of anchor points
- mislocation before impact
- fire

This classification of misfunctions enables us to analyze avoidable and unavoidable ones; furthermore, it clarifies possibilities for preventive measures. Injuries caused by design misfunctions can normally be prevented by the manufacturer. Injuries due to handling misfunctions can be avoided through information and education of the occupants. Injuries caused by induced misfunctions are normally not avoidable.

The combination of misfunctions results in typical motion sequences as

- excessive forward movement
- submarining
- excessive forward movement of the upper torso
- impacting against the belt-loops with excessive relative velocity

all these producing typical injury patterns of belt specific injuries (4).

MISFUNCTIONS OF AUTOMATIC AND STATIC THREE POINT BELTS

In 1975 Mackay's results (11, 12) were: "intrusion in the compartment is the most occuring compromising factor to belt performance" and "incorrectly positioned belts represent a particular threat to the abdominal area". Behrens et al (13) and Suren et al (14) found at the same Vehicle Deformation Index (VDI) a significantly higher OAIS level in case of misfunctions.

Our new results for the selected 38 cases with OAIS $\geq$ 2 are shown for the

- driver, three point automativ belt in Fig. 9
- driver, three point static belt in Fig. 10
- passenger, three point automatic belt in Fig. 11
- passenger, three point static belt in Fig. 11

Overall, 94 misfunctions were observed for the 38 occupants spreading up into

- 22 constructive misfunctions
- 33 handling misfunctions
- 36 induced misfunctions
- 3 age caused misfunctions

In the average, two misfunctions per passenger and case occured. The following most important misfunctions have been analyzed:

- intrusion	(18 out of 38)
- Δv to high	(15 out of 38)
- slack of shoulder belt	(13 out of 38)
- slack of lap belt	(11 out of 38)
- dashboard EA characteristics	(11 out of 38)
- position lap belt	(5 out of 38)

The lower dashboard represents a frequent cause of injuries, especially for the automatic-belted driver. The few cases "position lap belt" have all been very severe (AIS 5 or 6).

INJURY-INDUCING PARTS OF THE INTERIOR COMPARTMENT DURING THREE POINT AUTOMATIC AND THREE POINT STATIC BELT USAGE

In the classical investigation of Volvo (1) and a nowadays study of Saab (15) the injury inducing parts of the interior compartment in all collision types are evaluated. It is obvious that the importance of the steering column is reduced and that the windshield has almost no more influence (see Fig. 1).

Saab (15) stated that in many cases the belt system itself represents the limit of protection, in most cases however the contact to parts of the interior compartment. This result was also stated by Mackay et al (12). Injury inducing parts and points of the compartment for the belted 148 front passengers are shown in Figs. 12 - 15. For the driver with automatic belt as well as with static belt (see Figs. 12 and 13) the steering system, the lower dashboard, and the belt itself are the dominant injury causing parts. The driver with static belt suffers especially in the impact to the steering system more frequent and more severe injuries. This is supposed to be due to more belt slack and more forward displacement of the driver. For the front passenger (see Figs. 14 and 15) the belt itself is dominant in severe injuries, especially if the static belt is used.

UNAVOIDABLE AND AVOIDABLE INJURIES

Some 40% of the suffered injuries of belted occupants are caused by "Induced Misfunctions" and therefore seem to be unavoidable even with nowadays belt systems. Some 60% of the injuries are caused by "Constructive and Handling Misfunctions" and therefore seem to be avoidable to a great extent by a better design and better handling of belt systems. Special attention has to be paid to the lower dashboard, to the steering system and to the belt type.

With static belts the share of principally avoidable injuries drops to 50%. Due to more slack and the state of art being a few years behind static belts are worse compared to automatic belts.

CONCLUSIONS

1. The efficiency of belt systems is affected by misfunctions which can be classified into - design, handling, and induced misfunctions.

2. For injured occupants with an OAIS $\geq$ 2 level nearly all misfunctions appear; the distribution is -

constructive misfunctions	about	40%
handling misfunctions	about	50%
induced misfunctions	about	40%

3. Unavoidable are at least 40% of the injuries, avoidable are at maximum 60% of the injuries.

4. The most important misfunctions are intrusion, velocity, belt slack, dashboard EA-characteristics, lap belt position.

5. The static belt behaves much worse compared to the automatic belt.

6. No belt failed because of tearing, e.g. at run-through-, buckle- or anchor-plates as well as on seat frame contact points.

7. In 3 out of 255 cases the car burned.

8. For the driver, the contact with parts of the interior compartment is responsible for the protection limit, for the passenger the belt itself.

** The belt slack and the position of the belt are measured in the case car directly after the collision by means of a special manikin (16).

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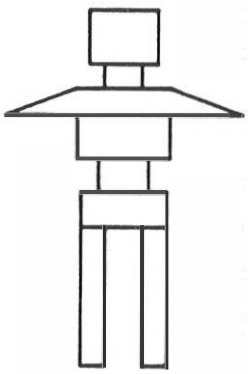
	Volvo 1967 28000 Accidents Driver Repair Cost ≥ 2500 DM			Saab 1975 856 Passengers Saab 99 Repair Cost ≥ 6300 DM					
	AIS 1-6			AIS 1-6			AIS 2-6		
Car Element	with Belt	without Belt	Reduction [%]	with Belt	without Belt	Reduction [%]	with Belt	without Belt	Reduction [%]
Steering Columne	23	15	35	11	6	46	8	1	87
Windscreen	19	7	61	8	-	96	9	-	100
Dashboard Bottom	14	6	53	11	6	45	11	3	69
Dashboard Top	4	1	75						
Roof, Roof Frame Sunscreen	7	1	78	6	3	57	8	4	46
Back Mirror	6	3	52	2	-	85	1	-	100
A-Pillar	3	1	67	2	2	32	4	1	71
Door, Side Door, B-Pillar	5	3	46	11	10	9	16	9	44
Belts	-	-	-	1	15	-	1	14	-
others	19	15	23	48	26	45	42	23	45
$\sum$	100	52	48	100	71	29	100	55	45
Number of Injuries per 100 Passengers	10,8	5,7		101	69		29	16	

ILM TU-Berlin | Injury Cousing Car Elements | 770414 | Appel/Gotzen

Fig. 1



	Driver with Belt	Driver witho. Belt	Passenger with Belt	Passenger witho. Belt
Head	15	31	15	34
Neck, Cerv. Spine	12	5	17	6
Arm, Shoulder	16	22	17	23
Thorax	23	14	21	6
Abdomen	3	4	4	2
Hip	-	-	-	-
Legs	29	23	23	27
others	3	1	3	1
$\sum$	100	100	100	100
Multipl. Injuries	1,5	2,8	1,9	2,9

Source: Dissertation Langwieder 1975

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Fig. 2

OAIS	Front			Side		Rear	Top	other
	3P Autom.	3P Stat	Diag Stat.	struckside	offside			
0	41	10	2	6	12	5	3	1
1	35	24	5	4	14	8	5	4
2	14	8	2	8	3	1	4	2
3	3	1	-	2	-	1	-	2
4	1	1	-	3	1	-	-	-
5	1	1	-	-	-	-	-	-
6	3	5	-	5	2	2	-	-
$\sum$	98	50	9	28	32	17	12	9

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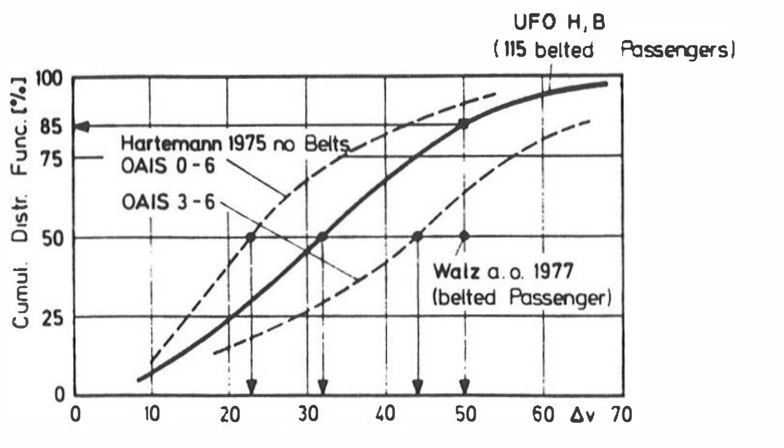
Fig. 3



ILM TU-Berlin	Cumulative Distribution Function of ΔV Frontal Impact	78 01 07 Appel/VuHan

Fig. 4

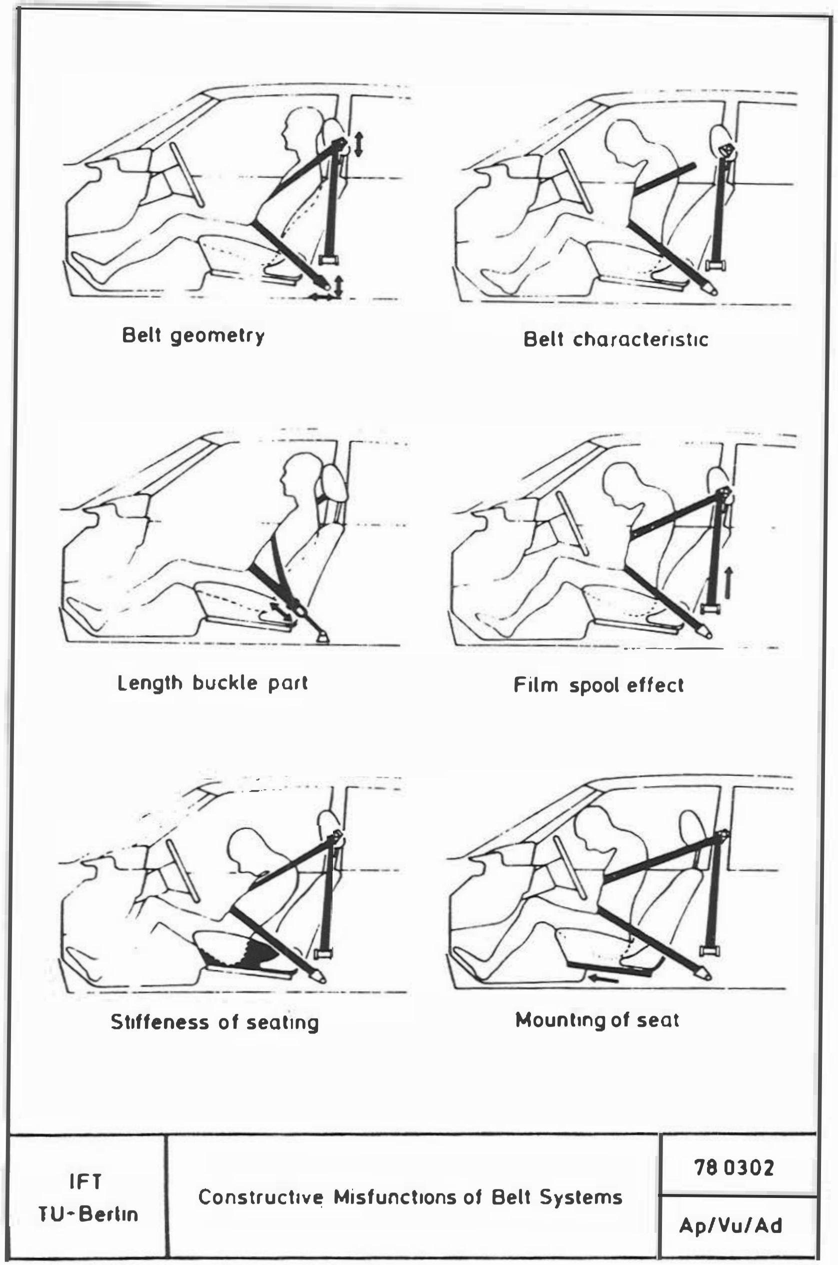

Belt geometry
Belt characteristic
Length buckle part
Film spool effect
Stiffeness of seating
Mounting of seat
IFT
TU-Berlin
Constructive Misfunctions of Belt Systems
78 0302
Ap/Vu/Ad

Fig. 6

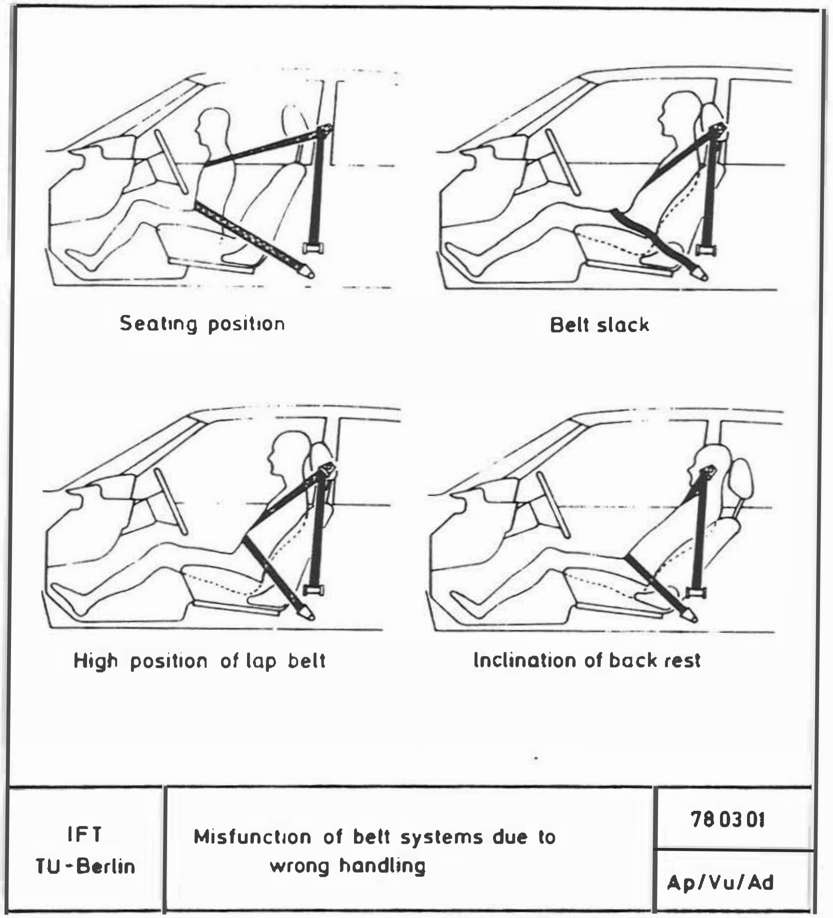
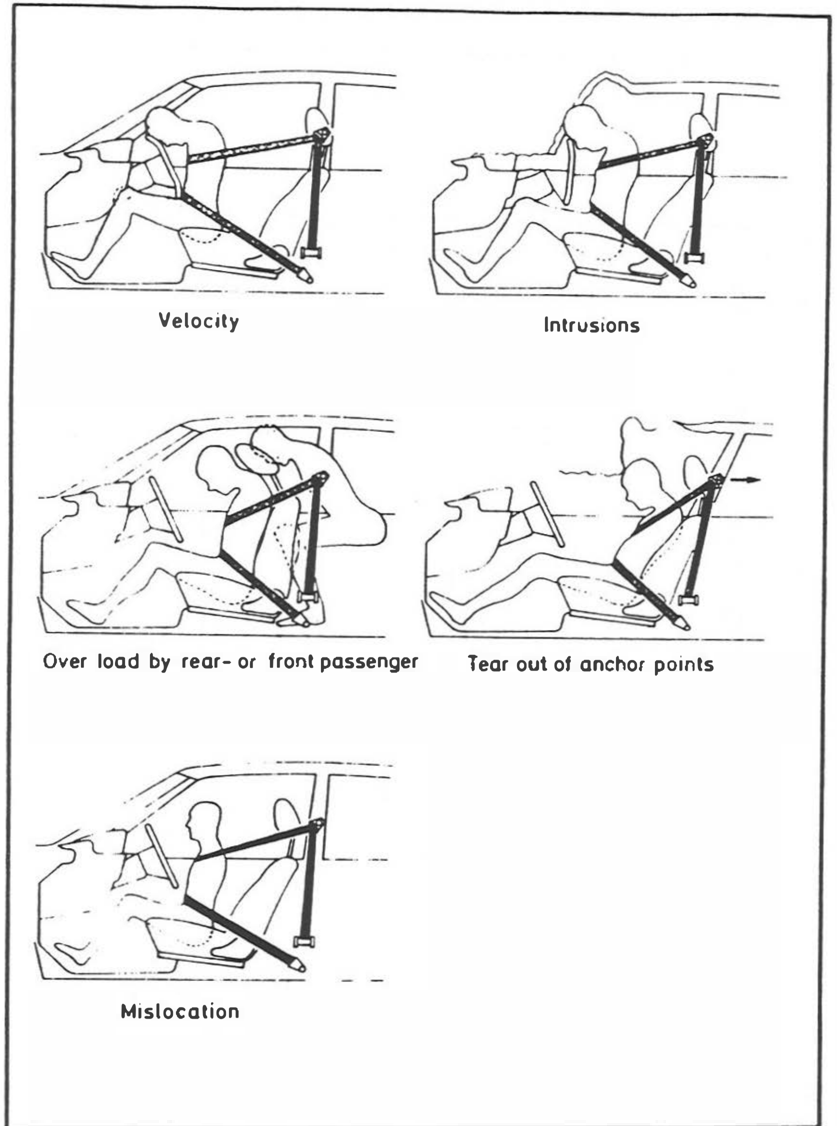
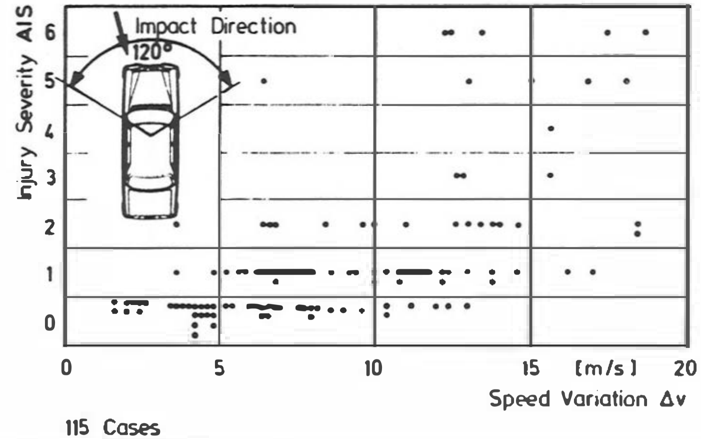

Seating position
Belt slack
High position of lap belt
Inclination of back rest
IFT
TU-Berlin
Misfunction of belt systems due to
wrong handling
78 03 01
Ap/Vu/Ad

Fig. 7



IFT TU-Berlin	Induced Misfunctions of Belt Systems	78 03 03 Ap/Vu/Ad

Fig. 8



ILM TU-Berlin	Injury Severity and Speed Variation with Belted Passengers, Frontal Impact	78 01 06 Appel/Vu Han

Fig. 5

Misfunction			Case-No. 2099	392	436	519	600	655	676	676	724	751	756	786	802	868	890	941	942
constructive	Belt Geometry								X										
	Belt Characteristic																		
	Stiffness Seat						X			X									
	Mounting Seat						X												
	Dashboard Bottom						X	X	X	X		X		X				X	
	Steer. Col. Intrusion															X	X		
handling	Seating Position					X													
	Belt Slack	Chest	X	X									X						X
		Hip		X									X						
	Belt Posit.	Chest													X				
		Hip				X													
induced	Overload										X								
	Intrusion					X	X	X	X	X	X	X		X		X	X	X	
	Δv						X		X	X		X				X	X	X	
	Rollover				X											X			
age																			
OAIS			2	2	2	6	5	3	2	4	6	2	2	2	2	2	3	2	2

out of 74 belted driver

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Fig. 9

Fig. 10

Misfunction			Case-No. 2061	229	294	348	505	511	572	595	683	797	920	5039
constructive	Belt Geometry													
	Belt Characteristic													
	Stiffness Seat													
	Mounting Seat				X				X					
	Dashboard Bottom				X			X	X					
	Steer. Col. Intrusion				X			X						
handling	Seating Position										X			
	Belt Slack	Chest	X						X	X		X		X
		Hip	X	X					X	X		X		X
	Belt Posit.	Chest					X							
		Hip			X				X					
induced	Overload													
	Intrusion				X	X		X	X	X			X	
	Δv				X	X		X	X	X			X	
	Rollover													
age			X											
OAIS			2	2	5	6	2	6	6	2	2	2	4	2

out of 36 belted driver

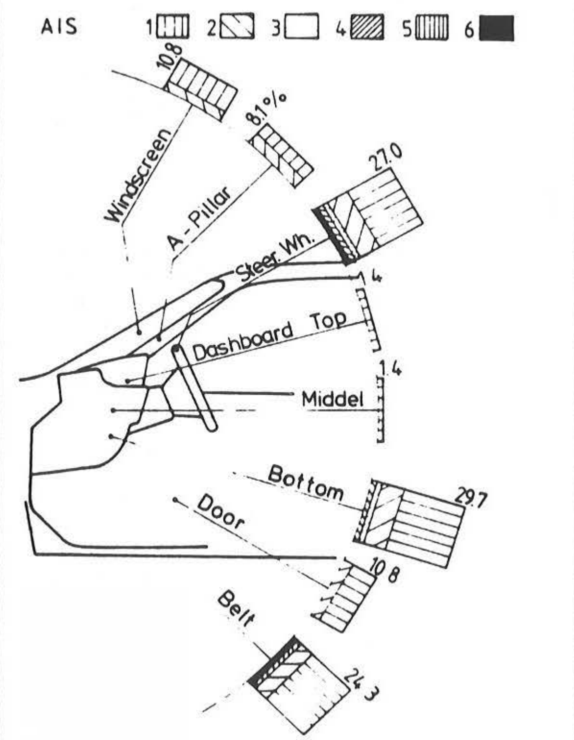
ILM TU-Berlin	Misfunctions of Belt Systems Frontal Impact, 3-Point Static Belt, Driver, OAIS≥2	780406 Vu-Han / Appel

Misfunction			3-Point Automatic					3-Point Static			
			Case-No.					Case-No.			
			2600	668	756	859	933	2061	169	505	920
constructive	Belt Geometry										
	Belt Characteristic										
	Stiffness Seat		X								
	Mounting Seat										
	Dashboard Bottom										X
handling	Seating Position										
	Belt Slack	Chest		X				X	X	X	
		Hip						X	X	X	
	Belt Posit.	Chest									
		Hip					X			X	
induced	Overload										
	Intrusion										X
	Δv		X								X
	Rollover										
age						X		X			
OAIS			3	2	2	2	6	6	2	6	3

out of 24 out of 14 belted Passangers

ILM TU-Berlin	Misfunctions of Belt Systems Frontal Impact, Passanger, OAIS ≥ 2	780407 Vu-Han / Appel

Fig. 11



74 belted driver (≙ 100%)

ILM TU-Berlin	Injury Cousing Car Elements, Frontal Impact, Driver, 3-Point Atomatic Belt	780408 Vu-Han/Appel

Fig. 12

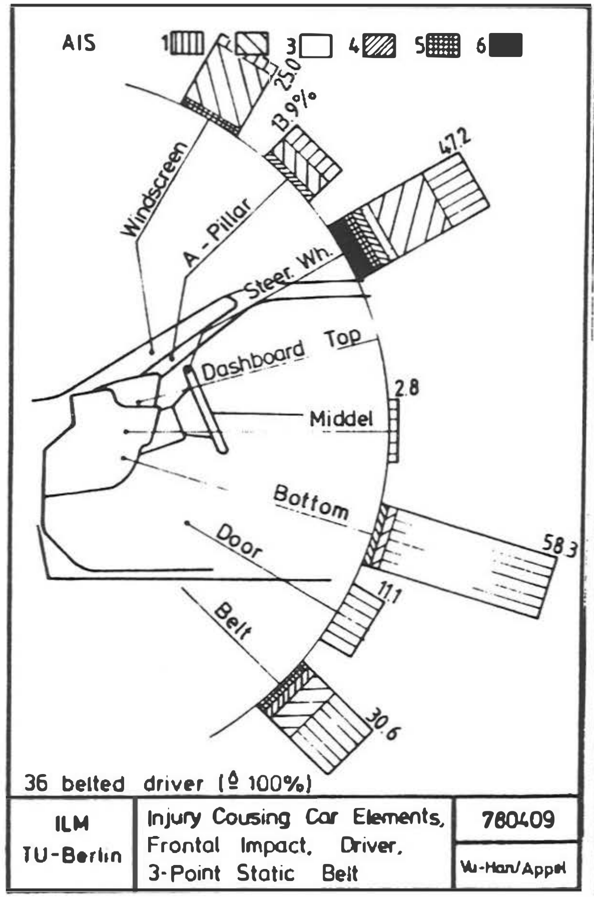


Fig. 13

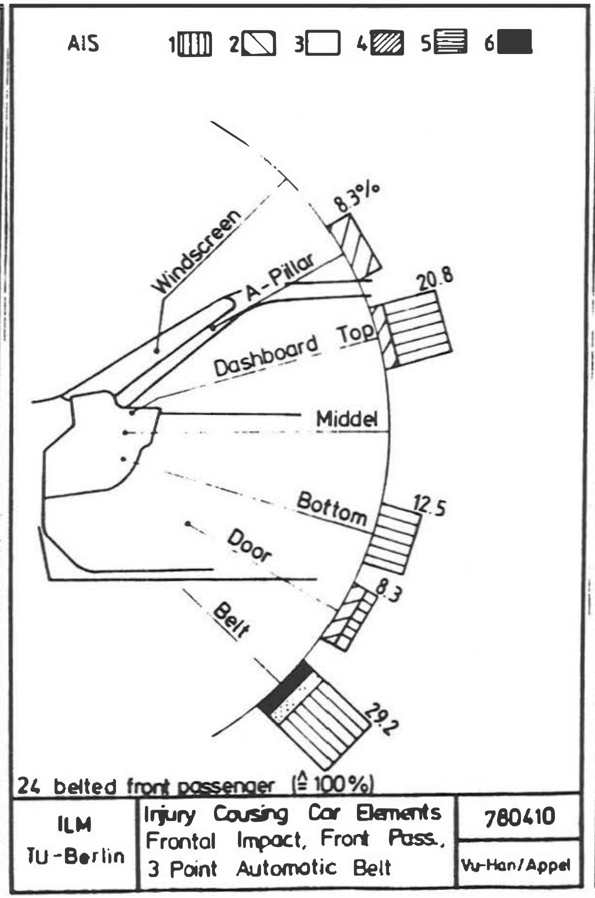


Fig. 14

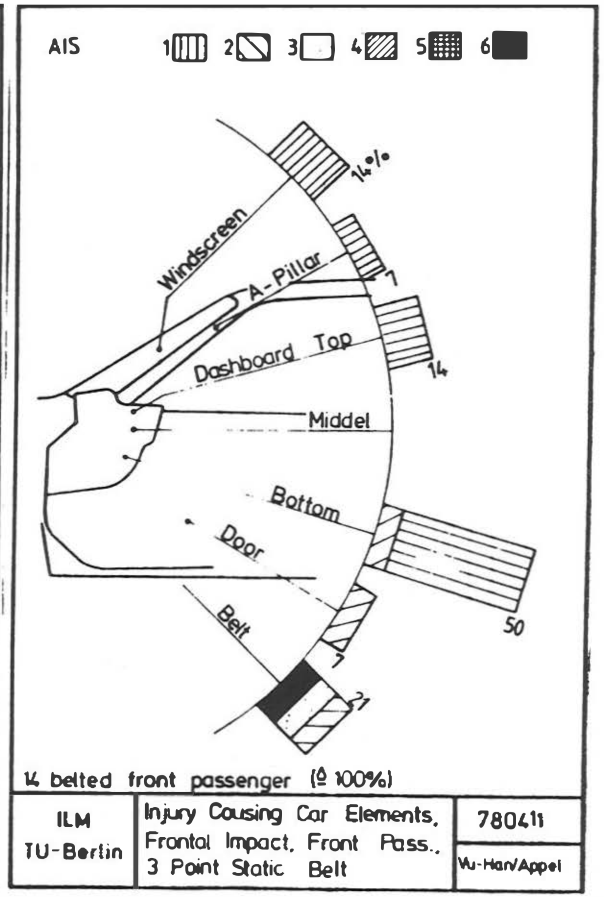


Fig. 15