Final Report for Publication

I C E P S

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Project Coordinator:	**TÜV Kraftfahrt GmbH (TÜV), Germany**
Partners:	**Hapag-Lloyd Flug GmbH (HL), Germany**
	Leopold Franzens University of Innsbruck Institute of Forensic Medicine (GMI), Austira
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Injury Criteria for Enhanced Passive Safety in Aircraft (ICEPS)

1 Partnership

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Participants	WP1	WP2	WP3	WP4	WP5	WP6	WP7
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C= Workpackage co-ordinator, P = participant in workpackage							

2 Executive Summary

In aircraft as well as automotive technology, the HIC (Head Injury Criterion) is being used as an assessment criterion for head injuries in accidents.

As pass-fail criterion, however, the HIC is disputed and is discussed controversially. Strictly speaking, the HIC is applicable only for head impacts on rigid structural components in a forward motion.

As sole assessment criterion for passive safety in aircraft, the HIC is definitely insufficient. In addition, there are currently the maximum-limited thigh forces, maximum shoulder belt forces - if existing - and, in particular for the downward test, the force in the vertebral column. The existing Joint Airworthiness Requirements (JAR) for transport aircraft are outlined in section JAR 25.562.

In automotive technology, there are far more assessment criteria such as chest impression; chest acceleration; pelvic acceleration; etc. Furthermore, there are a number of requirements (FMVSS; ECE) to assess the interior of a passenger car.

In a first step, passenger injuries were determined for two aircraft accidents, Kegworth and Warsaw, and the loads effective in the aircraft cabin were derived. For the assessment of the severity of injuries, the generally acknowledged Abbreviated Injury Score (AIS) was applied. The AIS values allow a clear representation of the passengers' severity of injuries for each body region. It was possible to derive fundamental statements about the passengers' motion course during the crash and the resulting visually perceivable injuries as well as fractures and interior injuries.

Overviews of relevant criteria for the enhancement of passive safety in aircraft were set up, based on an analysis of the protection criteria for dummies used in the automotive industry, by which the safety of passenger cars is assessed with simulated car accidents. Furthermore, criteria for the assessment of the passenger car interior were analysed and applied at the example of the two aircraft types A310 and B737.

The evaluation of criteria for the enhancement of passive safety in aircraft cabins is aimed at the general prerequisite that passengers must rescue themselves at first after a crash. Immediately after a crash, there is normally no direct help available trying to evacuate the passengers from outside. The passengers must be able to free themselves and leave the aircraft on their own. This requirement includes those criteria which evaluate

- the passengers' state of consciousness,
- the passengers' ability to free themselves and
- the passengers' ability to walk.

The criteria were compared with the determined passenger injuries of the two examined aircraft accidents. Injuries by which the passengers' autonomous evacuation is endangered, for which, however, no adequate criteria are applied so far, e. g. injuries of the arms or legs, are outlined separately.

A biomechanic consideration compiles human tolerance currently dealt with in literature. The protection criteria derived from the tolerance limits and the limits currently discussed are represented for each body region.

Based on the accident analyses and criteria applied in automobile and aircraft industry, and on human tolerance defined in literature, criteria were derived for an enhancement of passive safety in aircraft cabins.

The research project was presented to and discussed with representatives of the aviation authorities of Austria and Germany.

3 Objectives of the project

The existing Joint Airworthiness Requirements (JAR) for transport aircraft emergency landing conditions are outlined in section 25.562. This section defines minimum requirements for seats.

Also so-called injury criteria are demanded as pass/fail criteria such as:

- head injury criteria (HIC)
- forces acting on the femurs
- force acting on the spinal column

Such criteria, however, are by far insufficient to evaluate a “passenger-friendly“ aircraft cabin in a crash.

In recent years, aircraft accidents demonstrate that despite the introduction of 16g seats, injuries of passengers during an emergency landing or crash are severe up to fatal.

The reasons for such injuries are to be analysed and compared with available injury criteria for the certification of seats.

In the field of passive safety, automotive technology has advanced very far.

In this context, it is essential to transfer reasonable approaches for an enhancement of passive safety to aircraft technology.

The main project objectives are as follows:

- Development of new, improved evaluation criteria for an enhancement of passive safety in aircraft cabins in order to increase aircraft passenger survivability in an emergency landing or in a crash.
- Establishment of proposals for the further development of European Airworthiness Requirements.

4 Means used to achieve the objectives

Within the framework provided by the main objectives, a number of operational objectives are addressed as the project proceeds. The main operational objectives include:

1. finding out a technical description of the accidents, and injuries relating to the seat.
2. giving an overview of all existing evaluation criteria in aircraft and automotive technology.
3. defining a correlation between injury focuses from accident analysis and evaluation criteria.
4. making a compilation with regard to biomechanic tolerance data on aircraft seating occupants.
5. discussing the new evaluation criteria with representatives of aviation authorities.

5 Scientific and technical description of the project

The following overview represents the workpackages (WP):

WP 1	Project Management
WP 2	Accident Analysis
WP 3	Evaluation of Injury Criteria
WP 4	Correlation between Injury and Evaluation Criteria
WP 5	Biomechanics
WP 6	Injury Criteria for enhanced Passive Safety in Aircraft Cabins
WP 7	Proposals for European Airworthiness Requirements

5.1 Project Management (WP 1)

The following tasks were performed within the project management:

- Co-ordination of tasks as well as of the preparation of the technical and financial reports among the partners;

- Kick-off meeting in Brussels on 1st of July 1997;

- ICEPS-Meeting on 20th of January 1998 in Cologne:
  - Status report on workpackages WP2, WP3, WP5
  - Future activities in the workpackages WP2, WP3, WP4, WP5, WP7
  - Timetable, cost statement;

- Conversation with Lufthansa representative on 22nd of January and 18th of February 1998 in Frankfurt:
  - explanation of the details of the accident
  - description of the determined injuries;

- Support of the GMI in literature research on the accident near Kegworth;

- Co-ordination of the exemplary application of the ECE-Regulations 17 and 21 in the cabins of the aircraft types A310 and B737 on 4th of March 1998 in the premises of Hapag-Lloyd GmbH in Hanover;

- Co-ordination of the work meetings of the TÜV and the GMI on 1st of October 1998 in Innsbruck: The workpackages WP2, WP3 and WP5 were on the agenda;

- Preparation of the meeting with representatives of Airbus in Hamburg on 19th of February 1999. Topics of this meeting was to collect information about crashworthy structure elements of the fuselage.

- Preparation of the meeting with representatives of Austro Control GmbH, Vienna (A) on 24th of March 1999. Participants of the meeting were, among others, members of the JAA Cabin Safety Study Group. The examined accidents were presented and the derived requirements for an enhancement of cabin safety were explained and discussed;

- Preparation of the discussion with Prof. Wallace, Department of Orthopaedic and Accident Surgery, Queen's Medical Centre, Nottingham (UK) on 15th of April 1999. Prof. Wallace was Chairman of the NLDB Study Group. The investigations performed by the Queen's Medical Centre concerning the Kegworth-Accident were discussed, among other things, and additional literature about the topic was made available.

- Preparation of the discussion with employees of DERA, Centre for Human Sciences, Farnborough (UK) on 16th of April 1999 which performed the tests with the aircraft seats of the Boeing 737-400 (Kegworth accident). The tests were discussed and an original aircraft seat from the Kegworth accident could be investigated on the spot;

- Preparation of the meeting with representatives of the Luftfahrt-Bundesamt (LBA), Braunschweig, and the German Federal Bureau of Aircraft Accidents (BFU), Braunschweig, on 27th of April 1999. Participants of the meetings were, among others, LBA members of the JAA Cabin Safety Study Group and employees of the BFU, who had examined the accident of the A320 in Warsaw. The accident of the A320 and the injury criteria for enhanced passive safety derived from the ICEPS examinations were discussed;

- Preparation of the interview with flight attendants of the accident flight to Warsaw. Two flight attendants were interviewed about the details of the accident. One flight attendant could only by interviewed by telephone, the interview with the second flight attendant was made on 31st of April 1999 in Frankfurt;

5.2 Accident Analysis (WP 2)

In Workpackage 2 two accidents with part 25 aircrafts involved were investigated. This workpackage concentrate all relevant information about passive safety in an aircraft cabin during an emergency landing or a crash.

The analysis of the Kegworth accident is based on the respective reports on this crash and an conversation with the chairman of the NLDB Study Group. The analysis of the Warsaw accident is based on the documents made available to us by the airlines concerned and on the conversations held with the employees.

It was not possible to conduct our own medical and technical examinations of the accidents.

It should be noted that the medical reports on the accidents did not contain any photographs or x-rays of the injured passengers.

5.2.1 Engineering aspects

5.2.1.1 Engineering aspects of the Warsaw accident

On 14 September 1993, an Airbus A320 crashed during the landing on the Warsaw airport. Out of 64 passengers 33 persons remained uninjured. One passenger died from carbon monoxide poisoning.

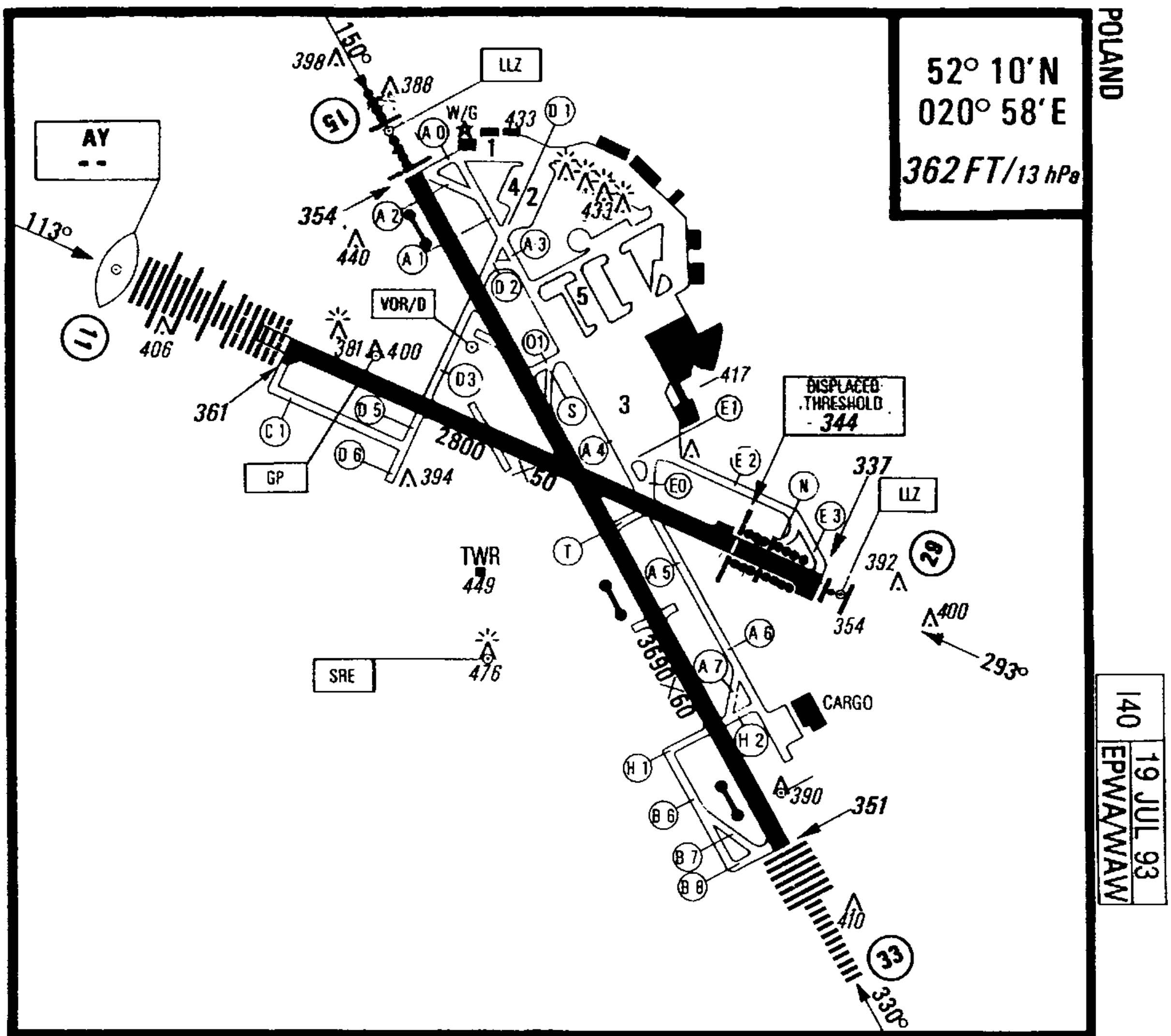
It was possible to reconstruct the details of the accident from the flight data of the Airbus A320. The evaluated data and information are not yet completely available. The A320 rolled and slipped over the runway onto a mound. Shortly before the crash, the pilot turned the aircraft to the right. The A320 slipped with a yaw angle onto the mound and crashed with the cockpit and the fuselage front section behind the mound. In this process, all kinetic energy was used up. The fuselage back remained on top of the mound. The aircraft did not break apart. The left power plant was partly torn off during the crash, and the A320 caught fire in this part. The fire then spread by and by over the entire aircraft cabin.

The sequence of events during the accident can be reconstructed as follows:

- Weather reported to the Captain: Wind from 150 degrees with 5 metre per sec., Ceiling and Visibility OK,

- Actual Weather: Wind from 270 degrees with 20 Knots, heavy shower, visibility 2000 metres,

- The A320 landed on runway 11 (113 degrees), see Figure 5.2-1. The runway consist of 2300 metres of asphalt path which is followed by a additional track of 500 metres. This additional track consists in the first part of asphalt and is for the last approximately 300 metres covered with concrete,



RWY	LENGTH TKOF	LDG	CWY	SWY	SUR-FACE	STRENGTH ACFT TYPE/AUW	RVR	APCH PROC	SLOPE %	LIGHTING RWY	CENTER	TDZ	APCH	THR	VASI
11	2300			500	AC	NWR	1	IV	-0.2	H 60			P 2	H	
29		2300		150	AC		1	V	+0.2	H 60			S	H	
15					AC	NWR	3	V	0	M 60			S	H	
33					AC		3	IVN	0	H 60			P 2F	H	

RWY	TYPE	TAKE OFF
11	C/D	0-0.4
29	C/D	0-0.4
15	C/D	0-0.4
33	C/D	0-0.4

TWY : 23m, C
Remarks : RWY 11/29 caution when wet.
RWY 33: TORA from TWY H2 3000m.
Psn 22-26 for A300, 27 for B747.

Figure 5.2-1 Airport Warsaw

- The A320 touched down approximately 700-750 metres behind the beginning of the runway, whereas the normal touche down is 300 metres behind the beginning.

- The wheel-brakes, spoilers and thrust reversers functioned as late as at 1,400 metres behind the start of the runway.

- Up to the reaching of the concrete runway, the brake systems were in operation. On the concrete runway, the phenomenon of a "rubber reversion" or. "steam-planing“ could be seen between wheels and concrete, with the consequence that the wheels lost their road grip, and the aircraft slided like on a steam carpet. The brakes were no longer effective either. After leaving the concrete runway, the aircraft had a remaining speed of approx. 70 knots.

- The concrete runway ends in the grass. Approx. 85 metres behind the concrete runway, a mound of approx. 6 metres height is filled up. The mound’s upper width is approx. 4 metres. The mound’s flank tilt is 35 - 40 degrees with the flank pointing to the runway being covered with concrete squares (compare. Figure 5.2-2*.).*

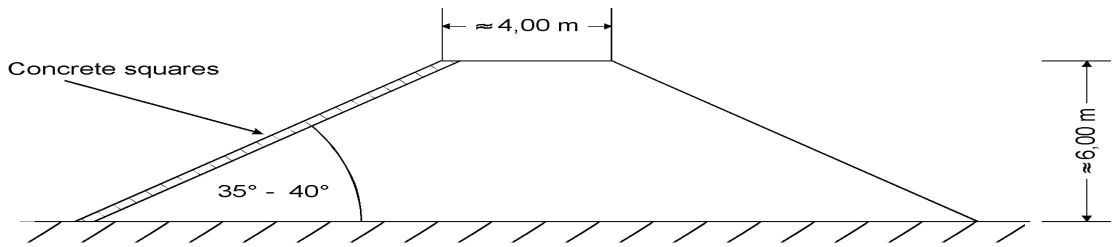


Figure 5.2-2 mound

- Briefly before the crash against the mound, the pilot turned the A320 to the right with the vertical rudder in order to prevent a crash with the fuselage nose.

- The A320 reached the mound with approx. 58 knots (107 km/h) and a yaw angle, i. e. turned towards the right. The yaw angle could only be assessed from the final aircraft position to be approx. 30 degrees.

- The aircraft slid over the mound and stopped behind it (compare Figure 5.2-3 and Figure 5.2-4.). In this process, the left power plant was torn off, and the landing gear buckled. After the crash, the back of the aircraft lay on top of the mound. The right wing extended up to the mound with a distance between the wing and mound of approx. 50 cm.

Figure 5.2-3 Photograph 1 of the A320 wreck

Figure 5.2-4 Photograph 2 of the A320 wreck

- The motion of the aircraft over the mound can only be reconstructed approximately. The A320 slid up the 6 metre high mound and over the approx. 4 metres broad mound plateau thus completely reducing its speed. It can be assumed that after sliding over the mound, the nose touched the ground only at the end of the crash, from a height of approx. 6 metres. This assumption is also supported by the statements and the injuries diagnosed for the flight attendants and passengers. Thus, some aircraft passengers in the rear part of the cabin did not realise the situation at first since they had not detected any increased accelerations. The injuries of the two flight attendants seated in the front or back respectively also differed. The accelerations in the direction of the vertical aircraft axis were considerably higher in the front (fractures coccyx of FB1R) than in the back. A flight physician assessed the accelerations to reach 22 to 25 g. The verification on the basis of biomechanical tolerance for the lumbar spine gave an acceleration at least 20g in the direction of the vertical aircraft axis.

- The accelerations acting in the aircraft's longitudinal and lateral axis could not be assessed with sufficient exactitude.

- According to the statements of witnesses, the overhead bins had not opened and no parts had fallen out.

- In the final position of the aircraft, a fire broke out in the area of the left power plant spreading to the fuselage after a couple of minutes. The surviving passengers and crew members could rescue themselves before the fire broke out.

Fuselage

It was not possible to carry out a detailed examination of the fuselage after the crash since it has burnt out and was removed very quickly from the accident scene. A comprehensive documentation of the damages at the aircraft passenger seats and the aircraft interior is not available. Due to the statements of the witnesses it can be assumed that the seats had only small structural damages. According to the statements, the aircraft passenger seats had not torn off the floor structure.

Passenger seats

The 26 aircraft seat rows were equipped with triple seats of the company SICMA AERO SEAT INC. of the series 9101, see Figure 5.2-5. The aircraft passenger seats were approved in accordance with the TSO C39B "Aircraft Seats and Berths", i. e. the comply with the criteria for 9 g static tests. Such seats shall further be suitable for 16g according to JAR 25.562 "Emergency landing dynamic conditions".

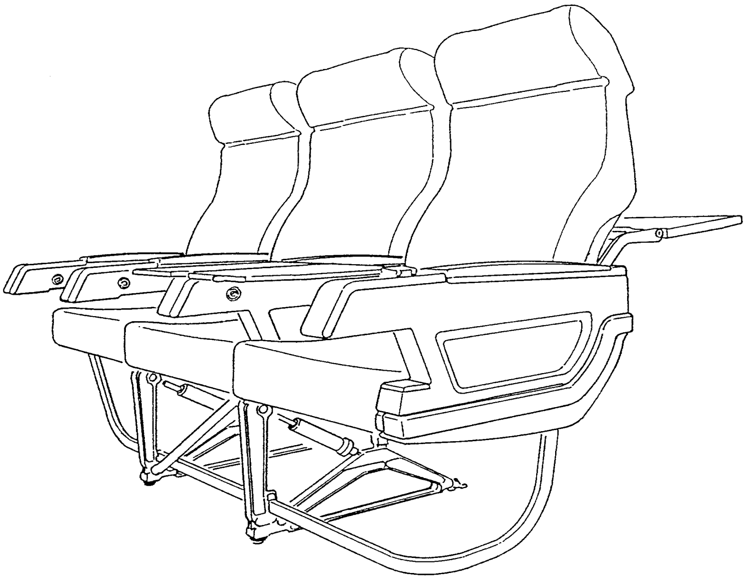


Figure 5.2-5 A320 Passenger triple seat (first row)

5.2.1.2 Engineering aspects of the Kegworth accident

During the night of 8 January 1989, a Boeing 737-400 aircraft crashed on the M1 motorway near Kegworth. From 119 passengers 39 died at the scene, 80 were rescued. Out of the primarily rescued persons 4 died the following days.

There were two phases of the crash on the M1 motorway, see Figure 5.2-6. First, the aircraft sat onto a field east of the M1. Since the M1 is shaped into the landscape, the Boeing then flew over the two lanes. The second severe crash then followed on the embankment in the west of the M1. During the second impact, the fuselage broke into three parts (forward, centre-section, tail), see Figure 5.2-7 and Figure 5.2-8.

The reports on the accident describe, among other things, the details of the accident simulated on computers. Data are given as regards the velocities and decelerations, with the calculations of the second impact rendering three different results. What is more, the loads acting on the aircraft passengers were simulated on the basis of the RUN 2 for the fuselage middle section, and the influence of different seating positions were examined.

The following data were determined for the first ground contact and the second impact:

First ground contact:

Pitch	13° nose up ±1°
Roll	4° right wing low ±1°
Yaw	4.5° nose left ±1°
Track	266°M

<u>impact velocities:</u>

Airspeed	113 knots CAS
Ground speed	between 104 kts (CAS corrected for wind) and 111 kts (from the aircraft Inertial Reference Unit)
Rate of descent	between 8.5 feet/sec (barometric rate of descent) and 16 feet/sec (radar altimeter rate corrected for terrain)

These velocities combined to give an aircraft final flight path angle of between 2.5° and 5°, consistent with the entry angles to the ground marks.

Second, and major, impact

The second, and major, impact occurred when the nose contacted the base of the western embankment. The first contact was made by the nose-wheel on the road surface, followed, within approximately 0.1 seconds, by the nose radome striking the embankment and the engine nacelles striking the road surface. The nose landing gear failed rearwards, the nose crushed against the embankment and both engine support structures failed upwards.

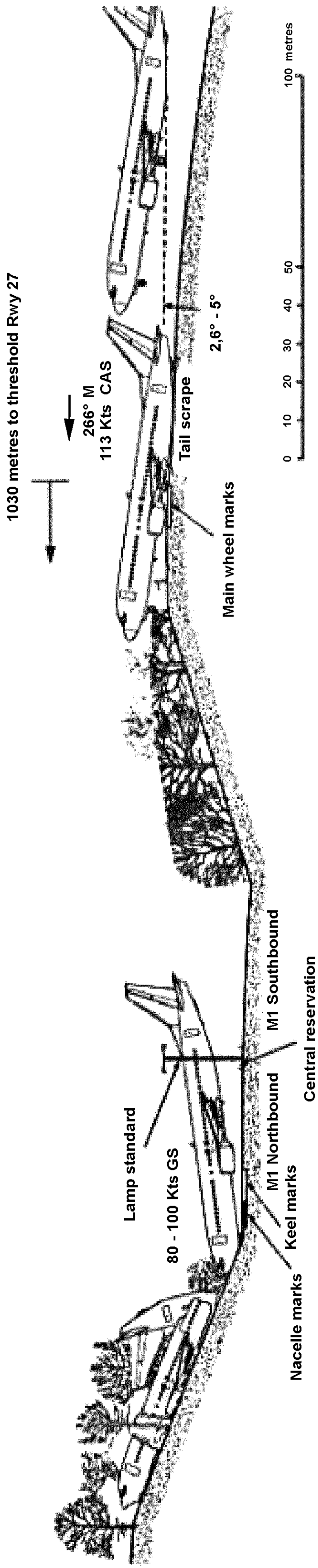


Figure 5.2-6 Kegworth impact sequence

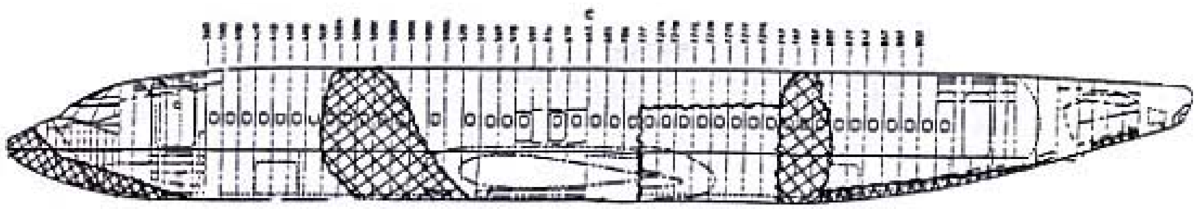


Figure 5.2-7 Kegworth Accident

Figure 5.2-8 Kegworth Accident

Pitch	between 9° and 14° nose down
Roll	2.5° right wing low ±1°
Yaw	0° ±2°
Track	266°M

a) A simple calculation of the ballistic trajectory from the first impact was made, giving velocities at the second impact of:

Resultant	50.0 m/sec (97.2 knots)
Horizontal	48.9 m/sec (95.1 knots)
Vertical	14.4 m/sec (28.0 knots)
Flight path	16.4° below horizontal

b) A first-order aerodynamic calculation using lift coefficient data from the aircraft manufacturer and mid-trajectory values of airspeed and angle -of- attack gave a lower boundary approximation of velocities at the second impact:

Resultant	39.4 m/sec (76.6 knots)
Horizontal	37.9 m/sec (73.7 knots)
Vertical	11.1 m/sec (21.6 knots)
Flight path	16.4° below horizontal

The above values were used for, respectively, 'Run 2' and 'Run 3' of the KRASH impact simulation.

c) The Boeing Company contributed an analysis of the impact sequence to provide a set of parameters for the second impact. This analysis gave parameters at the second impact of:

Resultant:	51 m/sec (99 knots)
Flight path	12° below horizontal
Pitch attitude	14° below horizontal

The velocity change in the second impact can only be estimated. For example, based on the measured crush distance of approximately 2.6 metres along the direction of motion in the nose area, a 25% change of velocity (from 51 m/sec) in the second impact would give a pulse with a mean deceleration of about 22g, lasting about 60 milliseconds.

Computer simulation

A calculating model was developed for the Kegworth accident. This KRASH model allowed for the theoretical calculation of the longitudinal and vertical deceleration for the centre-section of the fuselage, among other things. This was based on the determined parameters from the ballistic trajectory (RUN 2) and the aerodynamic calculation (RUN 3). The following maximum accelerations were determined:

peak deceleration	longitional	vertical
RUN 2	26,1g (t=60ms)	23g (t=161ms)
RUN 3	19,5g (t=75ms)	12,6g (t=381ms)

The examinations led to the result that the **aerodynamic calculation** depicts the second impact better than the ballistic trajectory.

In addition, a computer model was developed to simulate the motions and injuries of the aircraft passengers.

Passenger seats

At the time of the accident, G-OBME was configured with 156 passenger seats in a single class cabin with a total of 26 rows of pairs of triple seats. The seats were of a type designated as the Model 4001 tourist seat by the manufacturer, Weber Aircraft, Inc, see Figure 5.2-9. The seat rows were numbered conventionally from 1 to 27 (no row 13) from the front to the back of the aircraft. The seat pitch ranged from a maximum of 38 inches, for the 2 seat rows (12 and 14) next to the overwing emergency exits, to a minimum of 30 inches for row 27L. The remaining seat pitches were either 31 or 32 inches.

The Model 4001 seats were approved by the FAA in December 1985 as meeting the performance standards of TSO-C39A "Aircraft Seats and Berths" and were approved by the CAA in February 1986 as meeting the more stringent requirements of BCAR Sections D3-8 and D4-4. These seats shall furthermore be suitable for 16g in accordance with JAR 25.562 "Emergency landing dynamic conditions".

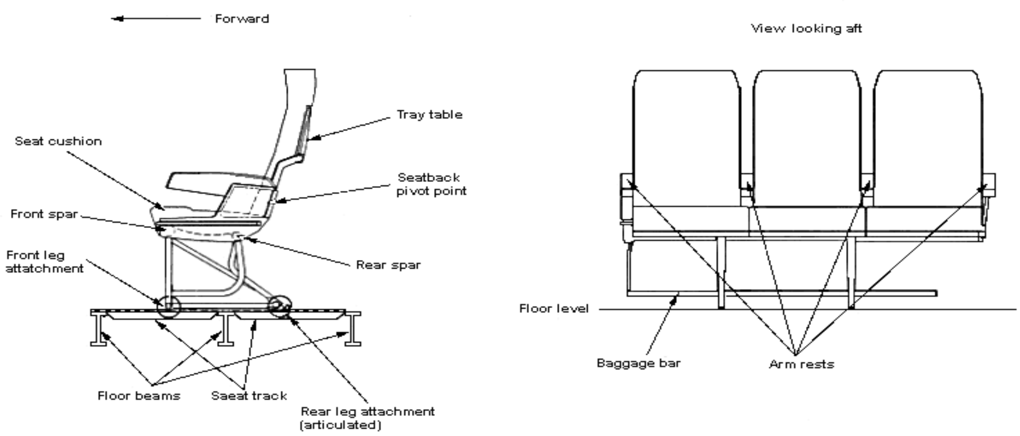


Figure 5.2-9 Boeing 737 passenger triple seat

Fuselage

The structural damage to the aircraft`s fuselage was assessed and scored according to the amount of damage sustained either to the floor, walls, or roof of the fuselage for each side, left and right. Damage was scored at each seat row on a scale of 0-5, with 0 the score for a normal structure and 5 indicating that the structure was absent. Thus for any given row a score of 0 indicates that the fuselage remained largely intact and a score of 30 that the fuselage was completly destroyed (see Chapter 5.2.2.2 Table 5.2-2).

5.2.2 Medical aspects

Introduction

To study the injuries of survivors and non-survivors of the reported aircraft accidents, an appropriate classification of in juries by type and severity is fundamental. For this description of the injuries and injury severity the Abbreviated Injury Score in its last revision (AIS90) was chosen.

The Abbreviated Injury Score (AIS) is the global system of choice concerning injury description and scaling. The first AIS has been published under the joint sponsorship of the American Medical Association (AMA), the Association for the Advancement of Automotive Medicine (AAAM) and the Society of Automotive Engineers (SAE) in 1971. Since then the AIS has become more and more the standard for crash investigation.

The AIS is an anatomically based system that classifies individual injuries by body region on a 6-point severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable). In AIS 90 each injury description is assigned a unique 6-digit numerical code in addition to the AIS severity score, separated by a decimal point. The first digit identifies the body region (1 = head, 2= face, 3 = neck, 4 = thorax, 5 = abdomen, 6 = spine, 7 = upper extremity, 8 = lower extremity, 9 = unspecified), the second digit identifies the type of anatomic structure, the third and fourth digits identify the specific anatomic structure or, in the case of injuries to the external region, the specific nature of the injury, the fifth and sixth digits identify the level of injury within a specific body region and anatomic structure. The digit to the right of the decimal point is the AIS score, according to the following severity codes: 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = maximum, 9 = unknown).

The AIS does not consider the combined effects of multiply-injured patients. Therefore the Injury Severity Score (ISS) has been established in 1974. The ISS is the sum of the squares of the highest AIS score in three different (ISS) body regions. The six body regions of injuries used in the ISS are: 1 = head or neck, 2 = face, 3 = chest, 5 = abdominal or pelvic contents, 5 = extremities or pelvic girdle, 6 = external. Injuries of rib cage and thoracic spine are included in „chest injuries“, lumbar spine lesions are included in „abdominal or pelvic girdle“. ISS scores range from 1 to 75, where a score of 75 results either with three AIS 5 injuries, or with at least one AIS 6 injury.

In a first step the available medical informations about Warsaw and Kegworth accidents were analysed according to the AIS and ISS systems. In a second step of the accident analysis the injuries were weighted according to the necessity of urgent medical treatment. In this system injuries coded as „1“ are classified in the AIS system as mild or minor injuries (AIS 1, for example bruising, laceration, soft tissue injuries without bone fracture) whereas injuries coded as „2" are classified in the AIS system as at least moderate (AIS 2 or more; for example long bone fractures, injuries of internal organs, ...). With this simplified illustration the main emphasis of injuries and therefore the starting points for effective injury prevention could be detected.

5.2.2.1 Medical aspects of the Warsaw accident

Members of the medical staff of Lufthansa provided us with detailed informations about the injuries of the passengers. Photographs, x-rays were not available.

Out of 64 passengers 33 persons remained uninjured. One passenger died from carbon monoxide poisoning. The others suffered from injuries with AIS codes from 1 to 3. Based on the detailed informations of medical staff members of the air carrier ISS values from 1 to 14 could be calculated. ISS values 1 to 5 for 22 persons, values from 6 to 10 for 6 persons and values from 11 to 15 for 2 persons.

8 persons were hurt during the evacuation of the aeroplane (3 upper arm fractures, 3 lower arm fractures, 1 lesion of the arm plexus, 1 fracture of the lower leg, 4 severe distortions of the ankle). An overview on the injuries regarding to the seating position is given in Figure 5.2-10 to Figure 5.2-13.

All 6 crew members were injured. The captain died from thoracic injuries. The other crew members suffered from injuries with AIS codes from 1 to 2, ISS values from 1 to 6. One of them was hurt during evacuation and suffered from a distorsion of the ankle. Table 5.2-1 shows the AIS-Score per seat and the parameter for the structural damage to the aircraft`s fuselage.

A detailed description of injuries for each passenger is listed in the appendix. The table furthermore gives an AIS assessment derived from the description for each body region as well as the ISS.

Figure 5.2-10 Seat distribution - Warsaw

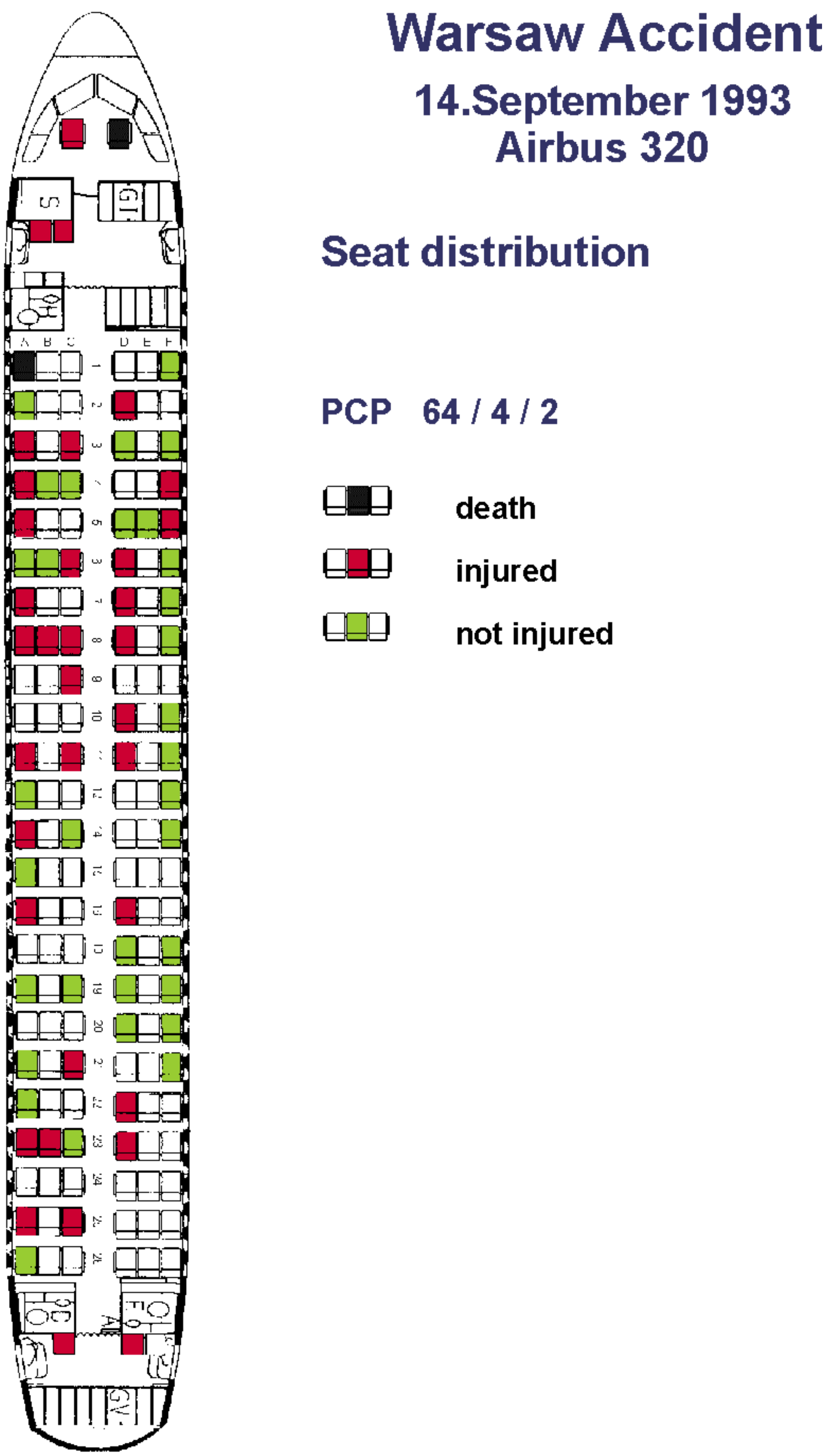
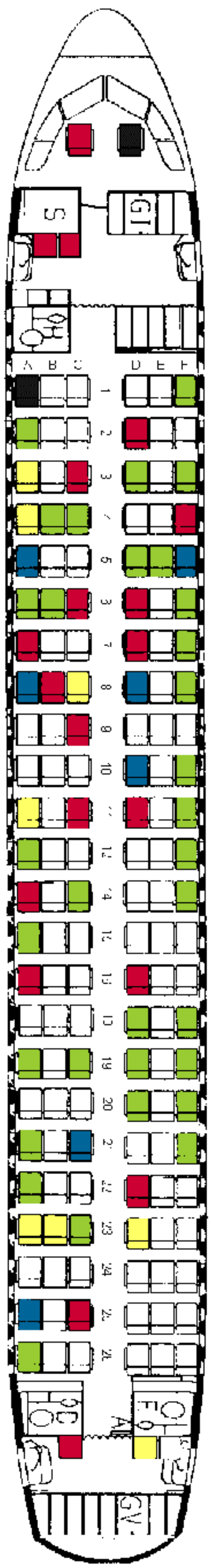


Figure 5.2-11 Injuries by impact and evacuation - Warsaw



Warsaw Accident

14.September 1993
Airbus 320

Injuries by impact and evacuation

PCP 64 / 4 / 2

death by impact

severe injured by impact

minor injuries by impact

severe injured during evacuation

not injured

minor injuries by evacuation: none

Figure 5.2-12 Head injuries - Warsaw

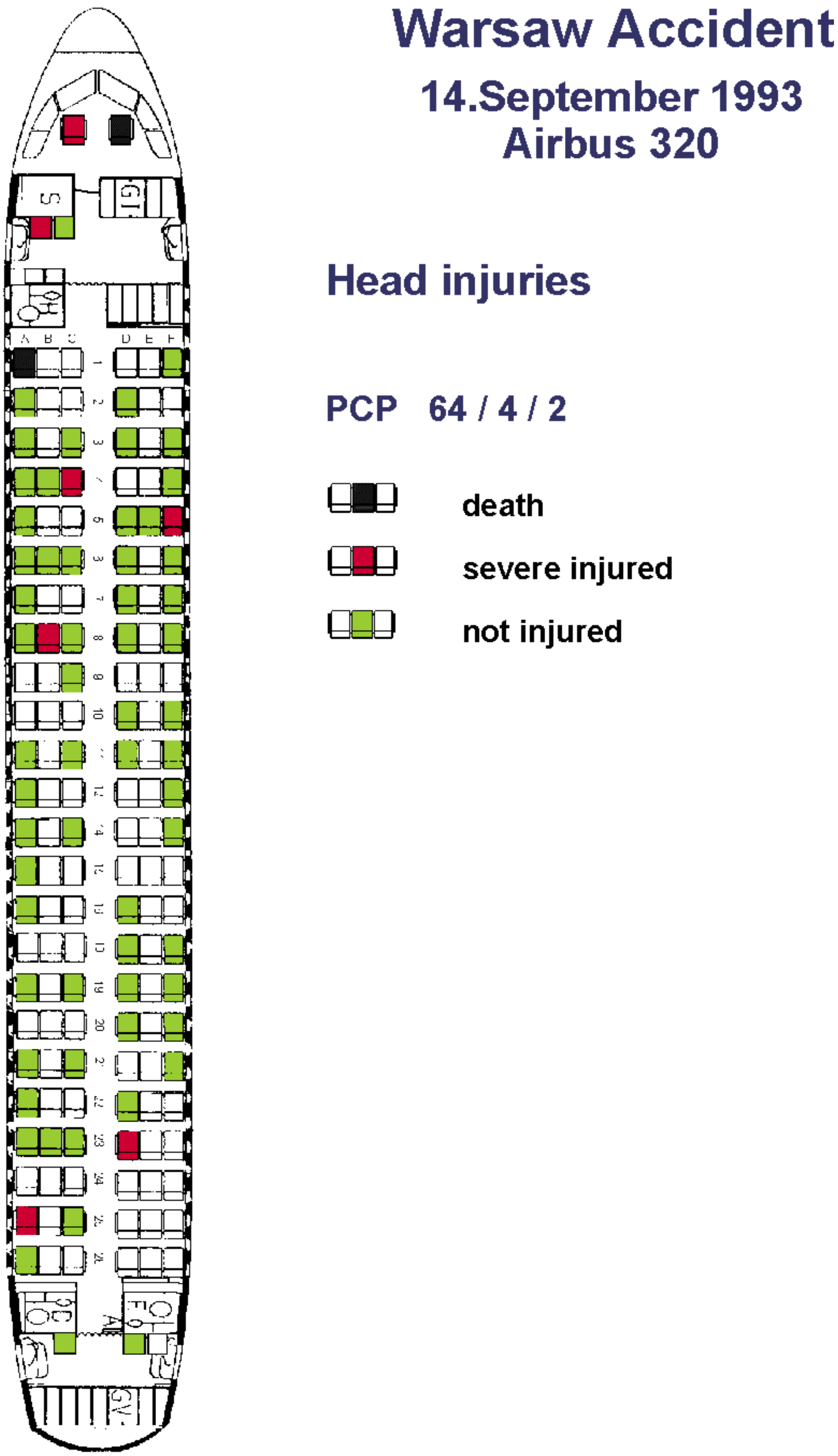


Figure 5.2-13 Spinal injuries of all survivors - Warsaw

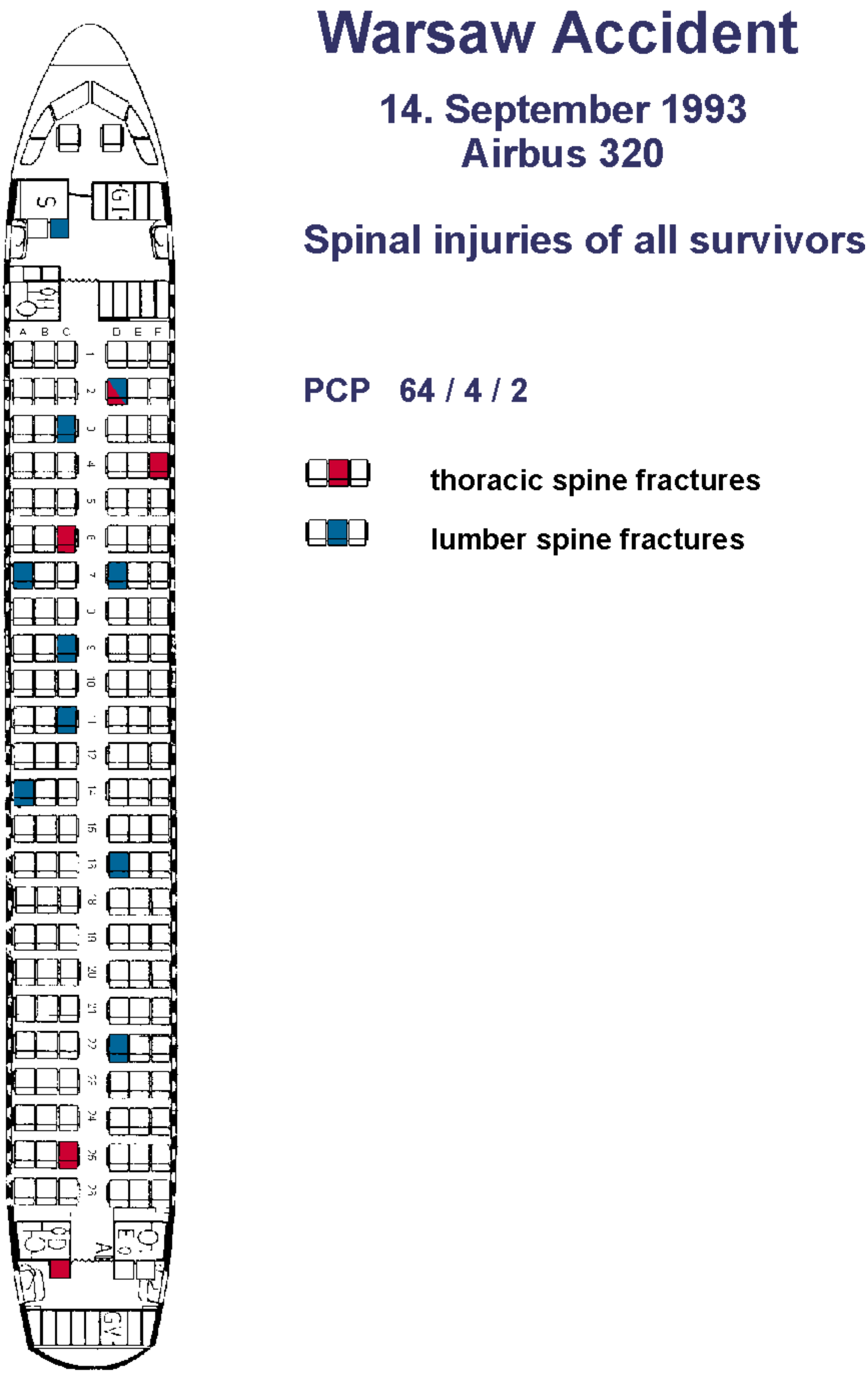


Table 5.2-1 AIS Score - Warsaw

Warsaw-Accident			Maximum Regional AIS – Score						
Seat	Outcome	ISS	Head	Face	Chest	Abdomen	Extremities	External	Structural Damage
1A	D	75	3				2		0
1B	S								0
2A	S								0
2D	S	8			2	2			0
3A	S	1			1				0
3F	S								0
3C	S	5		1		2			0
3D	S								0
4A	S								0
4B	S								0
4C	S	1		1					0
4F	S	5		1		2			0
5A	S	1			1				0
5D	S								0
5E	S								0
5F	S	2[9]	1		1		[3]		0
6A	S								0
6B	S								0
6C	S	5			2+1				0
6D	S	8			2	2			0
6F	S								0
7A	S	4				2			0
7D	S	4				2			0
7F	S								0
8A	S	[4]					[2]		0
8B	S	13	3		2				0
8C	S	1			1				0
8D	S	[4]					[2]		0
8F	S								0
9C	S	4				2			0
10D	S	[9]					[3]		0
10F	S								0
11A	S	1[1]				1	[1]		0
11C	S	4				2			0
11D	S								0
11F	S	5[1]			1	2	[1]		0
12A	S								0
12F	S								0
14A	S	4				2			0
14C	S								0
14F	S								0
15A	S								0
16A	S	1				1			0
16D	S	4				2			0
18F	S								0
18D	S								0
19A	S								0
19C	S								0
19D	S								0
19F	S								0
20D	S								0
20F	S								0
21A	S								0
21C	S	1[4]					[2]	1	0
21F	S								0

Warsaw-Accident			Maximum Regional AIS – Score						
Seat	Outcome	ISS	Head	Face	Chest	Abdomen	Extremities	External	Structural Damage
22A	S								0
22D	S	4				2			0
23A	S	1				1			0
23B	S								0
23C	S	2			1		1		0
23D	S	5		2				1	0
25A	S	2[4]		1			[2]1		0
25C	S	4			2				0
26A	S								0

Key: D= Deceased at scene; S= Survived impact.
[] = hurt during evacuation

5.2.2.2 Medical aspects of the Kegworth accident

Some results of the medical investigations of the injured persons in the Kegworth accident have been presented at a seminar organised by the Engineering in Medicine Group of the Institution of Mechanical Engineers, held in 1991. Other results of analysis of the injuries have been published in scientific journals or were the basis for a thesis to get doctor´s degree. Prof. Wallace, who was the chairman of the NLDB Study Group, gave detailed informations about the injuries of the surviving passengers in a personal communication in Nottingham. On this occasion some photographs of injured persons could be exemplary seen. Passengers who died at the scene have been investigated to answer questions like identity or time of death. An exact analysis of the injuries has not been documented in these cases.

From 119 passengers 39 died at the scene, 80 were rescued. Out of the primarily rescued persons 4 died the following days. The ISS values of the passengers varied from 1 to 75. ISS values 1 to 5 for 19 persons, values from 6 to 10 for 15 persons, ISS 11 to 15 for 16 passengers, ISS 16 to 20 for 7 persons, 21 to 25 for 6 persons, 26 to 30 11 persons, 31 to 35 7 persons, 36 to 40 3 persons, 41 to 45 11 passengers, 46 to 50 2, ISS more than 50 (except passengers who died with ISS 75) 3, and finally 19 passengers with an ISS value of 75.

There were 19 passengers with primary ISS values of 75, 20 other persons who died at the scene suffered from injuries with ISS values from 21 to 66. 4 fatalities were classified as early deaths (ISS values from 26 to 45). 4 hospital deaths occurred the following days, where the passengers suffered from primary injuries with ISS values from 11 to 41. The ISS values of the survivors ranged from 1 to 50.

All of the 7 crew members were injured with ISS values from 1 to 38. All of them survived the accident.

An overview on the injuries is given in Figure 5.2-14 to Figure 5.2-17. With the help of the detailed personal informations from Prof. Wallace an allocation of the injuries and AIS scores to the body region and the seating position could be made. The Table 5.2-2 shows the AIS-Score per seat and the parameter for the structural damage to the aircraft`s fuselage. The appendix gives a detail description of the injuries for each passenger per seat.

Photographs were also taken of the externally visible injuries, among other things. An outline of the externally visible injuries can be found in the Appendix.

Figure 5.2-14 Seat distribution - Kegworth

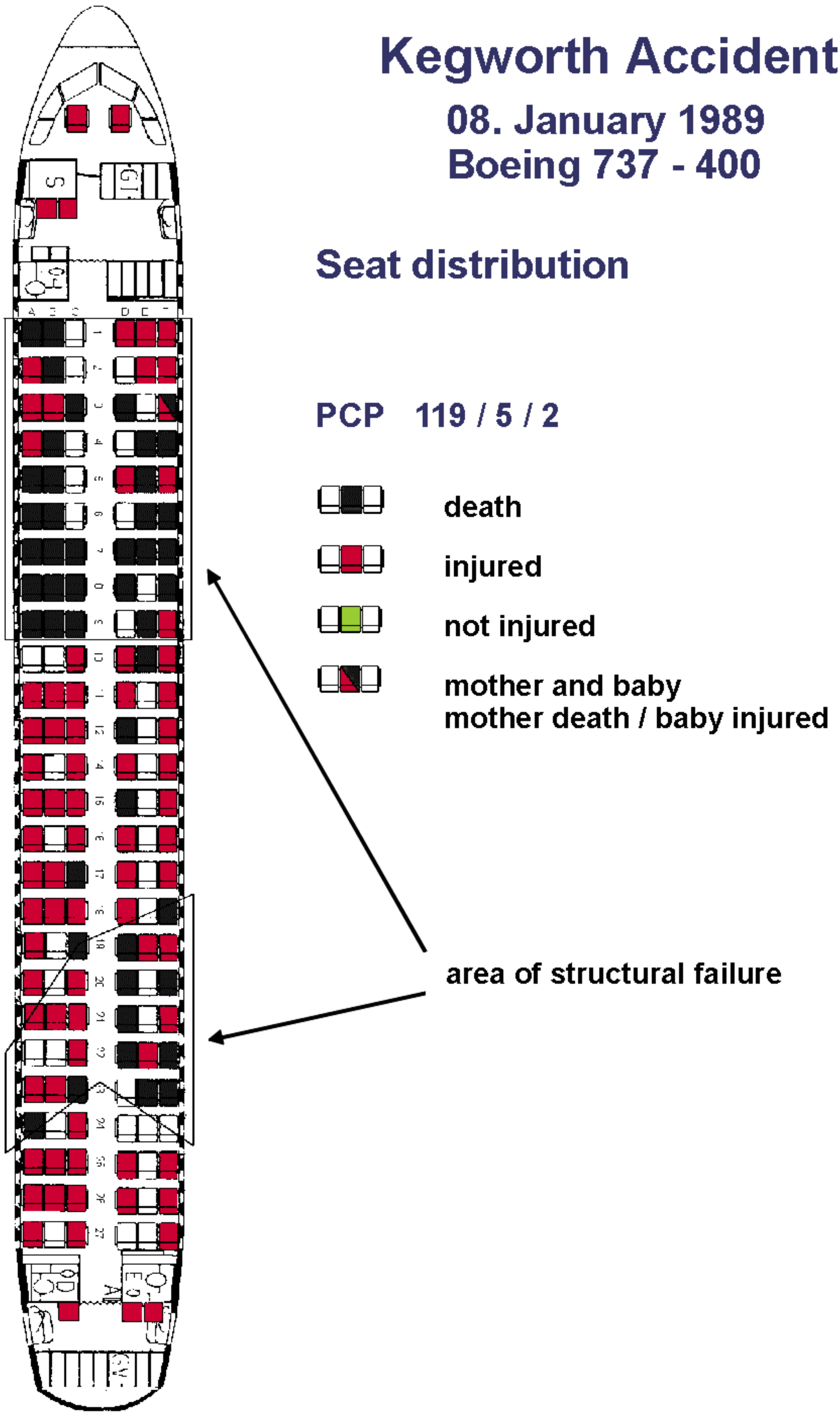


Figure 5.2-15 Head injuries of all survivors - Kegworth

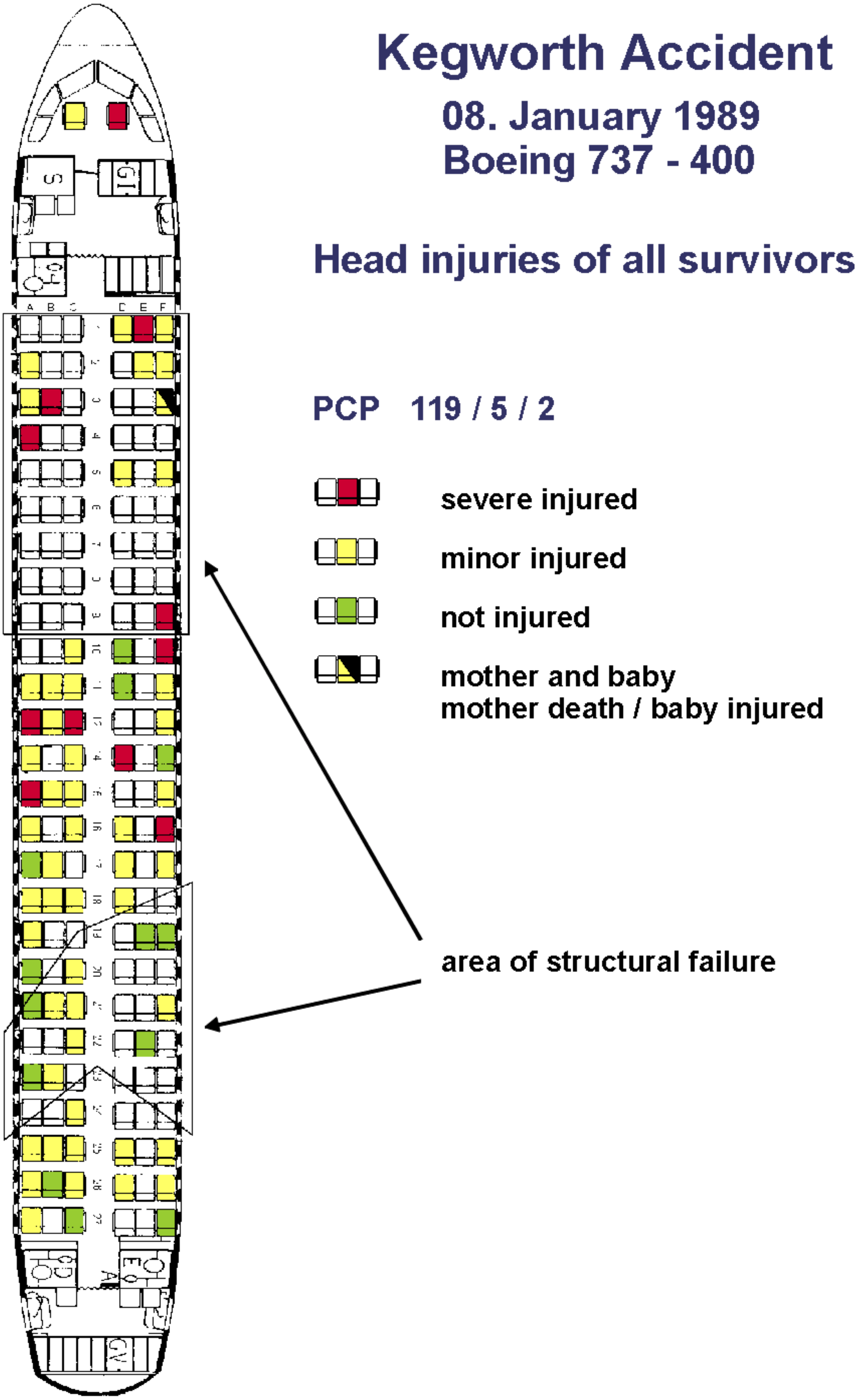


Figure 5.2-16 Spinal injuries of all occupants - Kegworth

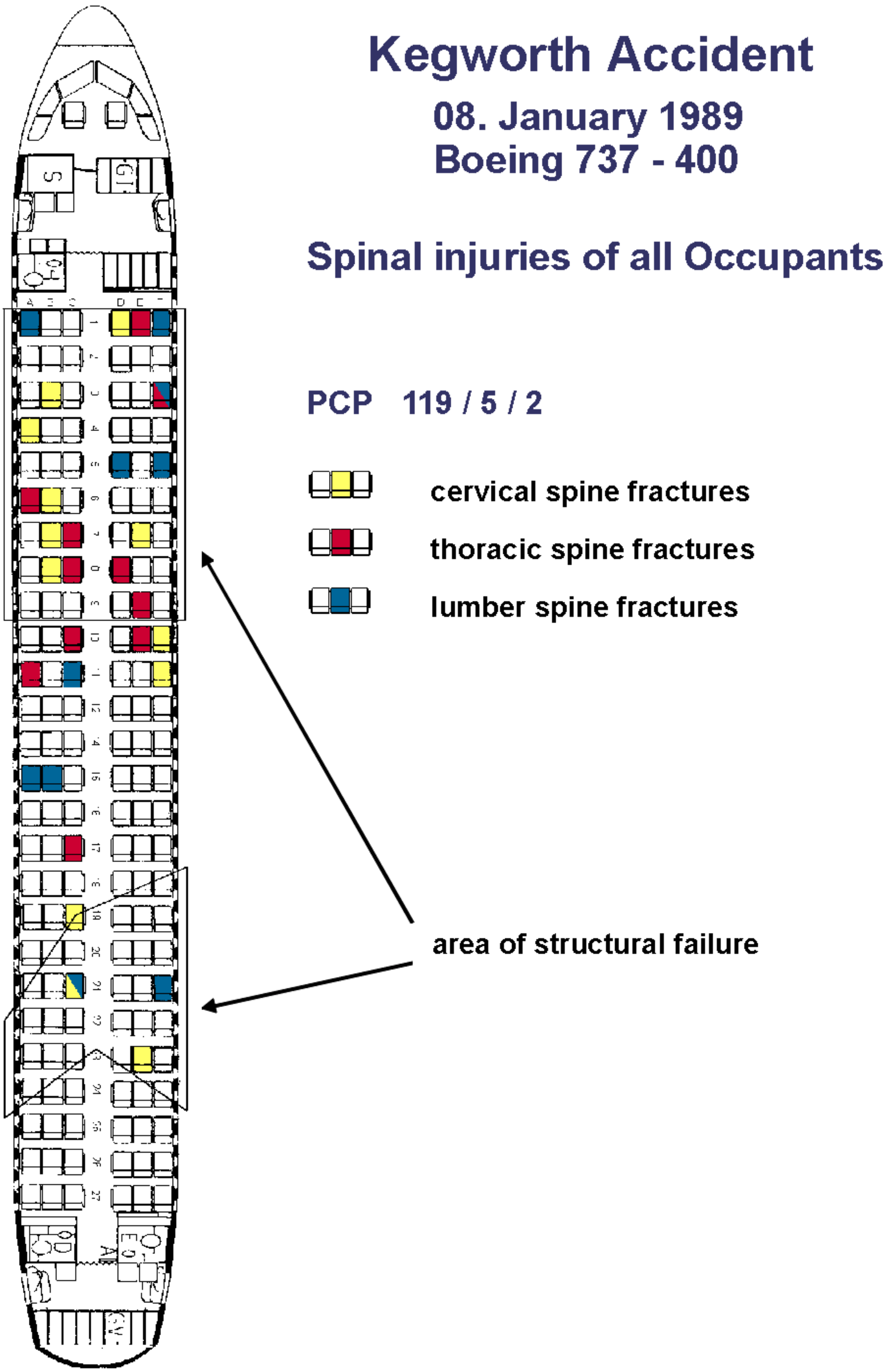


Figure 5.2-17 Leg injuries of all survivors - Kegworth

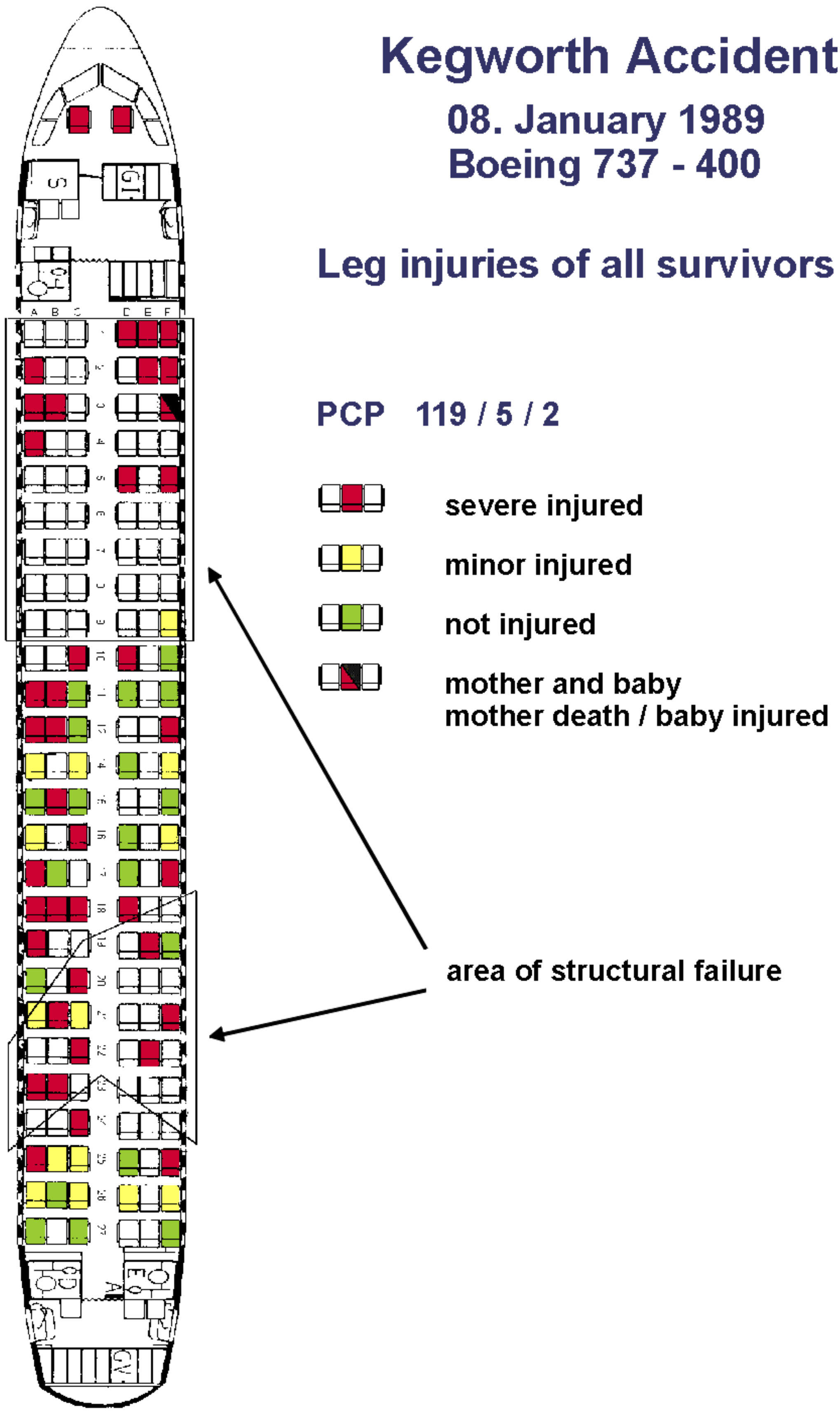


Table 5.2-2 AIS Scores - Kegworth

Kegworth-Accident			**Maximum Regional AIS Score**						
Seat	**Outcome**	**ISS**	**Head**	**Face**	**Chest**	**Abdomen**	**Extremities**	**External**	**Structural Damage**
1A	D	50	5	2	4	2	3	2	10
1B	S	26			4		3	1	10
1D	S	22	3		2		3	1	10
1E	S	19	3				3	1	10
1F	S	14				2	3	1	10
2A	S	10					3	1	10
2B	D	21		1	4		2		10
2E	S	14			2		3	1	10
2F	S	11		1			3	1	10
3A	S	14				2	3	1	14
3B	S	43	5		3		3	1	14
3C	D	43	4		4	3	3	1	14
3D	D	27	3	2	3		3	1	14
3F	S	41	2	1	4	4	3	2	14
3F*	S	14	2				3	1	14
4A	S	50	5	4		1	3	1	30
4B	D	34	3		4		3	2	30
4E	S	27	2		3	3	3	1	30
4F	D	34	4		3	3	3	1	30
5A	D	27	3		3		3	2	30
5B	D	34	3	2	4	2	3	2	30
5D	S	14				2	3	1	30
5E	D	29			4	2	3	1	30
5F	S	34			3	4	3	2	30
6A	D	75			6	5	3	3	30
6B	D	75	6	4	5	4	3	2	30
6E	D	75	5	2	6	3	3	2	30
6F	D	75	3		6	5	3	2	30
7A	D	75	1	1	6	3	3	2	30
7B	D	75	6	4	5	2	3	1	30
7C	D	75	4	3	6		3	2	30
7D	D	66	4		5	5	3	2	30
7E	D	75	6		4	3	3	2	30
7F	D	75	6	2	3	2	4	1	30
8A	D	75	6	3		5	3	2	30
8B	D	75	6		5	5	3	2	30
8C	D	75	6	3	5		3	2	30
8D	D	75	5		6		3	2	30
8F	D	75	6	4	4	3	3	2	30
9A	D	34	4		3	3	3	1	30
9B	D	34	3	1	4		3	2	30
9C	D	75		1	6		3	2	30
9E	D	38	3	1	5		2	2	30
9F	S	22	3		3		2	2	30
10C	S	29	2	2	4		3	1	11
10D	S	22			3		3	2	11
10E	S	41	5		4				11
10F	S	17	3			2	2	1	11
11A	S	27	3	2	3	2	3	2	0
11B	S	10					3	1	0
11C	S	17			3	2	2	1	0
11D	S	1						1	0
11F	S	8	2					2	0
12A	S	45	4	1	5	2	3	1	0
12B	S	27	2		3	3	3	1	0

Kegworth-Accident			**Maximum Regional AIS Score**						
Seat	**Outcome**	**ISS**	**Head**	**Face**	**Chest**	**Abdomen**	**Extremities**	**External**	**Structural Damage**
12C	S	14	3				2	1	0
12D	S	33	5				2	2	0
12F	S	27	3		3		3	2	0
14A	S	3			1		1	1	0
14C	S	14	2				3	1	0
14D	S	43	5		4			1	0
14F	S	9	2				2	1	0
15A	S	9				2	2	1	0
15B	S	14	2			1	3	1	0
15C	S	4						2	0
15D	S	45	5		4		2	1	0
15F	S	2				1		1	0
16A	S	2		1				1	0
16C	S	5					2	1	0
16D	S	1						1	0
16F	S	12	2			2	2	1	0
17A	S	6				1	2	1	6
17B	S	19			3		3	1	6
17C	D	38			5	3		2	6
17D	S	12			2	2	2	1	6
17F	S	9				2	2	1	6
18A	S	5					2	1	19
18B	S	5					2	1	19
18C	S	9	2		1		2	1	19
18D	S	13					3	2	19
18F	S	11				1	3	1	22
19A	S	10					3	1	22
19C	D	75	6		5		3	2	22
19D	D	57	4	1	5	4	3	1	22
19E	S	22	2		3		3	1	22
19F	S	2				1		1	22
20A	S	5					2	1	22
20C	S	26			4	1	3	1	22
20D	D	36	4		4	2		2	27
20F	S	30			5	2		1	27
21A	S	10					3	1	27
21B	S	6				1	2	1	27
21C	S	41	4		3	4	3	1	27
21D	D	41	3		4	4	2	2	27
21F	S	11			1		3	1	27
22C	S	11			1		3	1	27
22D	D	66	5		5	4	3	1	27
22E	S	19				3	3	1	27
22F	D	47	4		5	4	3	2	27
23A	S	19	3				3	1	27
23B	S	9	2				2	1	27
23C	D	75			6	3	3	1	27
23E	D	75	6		5	4	3	1	27
23F	D	75	4		6	5	4	2	27
24A	D	43	3		5	3	3	1	24
24C	S	17	2				3	2	24
25A	S	10					3	1	11
25B	S	6			1	1	2	1	11
25C	S	5					2	1	11
25D	S	14	2				3	1	11
25F	S	24	4				2	2	11
26A	S	2					1	1	11

Kegworth-Accident			Maximum Regional AIS Score						
Seat	Outcome	ISS	Head	Face	Chest	Abdomen	Extremities	External	Structural Damage
26B	S	9		2			2	1	6
26C	S	1						1	6
26D	S	6				1	2	1	6
26F	S	5					2	2	6
27A	S	1						1	4
27C	S	2				1		1	4
27F	S	1						1	4

Key: D= Deceased at scene; S= Survived impact.
3F* infant in mother´s arms.

5.3 Evaluation Injury Criteria (WP 3)

5.3.1 Objective and basis of WP 3

WP 3 "Evaluation of Injury Criteria" gives an overview of all criteria in aircraft and automotive technology. WP 3 shows the possibility of transferring results from the automotive sector to the aircraft sector. The evaluation criteria for an enhanced passive safety are investigated in view of their applicability in an aircraft cabin.

5.3.2 General aspects for passive safety in aircrafts

The accident analysis (see Chapter 5.2) demonstrates that the structure of the aircraft fuselage may be damaged after a crash, but for every passenger, there must remain a survival area. An aircraft-typical survival area can be described as follows: it consists of the cabin floor, the fuselage wall, the ceiling, overhead bins, the passenger seat and seats or bulkheads occupied by the passengers (compare Figure 5.3-1).

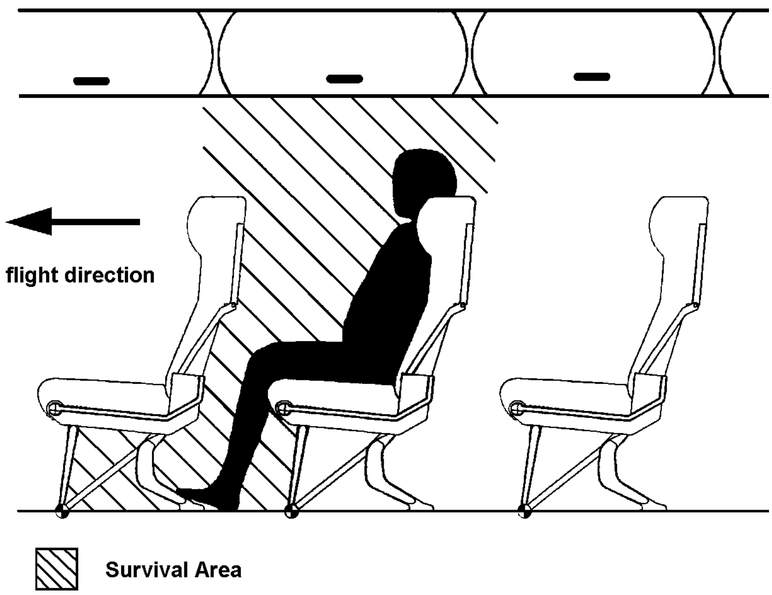


Figure 5.3-1 survival area in aircraft cabins

Passengers are restrained with the pelvic belt in their seat. All forces acting due to the restraint effect run over the seat frame and must be introduced into the seat rails on the cabin floor. The pelvic belt allows passengers a relatively large forward displacement in a longitudinal deceleration. An impact of the head, chest, and upper and lower extremities on structural parts of the seat in front or other components in the cabin are thus tolerated.

If passive safety of passengers in an aircraft cabin is to be improved, the seat must be considered together with the pelvic belt and also the immediate surroundings of the respective seat must be considered.

5.3.3 Regulations of the Economic Commission for Europe (ECE-Regulation) for vehicles

The following Chapter outlines the requirements of the ECE-Regulations as regards the protection criteria for enhancing the passive safety in vehicles. Any ECE Regulations which are not transferable to aeronautical engineering are not considered in more detail.

5.3.3.1 Reference systems (H-Point) of the human body

The dimensions, masses and defined reference points of the human body are used e. g. for designing and dimensioning car seats and for determining hazard potentials in the vehicle interior. The definition and determination of the reference points is outlined e. g. in the ECE-R 17, 21, and 94.

Though the human joints have no exact rotational axes, it is sufficient to define simple, theoretical rotational axes which come very close to real-life motions of the joints, rather than the complicated actual anatomic relations. The rotational point between the centrelines of the torso and the femurs is of particular significance (see H-point / rotational point of the torso line - femur line, Figure 5.3-2). This theoretical intersection - which is in the human median plane (perpendicular longitudinal centreplane) is called the Hip-point (H-point).

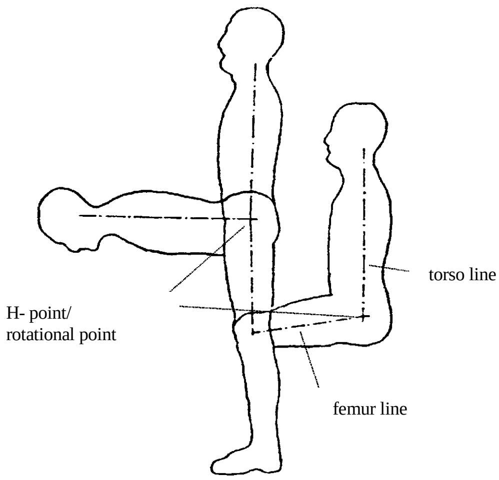


Figure 5.3-2 the H-point

The position of the H-point in a motor vehicle or an aircraft is due to the respective seats, e.g. the seat assembly and the materials used. Thus, e. g. differently padded seats also have a different H-point position (compression behaviour).

The H-point is determined with a so-called three-dimensional H-point-machine (3DH machine). The 3DH machine is mainly made of the back and seat pan, and the leg elements (see Figure 5.3-3).

The dimensions and the weight of the 3 DH machine correspond to those of a 50 percentile male person with a mass of 70 kg. For measuring the H-point, the 3 DH machine is attached to the measured seat, and the load masses for the torso, the buttock weights as well as for the lower legs and femurs are fixed in the focal points of the body segments.

In the measured aircraft passenger seats, the position of the H-points is due to the front stud of the seat and the cabin floor surface.

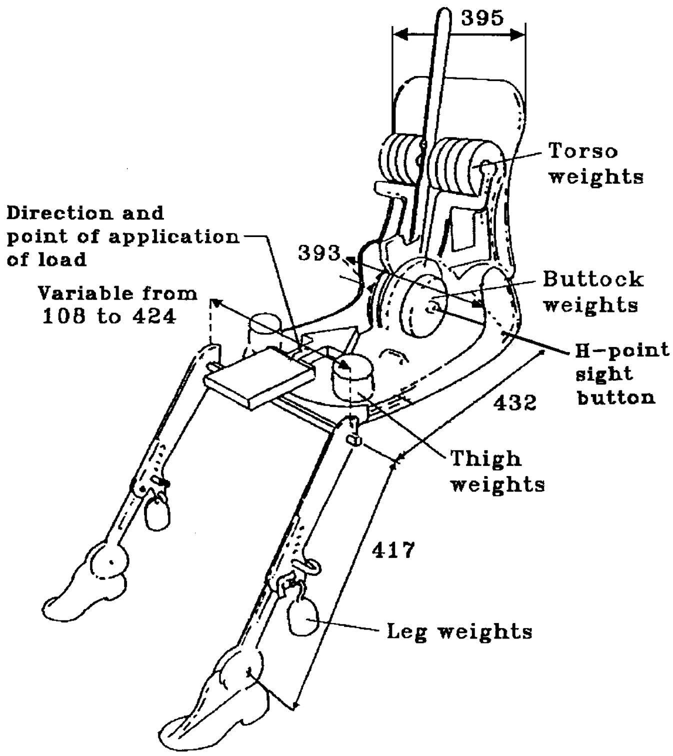


Figure 5.3-3 3DH machine

5.3.3.2 ECE - R 12 Protection of driver against steering mechanism

The ECE - R 12 "Uniform provisions concerning the approval of vehicles with regard to the protection of the driver against the steering mechanism in the event of impact" is not relevant for aircraft passengers.

5.3.3.3 ECE - R 14 Vehicles approval with regard to safety-belt anchorages

ECE - R 14: "Uniform provisions concerning the approval of vehicles with regard to safety-belt anchorages". This regulation applies to anchorages for safety-belts for adult occupants of forward-facing seats in vehicles.

Apart from the hardness test of the safety-belt anchorage points, also their position is evaluated. We will not deal with hardness tests here in more detail since comparable procedures are outlined in the SAE AS8049 (Aerospace Standards (AS) of the

Engineering Society For Advancing Mobility Land, Sea, Air and Space (SAE) with the term SAE AS8049 Revision A "performance standard for seats in civil rotorcraft and transport aeroplanes").

The position of the lower safety-belt anchorage points is assessed from a reference point, see Figure 5.3-4. The angle between the horizontal plane and the safety-belt anchorage points of the pelvic belts is predefined. The minimum distance between the safety-belt anchorage points is defined as well.

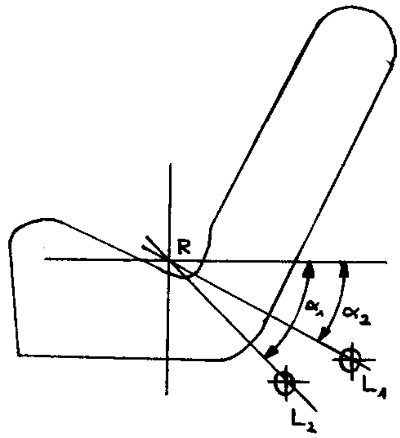


Figure 5.3-4 Location of belt anchorages (L1, L2)

For aircraft passenger seats with the pelvic belts attached directly to them, the following values result due to the ECE-R 14 (L1 = left hand side; L2 = right hand side):

- angle to the reference point (α_1, α_2): 60 deg ± 10 deg
- minimum distance between the anchorage points (L_1, L_2): 350 mm

For the reference point, it must be distinguished between a constructively determined point (R-Point), and a measured point (H-Point), see ECE R14. The reference point is generally above the seating area and takes, among other things, the compression of the seat padding by the passenger into consideration.

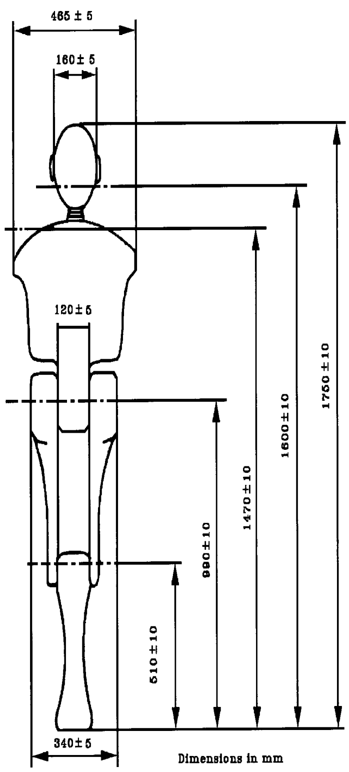
5.3.3.4 ECE-R 16 Safety-belts and restraint systems

ECE-R 16: "Uniform provisions concerning the approval of safety-belts and restraint systems for adult occupants of power-driven vehicles". The Regulation applies to safety-belts and restraint systems for separate use, i.e. as an individual equipment, by persons of adult build and facing forward in the seats.

The ECE-R 16 defines restraint systems as systems made up of the seat attached to the vehicle structure and the safety belt attached to the seat.

The ECE-R 16 requires a dynamic test of the restraint systems. For this purpose, the restraint system shall be mounted on a test carriage (sled). Then, a test dummy shall be fastened on the seat.

The test dummy (manikin) has a mass of 74.5 kg ±1 kg, and an upright height of 1750 mm ± 10 mm, compare Figure 5.3-5. The test carriage shall be accelerated to 50 km/h ± 1 km/h at the crash moment without being propelled. The deceleration of the test carriage measured over the time shall reach a value between 26 g and 32 g, see Figure 5.3-6. The stopping distance of the test carriage shall be 40 cm ± 5 cm.



Components of manikin	Mass in kg
Head and neck	4,6 ± 0,3
Torso and arms	40,3 ± 1,0
Thighs	16,2 ± 0,5
Lower leg and foot	9,0 ± 0,5
Total mass including correction weights	74,5 ± 1,0

Figure 5.3-5 ECE-R16, Description of the manikin

The test shall meet the following conditions:

- no part of the belt assembly or a restraint system affecting the restraint of the occupant shall break and no buckles or locking or displacement system shall release or unlock; and
- the forward displacement of the manikin shall be between 80 mm and 200 mm at pelvic level in the case of lap belts.

A major part of the tests outlined in this Regulation is comparable to the tests of the aviation Joint Technical Standard Order JTSO C114 "Torso Restraint Systems" and JTSO–C22g "Safety Belts").

Accordingly to ECE-R 16, aircraft passenger seats with a pelvic belt shall be classified as restraint systems.

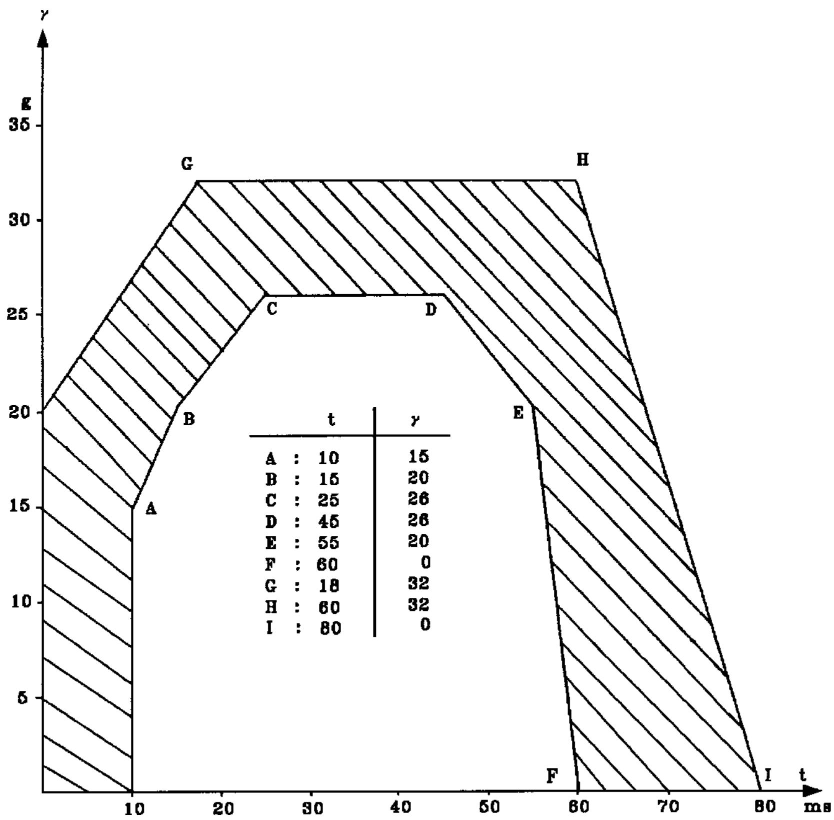


Figure 5.3-6 ECE-R16, Deceleration as a function of time

5.3.3.5 ECE-R 17 Seats, their anchorages and head restraints

The ECE-R 17 "Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorages and head restraints" applies to the strength of the seats and their anchorages, whether or not fitted with head restraints in motor vehicles. The regulation is additionally used for designing the **rear parts of seat-backs**.

The Regulation 17 presupposes, among other things, that the components of a seat cause a different risk of injury in an accident. It depends e. g. which body segments may contact which seat components. From this result requirements for the energy absorbing of seat components, and requirements e.g. for minimum radii of curvature.

The ECE-R 17 outlines requirements for parts projecting from the surface of the seat-backs. Depending on the impact area at the seat-backs, the projecting parts shall be blunted and padded.

Head restraints, if present, shall comply with specific requirements. In accordance with the ECE-R 17, head restraints shall have a height of at least 800 mm for front seats and for the other seats 750 mm, measured from the H-point of the seat. The aircraft passenger seats tested in the following are not fitted with head restraints within the meaning of this regulation, see chapter 5.6.4.

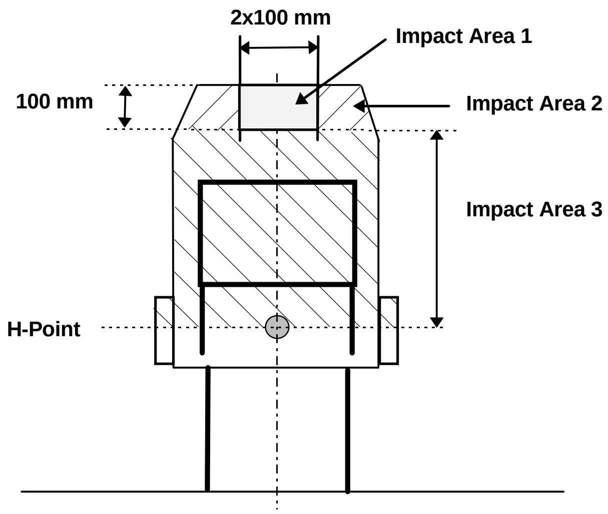


Figure 5.3-7 Areas (rear view of a passenger seat)

Figure 5.3-7 depicts the rear view of an aircraft passenger seat for which the three impact areas are marked according to the Regulation 17.

Excepted from this Regulation are those parts within the individual impact areas which project by less than 3.2 mm from the surface, which are twice as broad as high and have blunted edges. All other parts shall comply with the requirements listed in the Table 5.3-1.

Table 5.3-1 Requirements for the ECE R 17

impact area	minimum requirements for radii of curvature (mm)	energy absorption test
1	> 2.5 mm	< 80 g over 3 ms, after test no sharp edges
2	2.5 - 5.0 mm	< 80 g over 3 ms, after test no sharp edges
3	> 3.2 mm	---

The energy absorption test must be done for all impact points with radii of curvature less than 5 mm in the impact area 1 and 2. If the impact areas 1, 2 or 3 contain parts covered with material softer than 50 Shore (A) hardness, the rigid parts under the cover shall apply the minimum radii of curvature of Table 5.3-1.

5.3.3.6 ECE-R 21 Interior fittings

The ECE-R 21 "Uniform provisions concerning the approval of vehicles with regard to their **interior fittings**" applies to the interior parts, the arrangement of the controls, the roof, the seat-back and the rear parts of seats.

The ECE-R 21 deals with the passenger compartment in the driver and frontseat passenger area both seated in the front seats as well as the backseat passengers.

The rear part of the seats mounted in the vehicle and the roof area are assessed separately.

The hazard potential by control handles, levers, knobs, any other projecting objects, shelves and the edges of structural components fitted with energy-absorbing materials are considered.

Front Interior

The impact area of aircraft passenger seats above the reference height (head impact area) is determined with a test disc 165 mm in diameter attached with a thread to the H-point of the seat centre. The dimension from the pivotal point of the hip to the top of the head is continuously adjustable between 736 mm to 840 mm (compare Figure 5.3-8.). The impact area is determined and assessed within these adjustments.

The maximum downward movement is to a position where the head is tangential to a horizontal plane situated 25.4 mm above the H point. In a backward movement, the area is limited by a vertical plane which passes through the H-point.

Below the H-point, the “foot space“ is detected with a knee template for each seat aimed at recording projecting components, structures, shelves etc.. The knee template is similar to a wedge with a flank tilt angle of 2x 30 percent, a length of 250 mm and a width of 120 mm. The wedge tip is rounded, having a radius of 60 mm (compare ECE-R 21).

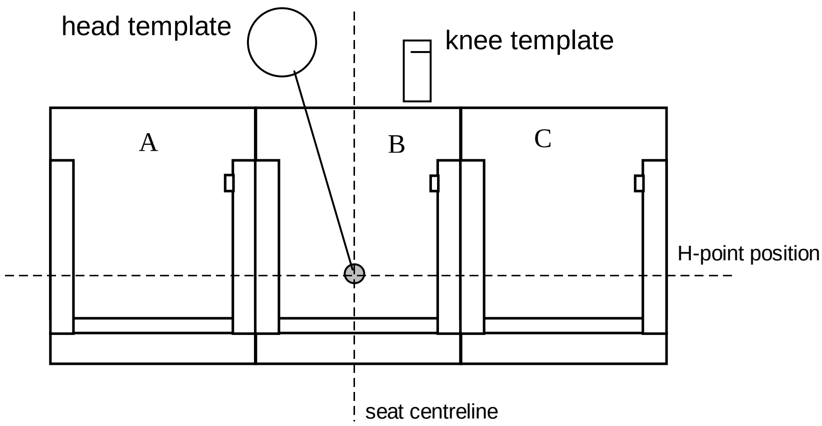


Figure 5.3-8 Determination of the head impact area and the knee area
(top view of a triple seat row in an aircraft)

A spherical headform apparatus shall be used for determining the height of projecting edges or control elements (see Figure 5.3-9, as outlined in the ECE-R 21).

Rigid structural elements shall have specific radii of curvature above and below the H-point if such structural elements lie behind a covering which is softer than 50 Shore A (compare table below).

Separate tests are necessary for assessing the energy absorbing of structural parts and components. Such tests could be carried out e. g. on a drop test platform. The test is performed with a dropping body hitting on the component. The deceleration of the impact is measured in the longitudinal direction. The dropping body simulates a head with a weight of 6.8 kg and a diameter of 165 mm. When hitting on the tested component, the dropping body shall reach a speed of at least 24.1 km/h. The deceleration measured in the impact shall not exceed the value of 80g over cumulatively 3 ms. If so, the energy absorbing capacity of the component shall be improved. Energy absorbing tests have not been made within the framework of ICEPS.

Figure 5.3-9 Spherical headform apparatus for measuring projections and edges

Roof area:

In the aircraft cabin, the roof area corresponds to that area which lies above the passengers' heads and can be reached by them. Any projections shall be tested which can be contacted by the spherical headform in the roof area (see Figure 5.3-10). The projecting edges should have a radius (R) of more than 5 mm, and their width (W) should be larger than their height (H) (see Figure 5.3-11). If the radii of such protrusions are smaller, their energy absorbing capacity shall be verified in accordance with the ECE-R 21.

Figure 5.3-10 Determination of projections in the roof area

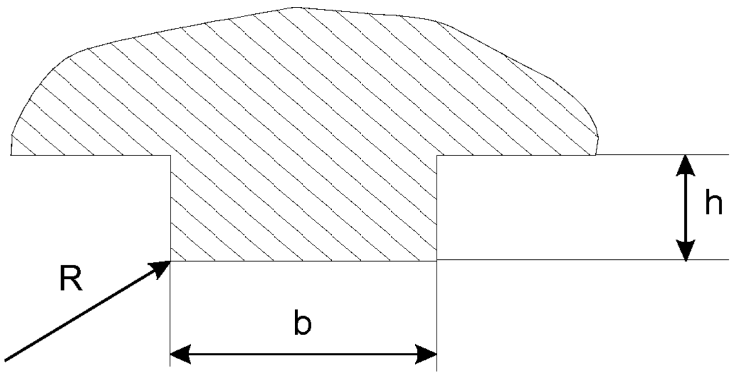


Figure 5.3-11 ECE-R 21 projections

Rear compartment:

Handles, levers, knobs and other projections in the rear compartment are considered which are located in front of the transversal plane of the H-point machine placed in the rear seats, and above the H-point. Those components are tested within the considered area which are contacted by a spherical headform apparatus (compare Figure 5.3-10).

Overview of the requirements according to the ECE-R 21:

impact areas	requirements
"head impact area“ in the front interior above reference level	Dangerous uneven surfaces and sharp edges shall be avoided. The edge radii shall be at minimum 2.5 mm. Excepted from this are protrusions projecting by less than 3.2 mm as well as such protrusions which are twice as long as wide and the edges of which are broken. The lower part of the instrument panel shall have a radius of more than 19 mm. The level of switches, knobs, handles, levers etc. shall be determined as defined in the ECE-R 21. If these components project between 3.2 mm and 9.5 mm, they shall have a surface not smaller than 2.0 qcm, and the edge radii should be at least 2.5 mm; longer switches, knobs etc. shall be impressible or tear off in accordance with the ECE-R 21. For switches, knobs, handles, levers etc. which are covered with a material softer than 50 Shore A, such soft material shall be removed. The remaining hard structure shall be tested directly, as outlined above. Any components within the "head impact area" shall be energy-absorbing, as defined in this ECE Regulation.
impact area in the front interior below reference level	Any protruding components which can be reached by the test wedge, shall be tested, such as switches, knobs etc. (see above). Storage shelves shall have no sharp edges. Storage shelves pointing to the interior shall • have a front height of at least 25 mm; their edge radius shall not be smaller than 3.2 mm, and an energy absorbing test shall be made, or • if storage shelves substantially deform or yield under a longitudinal force of 37.8 daN as defined in the ECE-R 21 without developing dangerous edges at the borders. • If part of a component is made of materials which are softer than 50 Shore A, such material shall be removed, and the storage shall be tested as outlined above. It is not necessary to perform an energy absorbing test.

impact areas	requirements
back interior	Where the handles, levers and knobs of operating facilities are touched by a test sphere with a diameter of 165 mm, the requirements for the head impact shall be fulfilled as outlined above. The edge radii of these components shall be at least 3.2 mm. Any levers, knobs etc. shall substantially deform or dissolve under a longitudinal force of 37.8 daN as defined in the ECE-R 21, without producing dangerous edges at the borders. Overhead lamps, handles, sun visors and other components which are not part of the roof construction shall have radii of curvature of at least 3.2 mm. If the width of protruding components is smaller than their vertical height, their energy absorbing capacity shall be tested. For rigid carriers etc. which are covered with a material softer than 50 Shore A. the above mentioned test shall be performed directly at such rigid carrier.
roof area	The roof shall have no sharp edges nor dangerous uneven surfaces. Any components which can be touched by a test sphere with a diameter of 165 mm shall meet the following requirements: • The width of protruding components shall not be smaller than their vertical height. Their edge radius shall be at least 5 mm. • Any rigid protrusions or rips shall not project by more than 19 mm downwards unless they pass the energy absorbing test.

5.3.3.7 ECE-R 25 Head restraints

ECE-R 25: "Uniform provisions concerning the approval of head restraints (headrests), whether or not incorporated in vehicle seats".

Head restraints shall meet particular requirements outlined in the ECE-R 17, such as the level of the head restraints. The tests of the aircraft passenger seats demonstrated that the seat-backs are shorter than required in the ECE Regulation (see ECE-R 17). Accordingly, the ECE-R 25 is not relevant.

5.3.3.8 ECE-R 32 Structure behaviour of impacted vehicles in rear-end collisions

The ECE-R 32 "Uniform provisions concerning the approval of vehicles with regard to the behaviour of the structure of the impacted vehicle in a rear-end collision" is not relevant.

5.3.3.9 ECE-R 33 Structure behaviour of impacted vehicles in head-on collisions

The ECE-R 33 "Uniform provisions concerning the approval of vehicles with regard to the behaviour of the structure of the impacted vehicle in a head-on collision" is not relevant.

5.3.3.10 ECE-R 94 Protection of occupants at frontal collisions

ECE-R 94: "Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision".

The regulation applies to power-driven vehicles with regard to the protection of the occupants of the front outboard seats.

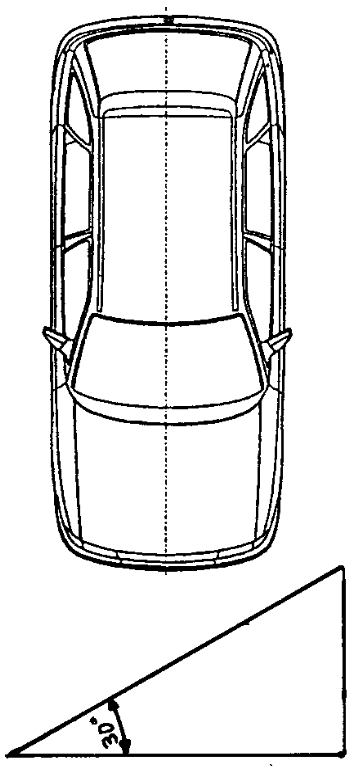


Figure 5.3-12 30°Barrier Test

In the test, the vehicle rolls against a barrier turned by 30 deg. at a speed of 50 km/h +0/-2 km/h, see Figure 5.3-12, so that the inboard side touches the barrier first. The test shall be carried out with Hybrid III Dummies which shall be seated on the two front seats.

Measurements of dummies in front seats are to be made in the following way:

- the acceleration referring to the centre of gravity in the head of the dummy;
- the chest deflection in the thorax of the dummy;
- the axial compression force in the femur of the dummy.

If the backseats are not fitted with three-point-safety belts, the seat behind the drivers` seat shall additionally be occupied with a Hybrid II Dummy without instrumentations.

The performance criteria of the dummies shall, among other things, fulfil the following conditions:

- head performance criterion (HPC) ≤ 1.000;
- thorax performance criterion (ThPC) ≤ 75 mm;
- femur performance criterion (FPC) ≤ 10 kN;
- After the impact, it shall be possible, without the use of tools, to release the dummies from the restraint system.

A detailed outline of the criteria can be found in Chapter 5.3.5.

5.3.3.11 ECE-R 95 Protection of occupants at lateral collisions

ECE-R 95: "Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision".

This Regulation deals with the lateral collision of a mobile barrier against the vehicle. Investigated are, among other things, the loads on the occupants which are caused by the components or structures displaced in the interior (Intrusion). This kind of loads is relevant in survivable aircraft accidents only in very rare cases.

5.3.3.12 Overview of the regulations for passive safety

The table shows the European and US regulations. Those regulations were compared each which outline similar or comparable requirements.

Economic Commission for Europe (ECE)		Federal Motor Vehicle Safety Standards (FMVSS), USA	
Regulation No.	**Title**	**Regulation No.**	**Title**
ECE-R 12	... protection of the driver against the steering mechanism ...	Art. 571.203 Art. 571.204	Impact protection for the driver from the steering control system. Steering control rearward displacement.
ECE-R 14	... safety-belt anchorages	Art. 571.210	Seat belt assembly anchorages
ECE-R 16	... safety-belts and restraint systems for adult occupants ...	Art. 571.209	Seat belt assemblies
ECE-R 17	... seats, their anchorages and head restraints	Art. 571.207	Seating systems
ECE-R 21	... interior fittings	Art. 571.201	Occupant protection in interior impact
ECE-R 25	... head restraints (Headrests) ...	Art. 571.202	Head restraints
ECE-R 32	... the behaviour of the structure of the impacted vehicle in a **rear-end** collision	Art. 571.301	Fuel system integrity (barrier crash)
ECE-R 33	... the behaviour of the structure of the impacted vehicle in a **head-on** collision	---	
ECE-R 94	... protection of the occupants in the event of a **frontal** collision	Art. 571.208	Occupant crash protection
ECE-R 95	... protection of the occupants in the event of a **lateral** collision	Art. 571.214	Side Impact protection

5.3.4 Directive 96/79/EC frontal impact

The Directive 96/79/EC of the European Parliament and of the European Council issued on 16 December 1996 outlines the protection of motor vehicle occupants in the event of a frontal impact.

The Regulation outlines a 40 percent offset test with a vehicle against a deflectable barrier (see Figure 5.3-13). The barrier has a width of 1000 mm and a height of 800 mm and is made of aluminium honeycombs.

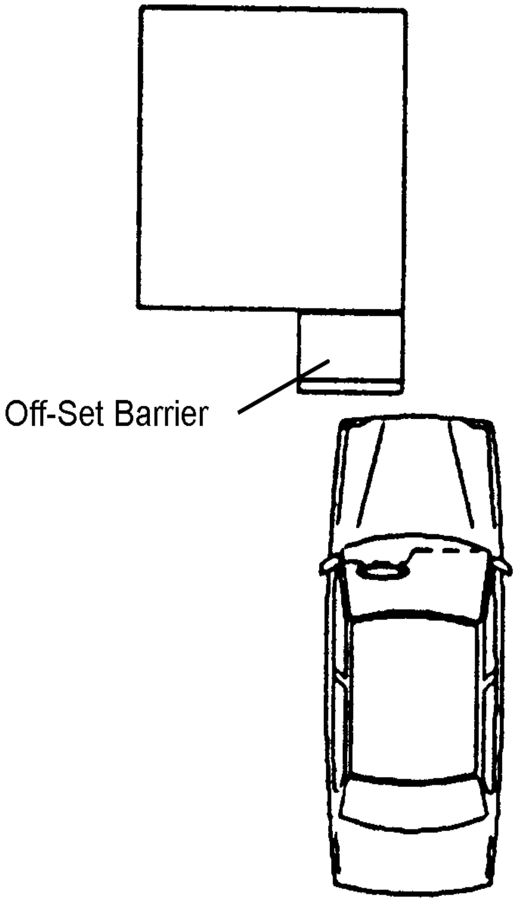


Figure 5.3-13 40 percent offset test

The vehicle shall be fitted with Hybrid III dummies on the front seats and shall reach a test speed of 56 km/h +1/-0 km/h in the collision. The vehicle shall overleap the barrier face by 40 percent ± 20 mm.

The performance criteria for the dummies shall meet the following conditions:

- the head performance criterion (HPC) shall not exceed 1000, and the resultant head acceleration shall not exceed 80 g for more than 3 ms. The latter shall be calculated cumulatively;
- the neck injury criterion (NIC) may not exceed the time-based tolerance limits for the torsion load (3,3 kN \ 0 ms; 2,9 kN \ 35 ms; 1,1 kN \ =60 ms) and shearing load 3,1 kN \ 0 ms; 1,5 kN \ 25-35 ms; 1,1 kN \ =45 ms);
- the neck bending moment around the y axis shall not exceed 57 Nm in extension;
- the thorax compression criterion (ThCC) shall not exceed 50 mm;
- the viscous criterion (V*C) for the thorax shall not exceed 1.0 m/s;

- the femur force criterion (FFC) shall not exceed the force-time performance criterion (9,07 kN \ 0 ms; 7,58 kN ≥ 10 ms);
- the tibia compression force criterion (TCFC) shall not exceed 8 kN;
- the tibia index (TI), measured at the top and bottom of each tibia, shall not exceed 1,3 at either location;
- the movement of the sliding knee joints shall not exceed 15 mm;
- after the impact, it shall be possible, without the use of tools, to release the dummies from their restraint system and to remove the dummies from the vehicle without adjusting the seats.

A detailed outline of the criteria can be found in Chapter 5.3.6.

5.3.5 Requirements of the Joint Aviation Authorities (JAA) for aircrafts

In Europe, aircraft approvals are based on the Joint Aviation Requirements (JAR). The JAR distinguish between large aeroplanes (JAR 25), propeller-driven aeroplanes and commuters (JAR 23), large rotorcraft (JAR 29) and small rotorcraft (JAR 27). The JAR's outline, among other things, requirements to emergency landing conditions and the emergency evacuation.

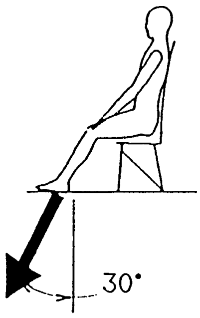
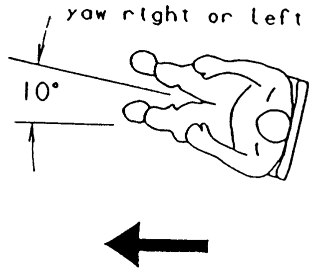
5.3.5.1 Emergency landing conditions

The JAR "emergency landing dynamic conditions" define, among other things, the following requirements:

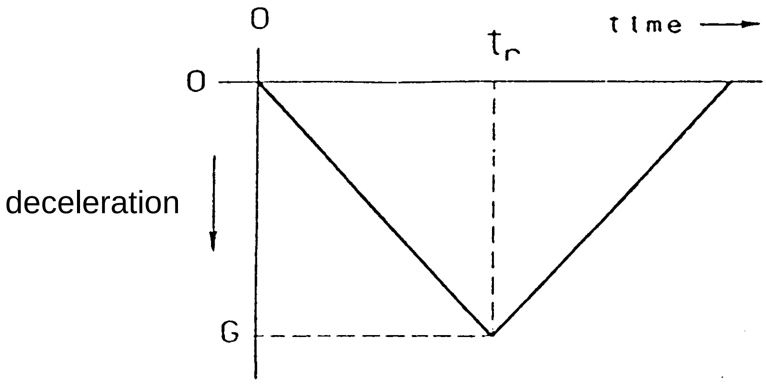
- the seat and restraint system in the aeroplane shall protect each occupant during an emergency landing condition;
- each seat type design approved for passenger occupancy shall successfully complete dynamic tests or be demonstrated by rational analysis;
- the tests shall be conducted with an occupant simulated by a 170-pound (77.11kg) anthropomorphic test dummy (Hybrid II) sitting in the normal upright position.

The JAR define different dynamic test requirements, depending on the respective aircraft type. The **JAR 25.562** is relevant for **large aeroplanes**.

The dynamic tests are outlined in the Aerospace Standards (AS) of the Engineering Society For Advancing Mobility Land, Sea, Air and Space (SAE) with the term SAE AS8049, Revision A: "performance standard for seats in civil rotorcraft and transport aeroplanes". The following overview (Figure 5.3-14) lists the dynamic impact test parameters for large aeroplanes.

JAR 25	Downward Test	Forward Test
Illustration shows a forward-facing seat Inertial load shown by arrow		
Min V_t km/h (ft/s)	38 (35)	48 (44)
Max t (s)	0,08	0,09
Min G	14	16
deform floor:		
Degrees roll (°)	0	10
Degrees pitch (°)	0	10

Test Pulse Simulating Deceleration - Time History:



t_r = rise time
V_t = Impact Velocity

Figure 5.3-14 Dynamic impact test parameters

The injury criteria, measured with Hybrid II Dummies, shall not be exceeded during the dynamic tests:

- Head Injury Criteria (HIC): $HIC = (t_2-t_1)\, [\, 1/(t_2-t_1) \int a dt]^{2,5} \le 1000$

  t_1 and t_2 are an interval between the beginning and the end of the head contact.
- lumbar load: $\le$ 6.67 kN

  maximum compressive load measured between the pelvis and the lumbar spine

•	upper torso strap loads:	≤ 7.78 kN maximum tension in each strap
•	dual upper torso strap loads:	≤ 8.9 kN maximum total strap tension
•	femur loads	≤ 10 kN maximum axially compressive load in each femur

5.3.5.2 Seat-to-seat installation test

The Attachment to Policy Ltr. TAD-96-002 outlines dynamic tests for the evaluation of aircraft passenger seats which go beyond the JAR 25.562 "Emergency landing dynamic conditions". In this context, the head impact is considered with regard to potential critical impact zones. The HIC serves as an evaluation criterion and shall not exceed 1000.

The seat-back of the seat in front of a passenger is divided into three zones to be tested (see Figure 5.3-15). Since it can be assumed that the side of the seat-back with the recline mechanism is harder than the other side of the seat-back, zones A and B were defined on the left and on the right-hand side next to the table. Zone C is in the centre of the seat-back, in the area of the table attachment, a telephone or a screen.

The tests shall be performed with two aircraft passenger seat rows each, for testing zones A and B, the maximum seat pitch shall be adjusted. For testing zone C, the minimum seat pitch shall be adjusted.

Comments: Since the tests are always performed with a dummy it is impossible to hit a particular seat component with the dummy head. Nor are the impact areas e.g. of the arms, legs and feet tested.

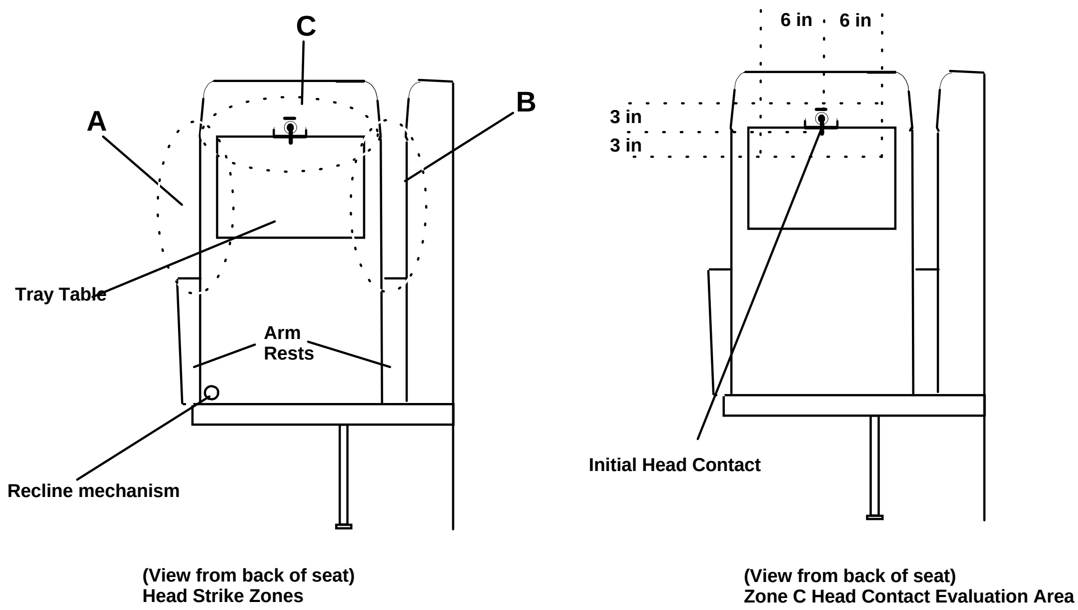


Figure 5.3-15 Head Strike Zones

5.3.5.3 Emergency evacuation

The JAR 25.803 outlines the requirements to an emergency evacuation for large aeroplanes, which include:

- each crew and passenger area shall have emergency means to allow a rapid evacuation in crash landings, considering the possibility of the aeroplane being on fire;
- for aeroplanes having a seating capacity of more than 44 passengers, it shall be shown that the maximum seating capacity can be evacuated from the aeroplane to the ground under simulated emergency conditions within 90 seconds;
- the simulated emergency conditions shall be shown by actual demonstration. A representative passenger load of persons in **normal health** shall be used;
- not more than 50 percent of the emergency exits in the sides of the fuselage of an aeroplane that meets all of the requirements applicable to the required emergency exits for that aeroplane may be used for the demonstration.

5.3.6 Description of Dummy Protection Criteria

Figure 5.3-18 show the summary of the dummy protection criteria in the aeronautic and automotive sector.

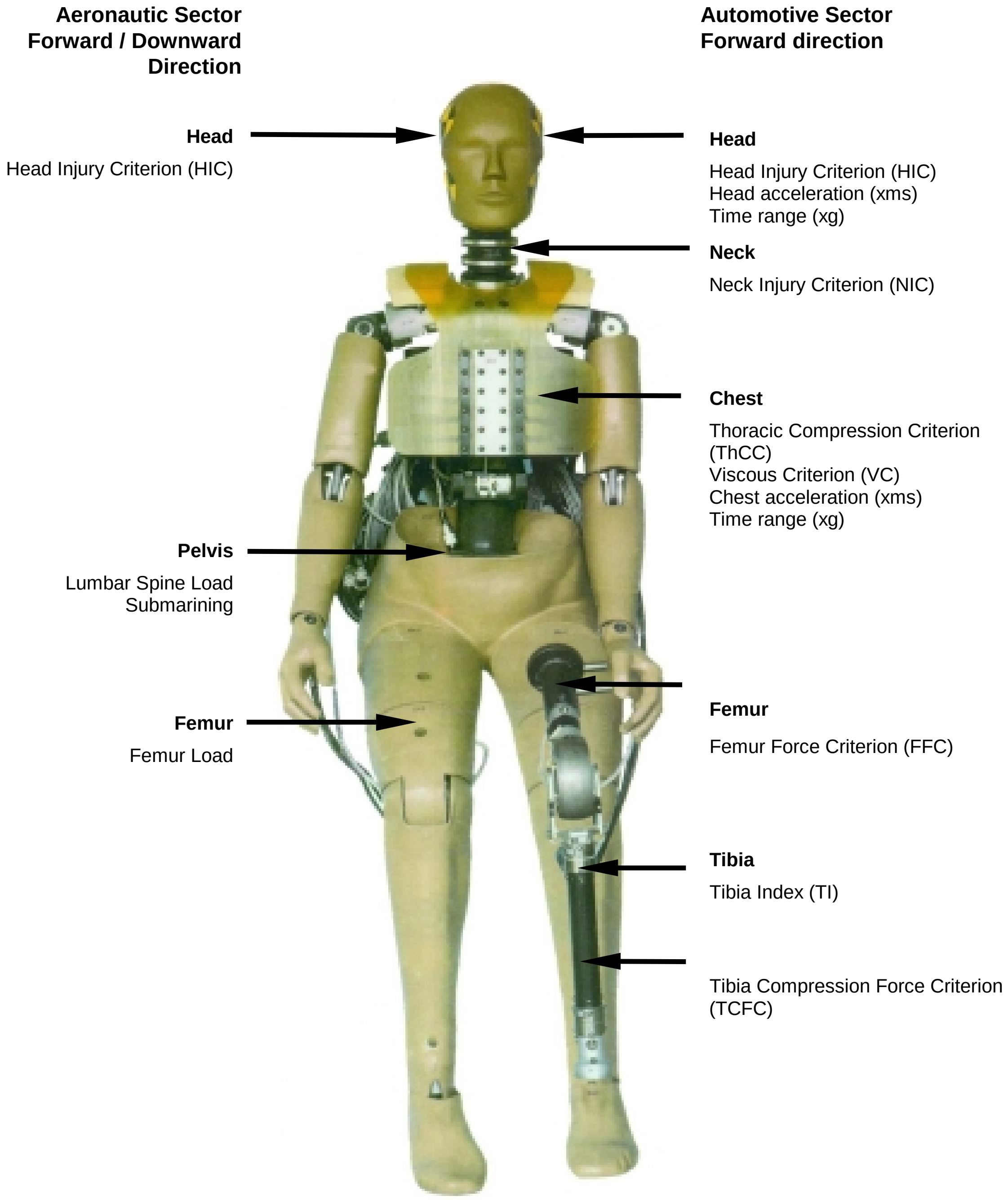


Figure 5.3-18 Dummy Protection Criteria

In order to present clearly the single criteria that are used for the evaluation of Crash tests and component tests, they are summarized briefly in the following.

First, there is a description of the criterion. Second a short description of the application area. This is followed by a specification of the mathematical calculation. Then there is an information about the laws and specifications with there individual pass/fail criteria.

The following criteria are described:

Head Criteria
- HIC
- HIC (d)
- HPC
- xms (a_{3ms})
- xg

Neck Criteria
- Time-Dependant
- NIC

Thorax Criteria
- VC
- xms (a_{3ms})
- xg
- ThCC

Pelvis Criteria
- Lumbar load
- pelvis restraint (submarining)

Femur Criteria
- FFC

Tibia Criteria
- TI
- TCFC

5.3.6.1 Head Criteria

5.3.6.1.1 HIC

HIC is the abbreviation for Head Injury Criterion.

Description

The HIC value is the standardized maximum integral value of the head acceleration. The length of the corresponding time interval is:

- unlimited : HIC
- maximum of 36 ms : HIC36
- maximum of 15 ms : HIC15

Application Area

In the automotive sector and the aeronautic sector, the HIC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

The calculation of the HIC value is based on the equation:

$$HIC = \sup_{t_1, t_2} \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \, dt \right]^{2,5} * \left(t_2 - t_1 \right) \right\}$$

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

with the resultant acceleration a of the centre of gravity of the head in units of each acceleration (g=9.81 m/s²). t1 and t2 are the points in time during the crash, for which the HIC is at a maximum. Measured times are to be specified in seconds.

Relevant Laws and Regulations with there individual pass/fail criteria:

FMVSS 208 „Occupant crash protection“
This standard specifies performance requirements for the protection of vehicle occupants in crashes.
Pass/fail criteria: The HIC36 shall not exceed 1000.

SAE AS 8049A „Performance Standard for seats in civil rotorcraft and transport airplanes“
This Aerospace Standard (AS) defines minimum performance standards, qualification requirements, and minimum documentation requirements for passenger and crew seats in civil rotorcraft and transport airplanes.
Pass/fail criteria: The maximum value of the HIC shall not exceed 1000 during head impact. Head impact is often indicated in the data by a rapid change in the magnitude of the acceleration. Alternatively, film of the test may show head impact that can be correlated with the acceleration data by using the time base common to

both electronic and photographic instrumentation, or simple contact switches on the impact surface can be used to define the initial contact time. t1 and t2 are the two time points, expressed in seconds, which define a period between the beginning of the head impact and the end of the recording, at which the HIC is at its maximum.

5.3.6.1.2 HIC(d)

HIC(d) is the Performance Criterion

Description

The HIC(d) value is the weighted standardized maximum integral value of the head acceleration and can be calculated from the HIC36 value.

Application Area

In the automotive sector the HIC(d) is used as a performance criteria for the interior when impacted by a free motion headform.

Mathematical Calculation

The HIC(d) value is then calculated in accordance with:

$$HIC(d) = 0{,}75446 * HIC36 + 166{,}4$$

with:

HIC36	HIC36 value (cf. HIC)

Relevant Laws and Regulations with there individual pass/fail criteria:

FMVSS 201 „Occupant protection in interior impact“
Pass/fail criteria: The HIC(d) shall not exceed 1000.

5.3.6.1.3 HPC

HPC is the abbreviation for Head Performance Criterion (criterion for the head strain)

Description

The HPC value is the standardized maximum integral value of the head acceleration. The length of the corresponding time interval is:

- maximum of 36 ms ref.: HPC36

The HPC value is identical to the HIC value.

Application Area

In the automotive sector the HPC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

The calculation of the HPC value is based on the equation:

$$HPC = \sup_{t_1,t_2}\left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right]^{2,5} * \left(t_2 - t_1\right)\right\}$$

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

with the resultant acceleration a of the centre of gravity of the head in units of each acceleration (g=9.81 m/s²).

If no head contact has been made, then this criteria is considered fulfilled.

If the beginning of the head contact can be determined satisfactorily, t1 and t2 are the two time points, expressed in seconds, which define a period between the beginning of the head contact and the end of the recording, at which the HPC36 is at its maximum.

If the beginning of the head contact cannot be determined, t1 and t2 are the two points in time, expressed in seconds, which define a period between the beginning and the end of the recording, at which the HPC36 is at its maximum.

Relevant Laws and Regulations with there individual pass/fail criteria:

ECE 94 „Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision"

Pass/fail criteria: The HPC must not exceed 1000.

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/fail criteria: The HPC must not exceed 1000.

5.3.6.1.4 xms (a_{3ms})

xms is a generalization of the 3ms value

Description

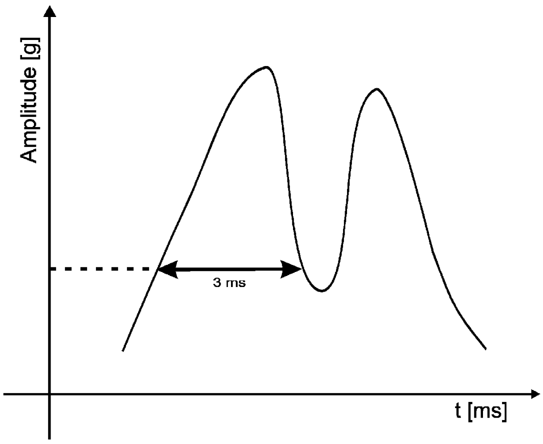
The xms value is the largest amplitude of an acceleration or a resultant acceleration expressed in units of earth acceleration g, that exceeds the level of the last specified duration for at least x milliseconds. The xms value is determined either individually (single peak, SAE) or as a group (multiple peaks, ECE R94, FMVSS). In the cumulative calculation, disconnected periods of the resultant acceleration are added until X ms is achieved.

Application Area

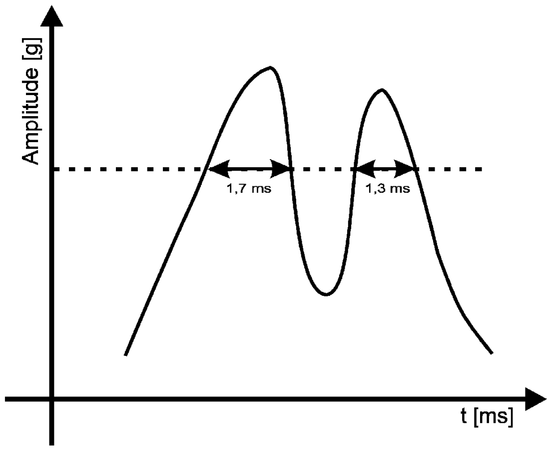
In the automotive sector the xms is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human. The xms is also used in component tests using a drop tower for energieabsorption tests.

Mathematical Calculation

- Calculation within a peak:



- Calculation over several peaks:



The calculation of the accumulated xms value can be based on the following algorithm, if the sampling rates are constant:

1. Measured values sorted in descending order
2. Acceleration value (sorted) in accordance with X ms is the required xms value.

During calculations in accordance with ECE R94, the rebound movement of the head is not to be taken into account.

Relevant Laws and Regulations with there individual pass/fail criteria:

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/fail criteria: The resultant head acceleration shall not exceed 80 g for more than 3 ms. The latter must be calculated cumulatively.

ECE R17, "Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorage and head restraints"

Pass/fail: This requirement is deemed to be met if in the tests carried out by the procedure specified in Annex 6 of ECE R17 the deceleration of the headform does not exceed 80 g continuously for more than 3 ms. Moreover, no dangerous edge shall occur during or remain after the test.

ECE R25, "Uniform provisions concerning the approval of head restraints (headrests), whether or not incorporated in vehicle seats"

Pass/fail: The deceleration of the headfrom shall not exceed 80 g continuously for more than 3 milliseconds.

5.3.6.1.5 Xg

Description

The Xg value is the time range for an acceleration that is greater than X[g].

Application Area

In the automotive sector the Xg is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human. The Xg is also used in component tests using a drop tower for energieabsorption tests.

Mathematical Calculation

The Xg-value is determined either singly (single peak) or combined/cumulative (multiple peaks) and corresponds to the time duration for which the resultant head acceleration was greater than X[g].
In the cumulative calculation, disconnected time ranges for which the resultant head acceleration was greater than X[g], are added up.

Relevant Laws and Regulations with there individual pass/fail criteria:

ECE R17, "Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorage and head restraints"

Pass/fail: This requirement is deemed to be met if in the tests carried out by the procedure specified in Annex 6 of ECE R17 the deceleration of the headfrom does not exceed 80 g continuously for more than 3 ms. Moreover, no dangerous edge shall occur during or remain after the test.

ECE R25, "Uniform provisions concerning the approval of head restraints (headrests), whether or not incorporated in vehicle seats"

Pass/fail: The deceleration of the headfrom shall not exceed 80 g continuously for more than 3 milliseconds.

5.3.6.2 Neck Criteria

5.3.6.2.1 Time-Dependant

Time-Depend Loading Criteria

Description

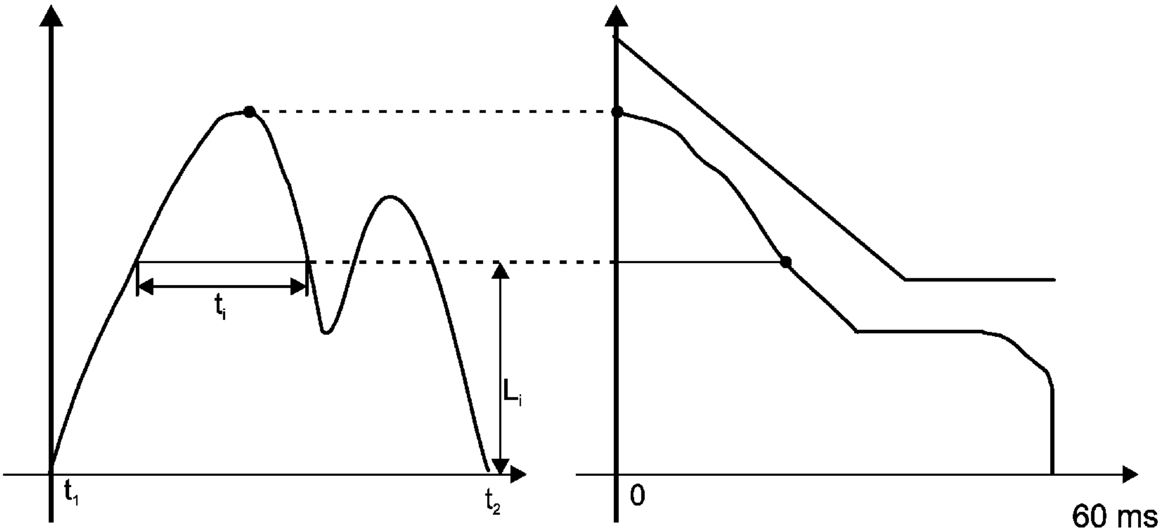
The time-depend loading criterion describes the maximum connected time interval during which the measurement of a signal has exceeded a particular lower threshold.

Application Area

In the automotive sector the Time- Depend Loading criterion is used in Crash- Tests with Anthropomorphic Test Device (ATD).

Mathematical Calculation

The method used to determine the connection between the measurement of the signal (e.g. the effective force) and its corresponding time-depend loading criterion, the time-depend „load criterion curve“ is as follows:



1. The threshold values are plotted on the ordinate, the durations on the abscissa.
2. This point is plotted on the ordinate of the criterion graph.
3. Divide the maximum value by 100. Create a matrix of two columns and 101 rows. In the first column store the load levels starting with the peak value. Every subsequent threshold value in this column corresponds to its predecessor; less the quotient, calculated from the maximum value divided by 100. Determine the maximum value of the criterion load and assign a duration of zero to it.
4. For each load in the first column, determine the maximum continuous time interval that the measure load exceeds the prescribed load level. Use linear interpolation to determine the time interval, round to the nearest millisecond and store in the second column of the matrix created in (b).
5. Each row of the matrix now defines a load and duration point. Plot these points on the criterion graph with its injury assessment reference boundary. Plot only those points whose durations are less than 60ms.
6. For each load-and-duration point, compute the ratio of the value of the time-dependent.

Load criterion curve divided by the value of the injury assessment

boundary and multiply by 100. The greatest value of these calculations is the injury assessment reference value for the loading curve.

Relevant Laws and Regulations with there individual pass/fail criteria:

SAE J1727, Injury Calculation Guidelines
Pass/ fail: -

5.3.6.2.2 NIC

NIC is the abbreviation for Neck Injury Criterion.

Description

The criteria for the neck injury are determined by the axial force of pressure, the axial tensile force and the shear forces at the intersection of the head and shoulders, expressed in kN, as well as the duration of these forces in ms. The criterion for the neck-bending-moment is determined by the bending moment, expressed in Nm, and recorded around a lateral axis at the intersection of the head and neck.

Application Area

In the automotive sector the NIC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

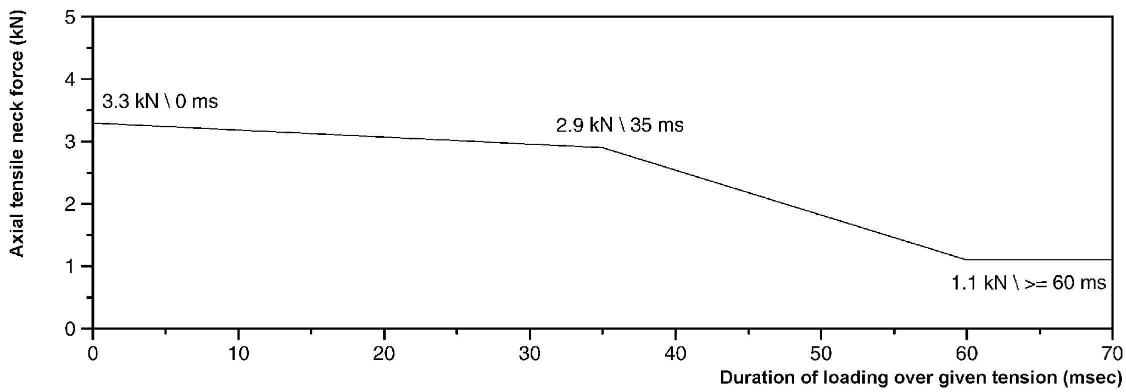
Mathematical Calculation

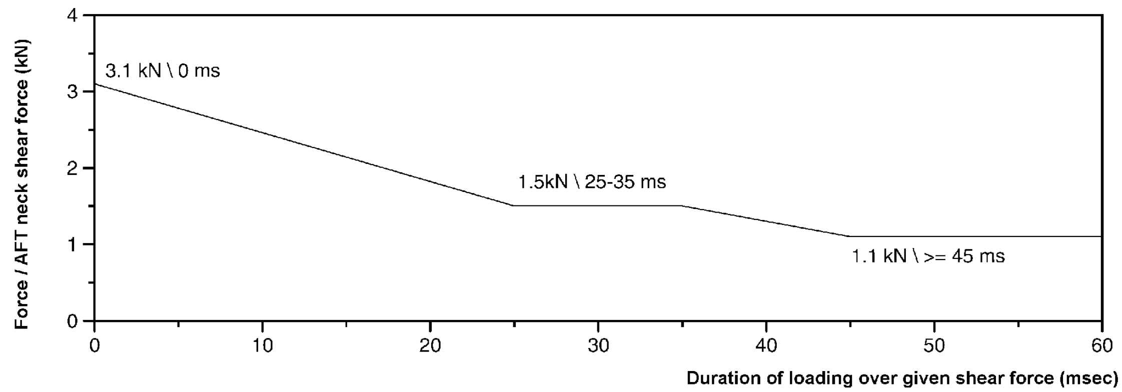
cf. time-dependent loading criteria

Relevant Laws and Regulations with there individual pass/fail criteria:

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/fail: The neck injury criteria (NIC) must not exceed the values shown in Figures below.





The neck bending moment about the y axis must not exceed 57 Nm in extension.

5.3.6.3 Thorax Criteria

5.3.6.3.1 VC

VC is the abbreviation for Viscous Criterion (velocity of compression), and is also called the Soft Tissue Criterion.

Description

VC is an injury criterion for the chest area. The VC value [m/s] is the maximum of the momentary product of the thorax deformation speed and thorax deformation. Both quantities are determined by measuring the rib deflection (side impact) or the chest deflection (frontal impact).

Application Area

In the automotive sector the VC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

The VC value is calculated using the following formulas:

- In accordance with ECE R94:

  $$VC = Scalingfactor * (Y_{CFC180} / Defconst.) * (dY_{CFC180} / dt)$$

- In accordance with SAE J1727:

  $$VC = Scalingfactor * (Y_{CFC600} / Defconst.) * (dY_{CFC600} / dt)$$

with:

Y	Thoracic deformation [m]
(dY_{CFCxxx} / dt)	Deformation speed
Scalingfactor	Scaling factor (depends on the type of dummy)
Defconst.	Dummy constant, i.e. depth or width of half of the thorax [mm] (see Determination of the Input Sizes (VC))

The deformation speed is calculated in accordance with ECE R94:

$$\frac{dY[t]_{CFC180}}{dt} = V[t] = \frac{8 \cdot \left(Y[t+\Delta t] - Y[t-\Delta t]\right) - \left(Y[t+2\Delta t] - Y[t-2\Delta t]\right)}{12\Delta t}$$

with:

Δt	Time interval between the single measurements in seconds

Relevant Laws and Regulations with there individual pass/fail criteria:

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/ fail: The viscous criterion (V*C) for the thorax must not exceed 1,0 m/s.

5.3.6.3.2 xms (a_{3ms})

xms is a generalization of the 3ms value

Description

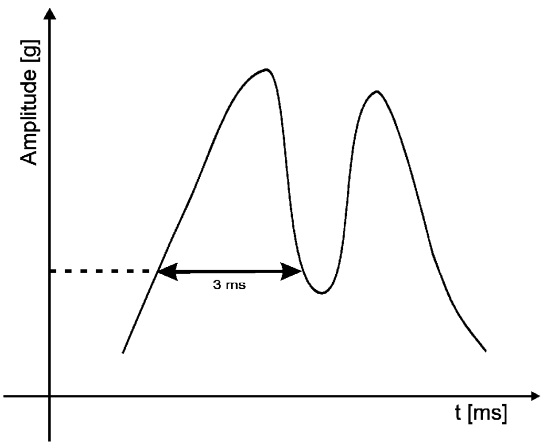
The xms value is the largest amplitude of an acceleration or a resultant acceleration expressed in units of earth acceleration g, that exceeds the level of the last specified duration for at least x milliseconds. The xms value is determined either individually (single peak, SAE) or as a group (multiple peaks, ECE R94, FMVSS). In the cumulative calculation, disconnected periods of the resultant acceleration are added until X ms is achieved.

Application Area

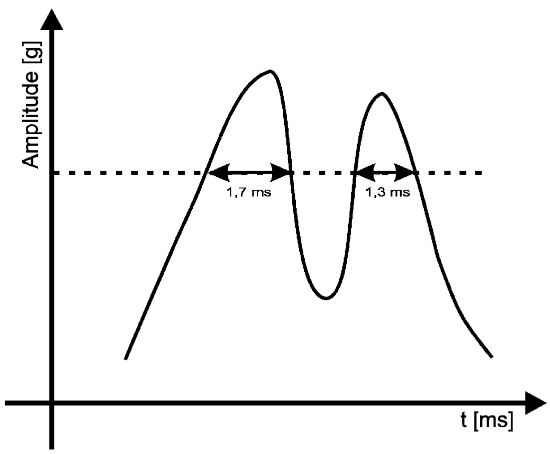
In the automotive sector the xms is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human. The xms is also used in component tests using a drop tower for energieabsorption tests.

Mathematical Calculation

- Calculation within a peak:



- Calculation over several peaks:



The calculation of the accumulated xms value can be based on the following algorithm, if the sampling rates are constant:

1. Measured values sorted in descending order
2. Acceleration value (sorted) in accordance with X ms is the required xms value.

Relevant Laws and Regulations with there individual pass/fail criteria:

ECE R44, "Uniform provisions concerning the approval of restraining devices for child occupants of power-driven vehicles ("Child Restraint System")"

Pass/fail: The resultant chest acceleration shall not exceed 55 g except during periods whose sum does not exceed 3 ms.

The vertical component of the acceleration from the abdomen towards the head shall not exceed 30 g except during periods whose sum does not exceed 3 ms.

ECE R12, "Uniform provisions concerning the approval of vehicles with regard to the protection of the driver against the steering mechanism in the event of an impact"

Pass/fail: When the steering control is struck by an impactor released against this control at a relative speed of 24.1 km/h, the deceleration of the impactor shall not exceed 80 g cumulative for more than 3 milliseconds.

FMVSS 208, „Occupant crash protection“

This standard specifies performance requirements for the protection of vehicle occupants in crashes.

Pass/fail criteria: The resultant acceleration at the centre of gravity of the upper thorax shall not exceed 60 g`s, except for intervals whose cumulative duration is not more than 3 milliseconds.

5.3.6.3.3 Xg

Description

The Xg value is the time range for an acceleration that is greater than X[g].

Application Area

In the automotive sector the Xg is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human. The Xg is also used in component tests using a drop tower for energieabsorption tests.

Mathematical Calculation

The Xg-value is determined either singly (single peak) or combined/cumulative (multiple peaks) and corresponds to the time duration for which the resultant head acceleration was greater than X[g].

In the cumulative calculation, disconnected time ranges for which the resultant head acceleration was greater than X[g], are added up.

Relevant Laws and Regulations with there individual pass/fail criteria:

ECE R12, "Uniform provisions concerning the approval of vehicles with regard to the protection of the driver against the steering mechanism in the event of impact"

Pass/fail: When the steering control is struck by an impactor released against this control at a relative speed of 24.1 km/h, the deceleration of the impactor shall not exceed 80 g cumulative for more than 3 milliseconds. The deceleration shall always be lower than 120 g with C.F.C 600Hz.

5.3.6.3.4 ThCC (or TCC)

ThCC (or TCC) is the abbreviation for Thoracic Compression

Criterion Description

ThCC is the criterion of the compression of the thorax between the sternum and the spine and is determined using the absolute value of the thorax compression, expressed in mm.

Application Area

In the automotive sector the ThCC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

-

Relevant Laws and Regulations with there individual pass/fail criteria:

ECE R94 „Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision“

Pass/ fail: The thorax compression criterion (ThCC) must not exceed 75 mm.

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/ fail: The thorax compression criterion (ThCC) must not exceed 50 mm.

Note:

This criterion is called the TCC in the German directive and ThCC in the English one.

5.3.6.4 Pelvis Criteria

5.3.6.4.1 Maximum compressive load in the lumbar column

Description

The maximum compressive load between the pelvis and the lumbar column of the dummy can be obtained directly from a plot or listing of the output of the load transducer at that location.

Application Area

In the aeronautic sector the compressive load in the lumbar column is used in dynamic tests with seats as an pass fail criterion.

Mathematical Calculation

-

Relevant Laws and Regulations with there individual pass/fail criteria:

SAE AS 8049A „Performance Standard for seats in civil rotorcraft and transport airplanes“
Pass/fail criteria: The maximum compressive load measured between the pelvis and the lumbar column of the anthropomorphic dummy does not exceed 6.67 kN (1,500 lbs.).

5.3.6.4.2 Retention of pelvis restraint (submarining)

Description
Retention of the pelvis restrained on the ATD's pelvis can be verified by observation of photometric or documentary camera coverage. The pelvis restraint shall remain on the ATD's pelvis, bearing on or below each prominence representing the anterior superior iliac spine, until ATD rebounds after the test impact and the pelvis restraint becomes slack. If the pelvis restraint does not become slack throughout the test, the belt shall maintain the proper position throughout the test.

Movement of the pelvis restraint above the prominence is usually indicated by an abrupt displacement of the belt onto the ATD's soft abdominal insert which can be seen by careful observation of photo data from a camera located to provide a close view of the belt as it passes over the dummy's pelvis. This movement of the belt is sometimes indicated in measurements of pelvis restraint load (if such measurements are made) by a transient decrease or plateau in the belt force, as the belt slips over the prominence, followed by a gradual increase in belt force as the abdominal insert is loaded by the belt. Retention of the pelvis restraint can also be verified by submarining indicators located on the ATD's pelvis without changing is essential geometry.

Application Area

In the aeronautic sector the retention of pelvis restraint is used in dynamic tests with seats as an pass fail criterion.

Mathematical Calculation

-

Relevant Laws and Regulations with there individual pass/fail criteria:

SAE AS 8049A „Performance Standard for seats in civil rotorcraft and transport airplanes“
Pass/fail criteria: The pelvis restraint remains on the anthropomorphic dummy’s pelvis during impact.

5.3.6.5 Femur Criteria

5.3.6.5.1 Femur Loads

Description
Data for measuring femur loads need to be collected in the tests discussed in this AS only if the ATD's legs contact seats or other structure. The maximum compressive load in the femur can be obtained directly from a plot or listing of each femur load transducer output.

Application Area

In the aeronautic sector the femur loads are used in dynamic tests with seats as an pass fail criterion.

Mathematical Calculation

-

Relevant Laws and Regulations with there individual pass/fail criteria:

SAE AS 8049A „Performance Standard for seats in civil rotorcraft and transport airplanes“

Pass/fail criteria: Where leg contact with seats or other structure occurs, the axial compressive load in each femur does not exceed 10,0 kN (2,250 lbs.).

5.3.6.5.2 FFC

FFC is the abbreviation for Femur Force Criterion

Description

FFC is the criterion of the force acting on the femur and is determined by the compression stress expressed in kN, which is transmitted axially to every femur of the dummy, as well as the duration of action of the compression force in ms.

Application Area

In the automotive sector the FFC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

cf. time-dependent loading criteria

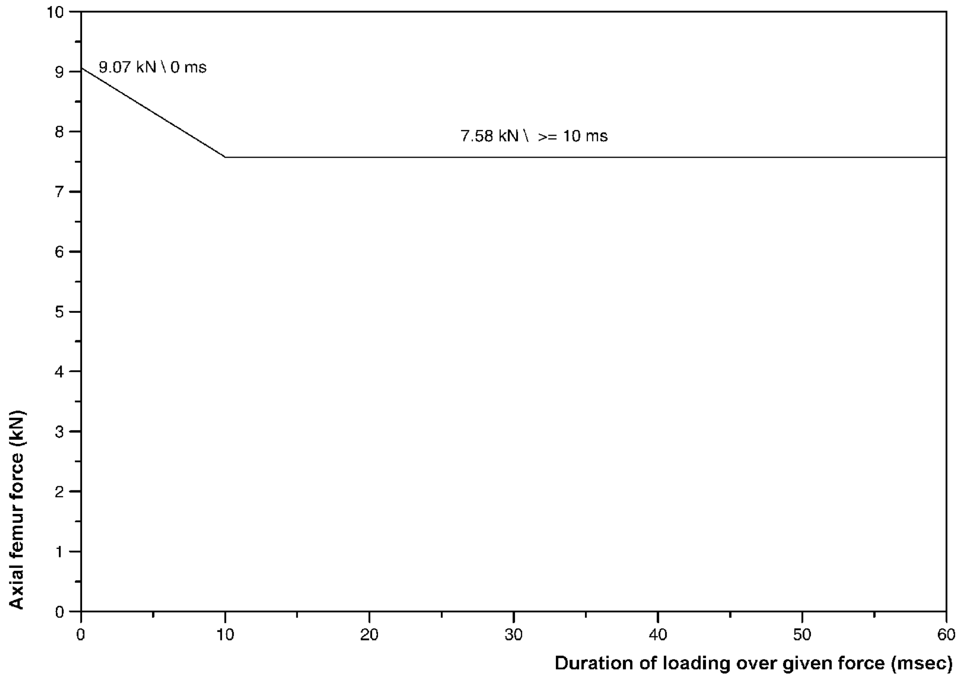
Relevant Laws and Regulations with there individual pass/fail criteria:

ECE R94 „Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision“

Pass/ fail: The femur performance criterion (FPC) must not exceed the 10 kN.

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/ fail: The femur criterion (FFC) must not exceed the force - time performance criterion shown in the figure below.



5.3.6.6 Tibia Criteria

5.3.6.6.1 TI

TI is the abbreviation for the Tibia Index

Description

The Tibia Index (TI) is an injury criterion for the lower leg area. It involves the bending moments around the x and y-axes as well as the axial force of pressure in the z direction at the top or bottom end of the tibia. If a „single-moment transducer“ is used the absolute measured value applies for the calculation. If there are two directions, the resultant moment is to be calculated and used.

Application Area

In the automotive sector the TI is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

The tibia index (TI) is calculated in accordance with:

$$TI = \left| \frac{M_R}{(M_C)_R} \right| + \left| \frac{F_Z}{(F_C)_Z} \right|$$

with:

M_R	$\sqrt{(M_x)^2 + (M_y)^2}$
M_X	Bending moment [Nm] around the x axis
M_Y	Bending moment [Nm] around the y axis
$(M_C)_R$	Critical bending moment (depends on the type of dummy)
F_Z	Axial force of pressure [kN] in z direction
$(F_C)_Z$	Critical force of pressure in z direction (depends on the type of dummy)

Relevant Laws and Regulations with there individual pass/fail criteria:

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/ fail: The tibia index (TI), measured at the top and bottom of each tibia, must not exceed 1,3 at either location

5.3.6.6.2 TCFC

TCFC is the abbreviation for Tibia Compression Force Criterion

Description

TCFC is the criterion for the tibia strain and is determined by using force of pressure Fz, expressed in kN, that is transferred axially to each tibia of the test dummy (cf. TI).

Application Area

In the automotive sector the TCFC is used in Crash-Tests with Anthropomorphic Test Device (ATD). An ATD is a dummy used in place of a human.

Mathematical Calculation

-

Relevant Laws and Regulations with there individual pass/fail criteria:

Directive 96/79/EC of the European Parliament and of the Council of 16 December 1996 on the protection of occupants of motor vehicles in the event of a frontal impact and amending Directive 70/156/EEC

Pass/ fail: The tibia compression force criterion (TCFC) must not exceed 8 kN.

5.3.7 Conclusions of WP 3

The protection criteria defined in the JAR 25.562 for the head, the thorax, the lumbar spine and the femurs and the additional criteria of the seat-to-seat tests are insufficient. The tests do not consider, among other things, the injury risks for the arms, legs, and feet.

After an emergency landing, it is e.g. absolutely necessary for the aircraft passengers and the crew to reach the exits and leave the aircraft themselves (compare JAR 25.803). It cannot be assumed that the evacuation is supported by rescue teams immediately. Only the passengers or crew members are on the spot to render first aid immediately after the crash.

The criteria for enhanced passive safety in aircraft cabins, which are described in Chapter 5.6 (WP6), should take the following aspects into account:

- head injuries which may lead to unconsciousness,
- leg injuries (femurs, tibiae, feet) which make it impossible to leave the aircraft oneself,
- hand and arm injuries which make it impossible for the affected person to unfasten the belts him or herself,
- injuries of the back which make it impossible to leave the aircraft oneself,
- other injuries, e. g. of the chest, abdomen, or cuts etc. should be as small as possible so that the person is able to leave the aircraft without assistance.

5.4 Correlation of injuries and evaluation criteria (WP 4)

The objective of Workpackage 4 is to demonstrate the interaction of injuries, or the failure behaviour of the cabin interior and evaluation criteria.

The basis is formed by the results of the workpackages WP2 (accident analysis) and WP3 (evaluation injury criteria), in particular the aircraft passengers' injuries found after the accidents and the provisions for the approval of vehicles and aeroplanes.

In a first step, the injury criteria were correlated to the body regions as defined for the Abbreviated Injury Score (AIS). The following body regions can be distinguished, and examples for injuries be given:

- head / face / brain, e.g. head injuries, lacerations in the face, contusions, concussions, cerebral contusions
- neck, e.g. vertebral fractures, splintered fractures of vertebral bodies, whiplash injuries
- upper extremities, e.g. humeral or antebrachial fractures, lacerations, contusions
- thorax, e.g. contusions and rib fractures
- spine, e.g. vertebral fractures, splintered fractures of the vertebral bodies
- abdomen, e.g. injuries of the soft parts, contusions
- pelvis, e.g. contusions
- lower extremities, e.g. femoral or tibia fractures, contusions

In the next step, the injuries were correlated to the decelerations effective during a crash.

Thereupon, the injuries are correlated to the protection criteria which were established in WP3 "Evaluation of Injury Criteria", both in view of the general severity of injury (survivability, permanent impairment), and for those injury criteria which are an import measurement for passengers' „self-evacuation", but have not been outlined sufficiently so far. Compared to a road accident, a passenger's ability to evacuate him or herself plays an integral role in an aircraft accident. In an aircaft crash, other than in a road traffic accident, sufficient external aid cannot be expected at short notice for quick evacuation.

5.4.1 The Warsaw accident

As outlined in WP2 (Chapter 5.2.1.1), the aircraft fuselage and seats have not been examined in detail. However, the statements made by the witnesses indicate that no striking damages have resulted in the aircraft cabin during the crash. Neither was the fuselage broken nor were any deformations seen in the fuselage interior. The passenger seats did not present striking damages or deformations. The overhead bins had not loosened from their anchorages, nor had they opened.

As outlined in WP2, it must be assumed from the Warsaw accident that the deceleration towards the vertical axis had more impact on the injuries than the deceleration towards the longitudinal axis.

It is not possible to make a direct correlation of injuries and damages to the aircraft cabins of the A320 for the accident in Warsaw. The deformations and damages to each aircraft seat can no longer be determined.

Based on the accident analysis which corresponds to the statements by the witnesses it can be assumed that the passengers' injuries were caused by the decelerations acting on the passengers during the crash rather than by deformations or structural failure of the fuselage, overhead bins or aircraft passenger seats. Figure 5.4-1 depicts the distribution of injuries, without considering the injuries the passengers had suffered during evacuation.

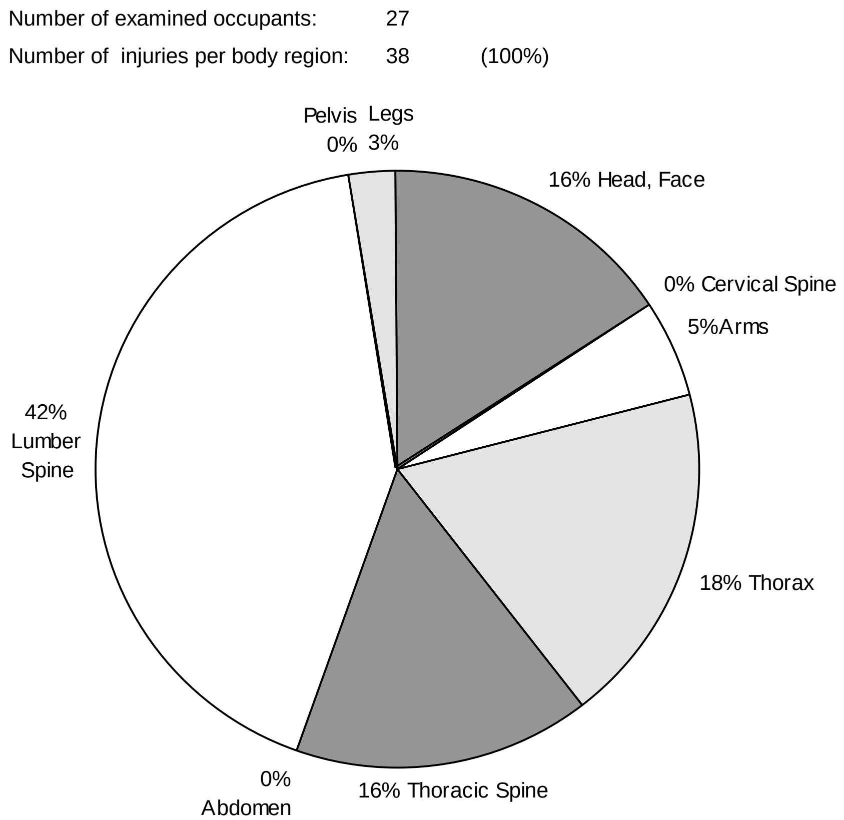


Figure 5.4-1 Distribution of injuries per body region - Warsaw accident -

A correlation of injuries and decelerations effective during the crash can be made only to a limited extent. Thus, the seating position during the crash and the way the passengers had fastened their pelvic belt had a crucial impact on the individual risk of injury besides the high biologic variability of factors such as age, sex, length, weight etc..

The high number of lumbar spine injuries is striking, despite these general restrictions. In particular the fractures of the vertebral bodies in the lumbar-thoracic junction (BWK12 / LWK 1) suggest that the passengers were exposed to a high deceleration in the longitudinal direction of the vertebral spine in the form of compression. This transitional region is anatomically and functionally particularly susceptible to compressions, because at this point, the physiological kyphosis of the thoracic spine leads into the lordosis of the lumbar spine, thus creating unfavourable combined loads.

The small number of leg injuries in the Warsaw accident is a sign for a relatively low deceleration towards the longitudinal axis. In high decelerations towards the longitudinal axis, the passengers' lower legs hit against the unpadded structure of the passenger seat in front. Due to the forces and moments effective in the legs, both the tibiae and femurs may break. In the analyses of the Kegworth accident, comprehensive examinations were performed in this context by the Queen's Medical Centre, Nottingham, where this connection was found (compare Chapter 5.4.2.).

As the passengers are fixed to the seat only with a pelvic belt, the torso moves forward due to flexion in the hip joint even in comparably small decelerations towards the longitudinal axis. The thus resulting head injuries may be explained by the fact that the deceleration first effective in the longitudinal direction of the aircraft moves the passenger's torso forward, and the torso then moves downward towards the vertical aircraft axis due to the strong deceleration, with the head hitting the seat-back of the aircraft seat in front of him or her or against his or her own knee joints. This motion pattern strongly depends, as was already outlined above, on the seating position and the way the passenger has fastened his or her seat-belt, which explains the relatively high number of head injuries compared to the low number of leg injuries.

The following table gives a correlation between the injuries in the Warsaw accident and known and new, unknown injury criteria:

Warsaw accident 14.09.1993											Known Relevant Injury Criterias											Unknown IC		
		Injuries by impact									Head		Neck	Chest			Abdo.	LS	Femur	Tibia		Arms	Thorax	Pelvis
Seat	alive	Head,Face	CS	Arms	Thorax	ThS	Abdo.	LS	Pelvis	Legs	HIC	a_{3ms}	NIC	ThCC	VC	a_{3ms}			FFC	TI	TCFC		ThS	
1A	s/d	2		2							x	x										x		
1B	s																							
2A	s																							
2D	s					2		2										x					x	
3A	s				1									-	-	-								
3C	s							1										-						
3D	s																							
3F	s																							
4A	s																							
4B	s																							
4C	s	2									x	x												
4F	s					2																	x	
5A	s					1		1										-					-	
5D	s																							
5E	s																							
5F	s	2			1						x	x		-	-	-								
6A	s																							
6B	s																							
6C	s				2	2								x	x	x							x	
6D	s					2		2										x					x	
6F	s																							
7A	s							2										x						
7D	s							2										x						
7F	s																							
8A	s																							
8B	s	2			2						x	x		x	x	x								
8C	s				2									x	x	x								
8D	s																							
8F	s																							
9C	s							2										x						
10D	s																							
10F	s																							

Key : s = Survived
d = Died

1 = Minor injuries
2 = Severe and fatal

x = Severe and fatal injuries assign to injury criterias
\- = Minor and fatal injuries assign to injury criterias

11A	s					1		1										-					-	
11C	s							2										x						
11D	s																							
11F	s				1			2						-	-	-		x						
12A	s																							
12F	s																							
14A	s							2										x						
14C	s																							
14F	s																							
15A	s																							
16A	s							1										-						
16D	s							2										x						
18D	s																							
18F	s																							
19A	s																							
19C	s																							
19D	s																							
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20D	s																							
20F	s																							
21A	s																							
21C	s																							
21F	s																							
22A	s																							
22D	s							2										x						
23A	s							1										-						
23B	s																							
23C	s			1	1					1				-	-	-			-	-	-	-		
23D	s	2									x	x												
25A	s	2									x	x												
25C	s							2										x						
26A	s																							

Key : s = Survived
d = Died

1 = Minor injuries
2 = Severe and fatal

x = Severe and fatal injuries assign to injury criterias
\- = Minor and fatal injuries assign to injury criterias

List of Abbreviations

CS	=	Cervical Spine
ThS	=	Thoracic Spine
LS	=	Lumber Spine
Abdo.	=	Abdomen
HIC	=	Head Injury Criterion
Head a3ms	=	Resultant acceleration of the head, except for intervals whose cumulative duration is not more than 3 milliseconds.
NIC	=	Neck Injury Criterion
ThCC	=	Thoracic Compression Criterion
VC	=	Viscous Criterion
Chest a3ms	=	Resultant acceleration of the chest, except for intervals whose (whichs) cumulative duration is not more than 3 milliseconds.
FFC	=	Femur Force Criterion
TI	=	Tibia Index
TCFC	=	Tibia Compression Force Criterion
IC	=	Injury Criterias

5.4.2 The Kegworth accident

During the Kegworth accident, the fuselage broke into three parts. Between rows 4 and 9, the fuselage tube was completely destroyed, and between rows 18 and 24, it was severely damaged (see Chapter 5.2.2.2.). Some passenger seats were severely damaged as well. In some passenger seats it could be seen that the seat feet and the seat rails, embedded in the floor, were no longer firmly connected. The rear legs had loosened, the front legs had partly collapsed, and some front seat spars were broken. Due to the determined damages at the passenger seats and the performed simulations, the following dynamic behaviour could be reconstructed: The high structural loads on the seats result on the one hand from the restraint effect on the passenger by the pelvic belt and the seat, and on the other hand by the passengers' impact on the back part of the seat in front.

It is not possible to correlate decelerations and determined passenger injuries for each seat, since the fuselage structure was severely damaged in the front and rear part.

Figure 5.4-2 shows the injury pattern of the survivors. The injuries of the passengers fatally injured in the crash directly had not been documented sufficiently.

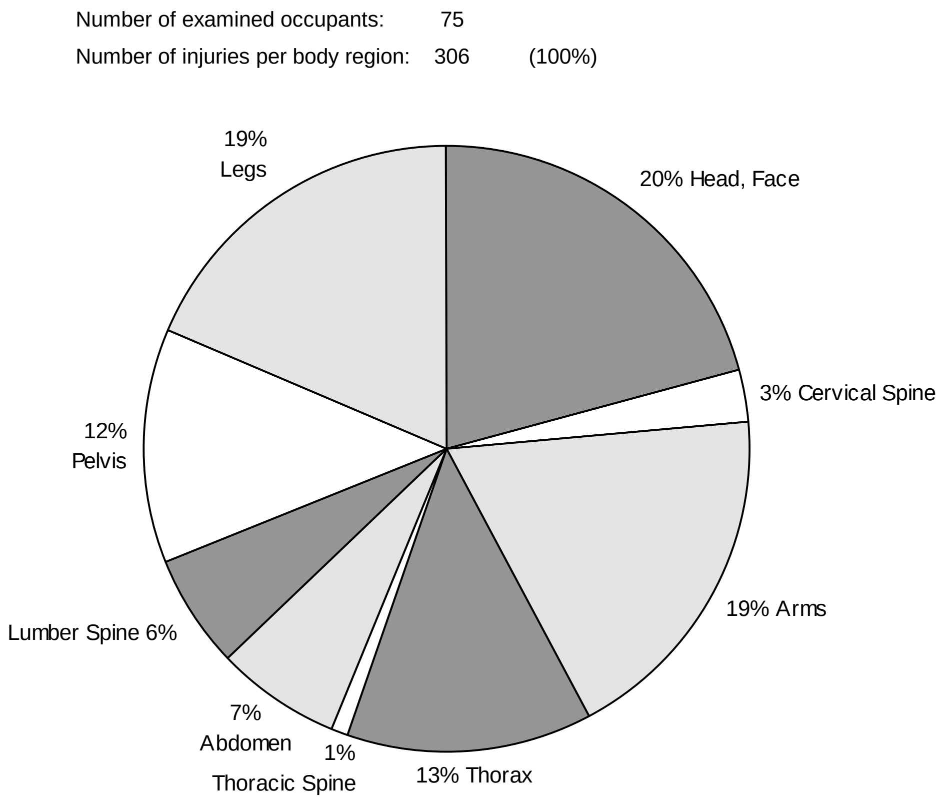

Figure 5.4-2 Distribution of injuries per body region - Kegworth accident -

In the Kegworth accident, the aircraft was first strongly decelerated in the longitudinal axis and then towards the vertical axis as well. In such decelerations, the motion pattern of an occupant, who is fastened to the passenger seat only with a pelvic belt and who sits in an upright position, can be described as follows: In a deceleration towards the longitudinal axis, the entire occupant first moves in a translational movement in a forward direction. When all belt play is used up, the torso and the head perform a rotational movement. The upper and lower extremities are pushed in a forward direction. The head hits against the seat-back of the passenger seat in front of him or her and then slips down the seat-back. The arms, too, hit against the seat in front. The legs are pushed against rigid, and partly sharp-edged structural parts of the passenger seat in front. If there is an additional deceleration towards the vertical axis, the body is first pushed downward with an even higher load acting on the occupant. The individual motion pattern of each passenger, however, cannot be assessed since the motion depends, among other factors, considerably on the seating position and the way of fastening as well as on the body features (weight, length, constitution etc.).

The injuries determined in the survivors of the Kegworth accident confirm the above outlined pattern. Particularly the arm and leg injuries have an injury share of 38 percent among the survivors. The examinations performed by the Queen’s Medical Centre furthermore confirm that a major part of severe leg injuries is due to high decelerations in the longitudinal axis. Arm injuries are mainly due to a hard impact of the arms against the seat-back structure.

The present data on head injuries and the documented, externally visible head injuries demonstrate that in most cases the head hits against hard structural parts of the seat in front.

In general, the injuries of the cervical spine were of minor relevance for the Kegworth accident, expressed in figures.

The injuries of the lumbar and thoracic spine (7 percent of all injuries) were especially found in the thoracic-lumbar junction. Due to its anatomy and function, the junction of the physiologic kyphosis of the thoracic spine to the lordosis of the lumbar spine is particularly susceptive to compressions.

Thoracic injuries (13 percent of all injuries), such as rib fractures, lung contusions, hemato-pneumothorax can be explained, among others, by the following mechanisms: In high longitudinal decelerations and additional vertical decelerations, the thorax hits against rigid seat structures or the own femurs. Ruptures of the aorta can also occur during whiplash processes without a direct impact. Such ruptures of the aorta are generally fatal on the spot. Due to the insufficient documentation of the injury patterns of fatally injured passengers, such data are not available in the examination report.

A major part of injuries in the pelvic and abdominal region (19 percent of all injuries) are externally visible abrasions and in some cases pronounced hematoma. When examining the passengers' exterior injuries, it was striking that most belt marks were visible on the femurs and the pelvis. This is a reliable sign that the pelvic belt must have moved on the femurs up to the pelvis and partly up to the abdomen during the crash. This pattern is typically caused by too loose pelvic belts, a wrong belt geometry, allowance in the attachment fittings as well as too soft seat padding. In some cases, it was even possible to reconstruct the position of the buckle from the injuries.

The following table correlates injuries caused in the Kegworth accident with known or new, unknown injury criteria.

Kegworth accident 8.January.1989											Known Relevant Injury Criterias											Unknown IC		
		Injuries by impact									Head		Neck	Chest			Abdo.	LS	Femur	Tibia		Arms	Thorax	Pelvis
Seat	alive	Head, Face	CS	Arms	Thorax	ThS	Abdo.	LS	Pelvis	Legs	HIC	a 3ms	NIC	ThCC	VC	a 3ms			FFC	TI	TCFC		ThS	
1D	s	1		2					1	2	-	-							x	x	x	x		-
1E	s	2		1						2	x	x							x	x	x	-		
1F	s	1		1			1			2	-	-					-		x	x	x	-		
2A	s	1		1						2	-	-							x	x	x	-		
2E	s	1		2	2					2	-	-		x	x	x			x	x	x	x		
2F	s	1		1					1	2	-	-							x	x	x	-		-
3A	s	1		1				2	1	2	-	-						x	x	x	x	-		-
3B	s	2	2		2				2	2	x	x	x	x	x	x			x	x	x	x		x
3E(3D)	d(s)	2		2						2	x	x							x	x	x			
3F	s/d	1			2			2		2	-	-		x	x	x		x	x	x	x			
4A	s	2	2	2						2	x	x	x						x	x	x	x		
4E	s/d	1		2	2		2	2		2	-	-		x	x	x	x	x	x	x	x	x		
5D	s	1		2				2		2	-	-						x	x	x	x	x		
5F	s	1		2				2	2	2	-	-						x	x	x	x	x		x
9F	s	2	1	2	2				2	1	x	x	-	x	x	x			-	-	-	x		x
10C	s	1		1	2	1		2		2	-	-		x	x	x		x	x	x	x	-	-	
10D	s			2	1	2			1	2				-	-	-			x	x	x	x	x	-
10E	s/d	1	2	2	1			1		1	-	-	x	-	-	-		-	-	-	-	x		
10F	s	2			2						x	x		x	x	x								
11A	s	1		2	2		1		2	2	-	-		x	x	x	-		x	x	x	x		x
11B	s	1		2	2				2	2	-	-		x	x	x			x	x	x	x		x
11C	s	1		1	2			2	2		-	-		x	x	x		x				-		x
11D	s								1															-
11F	s	1	2	1	1				1		-	-	x	-	-	-						-		-
12A	s	2		2	2		2	2	2	2	x	x		x	x	x	x	x	x	x	x	x		x
12B	s	1		2	2		2	2		2	-	-		x	x	x	x	x	x	x	x	x		
12C	s	2		1			1		2		x	x					-					-		x
12F	s	1	1						2	2	-	-	-						x	x	x			x
14A	s	1			1		1			1	-	-		-	-	-	-		-	-	-			
14C	s	1		2	1					1	-	-		-	-	-			-	-	-	x		
14D	s	2									x	x												
14F	s			1			1			1							-		-	-	-	-		

Key : s = Survived
d = Died

1 = Minor injuries
2 = Severe and fatal

x = Severe and fatal injuries assign to injury criterias
- = Minor and fatal injuries assign to injury criterias

Kegworth accident 8.January.1989											Known Relevant Injury Criterias											Unknown IC		
		Injuries by impact									Head		Neck	Chest			Abdo.	LS	Femur	Tibia		Arms	Thorax	Pelvis
Seat	alive	Head, Face	CS	Arms	Thorax	ThS	Abdo.	LS	Pelvis	Legs	HIC	a 3ms	NIC	ThCC	VC	a 3ms			FFC	TI	TCFC		ThS	
15A	s	2			1			2	2		x	x		-	-	-		x						x
15B	s	1		1				2	1	2	-	-						x	x	x	x	-		-
15C	s	1		1							-	-										-		
15F	s	1						1	1		-	-						-						-
16A	s	1		1			1		1	1	-	-					-		-	-	-	-		-
16C	s	1		1					1	2	-	-							x	x	x	-		-
16D	s	1		1							-	-										-		
16F	s	2		1				2	2	1	x	x						x	-	-	-	-		x
17A	s				2				2	2				x	x	x			x	x	x			x
17B	s	1		1	1		1		1		-	-		-	-	-	-					-		-
17D	s	1		1	2			2	2		-	-		x	x	x		x				-		x
17F	s	1		2				2		2	-	-						x	x	x	x	x		
18A	s	1							1	2	-	-							x	x	x			-
18B	s	1		1	1					2	-	-		-	-	-			x	x	x	-		
18C	s	1		1	1					2	-	-		-	-	-			x	x	x	-		
18D	s	1			1				1	2	-	-		-	-	-			x	x	x			-
18F	s/d	1			1		1			2	-	-		-	-	-	-		x	x	x			
19A	s	1		1	1				1	2	-	-		-	-	-			x	x	x	-		-
19E	s			1	2					2				x	x	x			x	x	x	-		
19F	s						1										-							
20A	s			2			1		2								-					x		x
20C	s	1		1	2					2	-	-		x	x	x			x	x	x	-		
21A	s			1		2	1			1							-		-	-	-	-	x	
21C	s	1	2	2	1			2		1	-	-	x	-	-	-		x	-	-	-	x		
21B	s	1		1						2	-	-							x	x	x	-		
21F	s	1		2	2					2	-	-		x	x	x			x	x	x	x		
22C	s	1		1	2		1			2	-	-		x	x	x	-		x	x	x	-		
23A	s			1				2		2								x	x	x	x	-		
23B	s	1		1	1		1			2	-	-		-	-	-	-		x	x	x	-		
24C	s	1	2	1	1				2	2	-	-	x	-	-	-			x	x	x	-		x
24D(22E?)	s	1		1	1		2		2	2	-	-		-	-	-	x		x	x	x	-		x
25A	s	1			2				2	2	-	-		x	x	x			x	x	x			x

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Kegworth accident 8.January.1989											Known Relevant Injury Criterias											Unknown IC		
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Seat	alive	Head, Face	CS	Arms	Thorax	ThS	Abdo.	LS	Pelvis	Legs	HIC	a 3ms	NIC	ThCC	VC	a 3ms			FFC	TI	TCFC		ThS	
25B	s	1		2	2		1			1	-	-		x	x	x	-		-	-	-	x		
25C	s	1		1	2			2		1	-	-		x	x	x		x	-	-	-	-		
25D	s	1		2	2		1		2		-	-		x	x	x	-					x		x
25F	s	1		1						2	-	-							x	x	x	-		
26A	s	1		2					1	1	-	-							-	-	-	x		-
26B	s			1					1													-		-
26C	s	1		1	2				1	1	-	-		x	x	x			-	-	-	-		-
26D	s	1			1					1	-	-		-	-	-			-	-	-			
26F	s	1							2	1	-	-							-	-	-			x
27A	s	1		1					1		-	-										-		-
27C	s						1		1								-							-
27F	s																							

Key : s = Survived
d = Died

1 = Minor injuries
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- = Minor and fatal injuries assign to injury criterias

List of Abbreviations

CS	=	Cervical Spine
ThS	=	Thoracic Spine
LS	=	Lumber Spine
Abdo.	=	Abdomen
HIC	=	Head Injury Criterion
Head a3ms	=	Resultant acceleration of the head, except for intervals whose cumulative duration is not more than 3 milliseconds.
NIC	=	Neck Injury Criterion
ThCC	=	Thoracic Compression Criterion
VC	=	Viscous Criterion
Chest a3ms	=	Resultant acceleration of the chest, except for intervals whose cumulative duration is not more than 3 milliseconds.
FFC	=	Femur Force Criterion
TI	=	Tibia Index
TCFC	=	Tibia Compression Force Criterion
IC	=	Injury Criterias

5.4.3 Conclusion of WP 4

The compilations made for the Kegworth and Warsaw accidents demonstrate that it is possible with the developed injury criteria to evaluate the severity of injury and the passengers' ability to free themselves after an accident. The criteria should in particular focus on

- the aircraft passengers' state of consciousness (no disturbance of consciousness),
- the possibility of freeing themselves and
- the passengers' ability to walk.

The correlations of injuries and injury criteria clearly demonstrate that the protection criteria currently available in aviation are insufficient for achieving the above-outlined objective. It is generally necessary to correlate protection criteria to each body region. It is thus possible to transfer the criteria applied in the automotive sector to the aeronautical requirements. The protection criteria currently used in the automotive industry, however, do not include all aeronautical requirements. Further research is needed here.

5.5 Biomechanics (WP 5)

5.5.1 Objective and basis of WP 5

In Workpackage 5, a compilation of biomechanical tolerance data of the human body has been worked out. On the one hand, human tolerance as regards the entire body is dealt with, and on the other hand injury criteria such as head, cervical column, thoracic/lumbar column, thorax, pelvis and upper as well as lower extremities.

A literature research was done using different databases as literature sources, such as MEDLINE, SAE Highway Safety Database, STAPP Car Crash Conference and Accident Reconstruction Technology Collection. The following keywords were used for research programs:

Biomechanics, tissue tolerance, mucosa tolerance, human tolerance values, body tolerance, fracture force, impact tolerance, human biomechanical tolerance, tolerance limit(s), tolerance values, strain thresholds, bone stiffness, human thresholds, biomechanical limits, tissue resistance, mechanical tissue resistance, tissue stiffness, threshold limits, pressure tolerance, human body limits, force limits, fracture tolerance, strength limit(s), muscle tolerance limit, skin tolerance, mechanical tolerance, facial force tolerance, subcutis tolerance, stress tolerance, tolerance criteria, nerval tolerance, nerve/nerval force tolerance, nerve resistance, nerve toughness, tissue toughness, toughness, tear resistance, parenchym tolerance, biomechanical resistance, human mechanical resistance, fragility, acceleration tolerance, breaking strength, weight bearing, load capacity, failure criteria, failure values, tear strength, load-bearing capacity, maximum resilience, maximum limits, level of peak load, weight bearing limit, weight limits, biomechanical limits, human tolerance thresholds, tolerance thresholds, joint tolerance, mechanical tolerance of human joints, knee joint force tolerance, Toleranzgrenzen, Belastungsgrenzen, failure folerance, injury tolerance, arm fractures, load to failure, force to failure.

Out of several thousand citations approximately 400 manuscripts and publications were read. Finally mor than 350 publications were reviewed in detail and in respect to material and methods and important results for biomechanic tolerance limits.

5.5.2 Biomechanic tolerance limits

The relevant literature was subdivided regarding to the interesting body regions. The categories were:

Others, overviews	45
Head, face, brain	70
Neck, cervical spine	40
Chest	35
Abdomen	19
Pelvis, vertebral column	33

Upper extremity	3
Lower extremity	55

The biomechanical tolerance limits are summarised in tabular form for each body region with the corresponding literature indicated in parentheses, see Table 5.5-1.

The tolerance limits indicated with [TUV] are taken from the TÜV research report "Crashworthiness in Aircraft" written in 1992. The project tasks were performed by order of the Federal Transport Ministry (BMVBW). This research project performed fundamental tasks dealing with biomechanic tolerance limits of the human body in aircraft passenger seats.

Biomechanical load or tolerance limits of the human body are necesary basic data for the conception and optimization of passive protective measures for aircraft occupants. Upon this basis, it is possible to derive recommendations and guidelines for accident situations with a priori "survivable marginal conditions" as well as, not least of all, requirements which can or should contribute to minimizing injury risks for aircraft passengers.

Before this background, the TUV study outlines suitable data available in the literature on biomechanical tolerance limits of the human body, i.e. on the one hand for the entire body (human tolerance) and on the other hand for individual body segments (head, vertebral spine, thorax etc.) in relation to specific relevant injury criteria. The applicability of suitable tolerance criteria and tolerance limits on the conditions in real-life accident situations is discussed.

Experimentally determined dummy loads of the so-called "16 g crash test" for aircraft seats (test procedure according to the JAR paragraph 25.562) were assessed in view of the corresponding injury criteria and tolerance limits.

Table 5.5-1 Tolerance Limits (Literature)

overall	• 60 g for < 3 ms [319] • 30 km/h EES, delta v 15 km/h side impact [192] • deceleration x-direction 45 g for t = 40 ms [TUV] • deceleration z-direction 15 g for t = 40 ms [TUV]
head, face, brain	• HIC < 1000 [263] • HIC < 1000 for t < 50 ms [TUV] • HIC >1500, free fall [92] • explosion, head 5000 m/s^2, HIC>1000, 3,6 kN [188] • concussion 1500 m/s^2 [269] • nasal bone fracture, contact speed 10km/h, 241 J [215] • subarachnoidal hematoma 250g [10] • subdural hematoma 300g [10] • bone fracture, circular impactor 5 cm^2 5000 N [3]

	• occipital impact, linear acceleration, axonal injury =/> 3000 m/s² [17] • 275-325 g for 3 ms reversible injury (AIS 2/3), falls, young children [71] • 550 g peak acceleration survival limit, falls, young children [71] • 445 and 610 lb tolerance of the skalp [80] • 8,1 kN facial fractures, males, 8,0 kN facial fractures females [111] • frontal bone fracture loads 750-1650 lb, depending on shape of surface [105] • basilar skull mean load at fracture 4.300 ∓ 350 N, 13,0 ∓ 1,7 J [108] • angular acceleration limit 4500 rad/s², bridging vein ruptures [140,166] • change of angular velocity >50 rad/s, bridging vein ruptures [166] • base of skull and temporal fractures > 4.0 m/s [179] • no fracture 2.640 lb, linear fractures 4350 lb [231] • 50 % concussions velocity change of 29.5 kph [264] • intracranial pressures above 25 psi, moderate injuries [332] • 206 g, 10 ms [332] • fracture 400-700 in-lb [226] • > 200 g, HIC >800, 3ms >100 (AIS 3) [179] • side impact 36 mph, concussion 46 mph [181] • frontal skull 4000 N, temporo-parietal 2000 N, zygomatic 890 N [277] • 76 g, 20 ms, closed brain injury [297] • 140 g, 10 ms [WSU] • a_{res} = 200 g for t = 2 ms [TUV] • a_{res} = 80 g for t = 6 ms [TUV] • Gambit g = 1 [TUV]
neck	• v >15 km/h [18] • v 10 km/h [187] • neck injuries 3.1 m/s [201] • frontal loading, neck fracture load 6.2 kN [42] • loading limits clivus 30 g to 59 g [132] • TH1 loading limits 23 g to 40 g [132] • bending moment flexion 190 Nm, extension 57 Nm [182] • fractures of the cervical vertebrae > 1.280 lbs (5.7 kN) [182] • near vertex head impact of 2.75 to 3.44 kN, axial neck force 1948 ∓ 666 N [202] • cord pressure levels minor injuries 35 - 75 N/cm^2 [242]

	• cord pressure levels fractures, dislocations 50 to 200 N/cm² [242] • cervical fractures Δv 40.3 kph (50%) [264] • moderate injuries EES 8-30 km/h, 4 - 15 g [275] • severe injuries EES 30 - 80 km/h, 16 - 40 g [275] • extension 90°, flexion 60 - 100°, transversal 40-57°, rotation 87° [275] • extension 57 Nm, F (shear) a-p 860 N [330] • extension 60°, flexion 80 -100°, angular velocity extension 10-20 rad/s, angular acceleration extension 500 rad/s^2 [330] • flexion 190 Nm [330] • pressure of 0.35 mPa [354] • anteflexion 40 - 50 g • retroflexion 20 - 36 g • 10.2 m/sec impact injury threshold [41] • peak forces 5.7 kN [41] • tolerance limit flexion 190 Nm, extension 57 Nm [41]
chest	• 25 % MAIS 4+, TTI 132,7 g [34] • 25 % AIS 4+ frontal impact VC 1,0 m/s [140, 319] • lateral impact VC = 1.5 m/s [323] • rib fractures 1.850 lb, 2.18 in chest deflection [231] • 45 mph (50%), upper shoulder harness load 1930 lb, chest Gadd Severity Index 560, peak acceleration 85 g [232] • 5.4 - 6.8 kN [188] • AIS1 25,5 mph, AIS2 31,5 mph, AIS3 34,5 mph [230] • 50 % AIS2+ 42 kph, AIS3+ 47 kph [264] • side impact, penetration to the chest 2.65 in (6.72 cm) [297] • sternal loading 3.3 kN [295] • 25 % 4 rib fractures, side impact (VC) max = 1.03 m/s, dissipated energy response 1.34 m/s, thoracic compression 35.4 % [302] • 3.29 kN maximum hub force on the sternum [319] • 25 % severe injury, compression level 35% (lateral: 38%) [319, 322] • aorta 1.200 mm Hg [327] • 60 g 100 ms a/p and p/a direction [185] • rib deflection: 45 – 65 mm [TUV] • rib fracture: 6 – 8 kN [TUV] • deceleration: 40 – 60 g / t< 45 ms [TUV]

	• vc criterium: 2,5 m/s [TUV]
abdomen	• deep liver ruptures 319,81 +/- 90,81 kp, 3,38 +/- 0,18 cm [64] • liver injury, right sided impact no injury - 40 km/h, 50 % injury - 45 km/h, 90 % injury - 50 km/h [173] • 25 % AIS 3+, compression 37.8%, 2.93 N, 166 kPa, 1.33 kN [190] • liver laceration 56 kph [264] • stomach rupture, 5.6-11.6 kPa, 1900-3300 ml [Rabl] • side impact, upper abdomen contact pressure 220 kPa [297] • AIS 3, side impact, 500 N for the liver, deflexion criteria 60 mm, force criteria 440 daN, viscous criteria 1.98 m/s [301] • side impact, 25 % critical injury VC 1.98 (2.0) m/s, abdominal compression 44 % [320] • liver, impact force: 1,7 – 1,8 kN [TUV] • liver compression: 300 N/m^2 [TUV]
pelvis	• lateral force, pelvic compression 27 % [322] • side impact 5000 N, 100 Ns [39] • 5 - 7 kN (female), 7 - 13 kN (male) [39] • side impact 30 - 35 km/h [39] • a/p direction, quasistatic, 4.7 - 10 kN [70] • sacroiliacal joints all directions, 500 N, 50 Nm [189] • side impact, 10kN - 3ms (50 % male), 4 kN - 3 ms (5 % female) [37] • side impact, 10 kN (mean age), 5 kN (high age) [131] • side impact, 9.78 +/- 0.52 kN pubic ramus [322] • side impact, AIS 2-3, 3 ms, 5600 N (female), 8600 N (male) [37] • acetabulum fractures, knee contact, 1.150 kp [327] • deceleration: 60 g [TUV] • impact force: 10 kN [TUV] • vc criterium: 2,5 m/s [TUV]
vertebral column	• lumbal compression 4,4 - 6,0 kN [120] • ultimate compressive strength of the lumbar spinal unit <40a 6.700 N, >60a 3.400 N [153] • total disruption at flexion load of 156 Nm in bending and 620 N in shear [217] • C5-Th1 33° of flexion rotation [289] • twisted spine, flexion angle at failure 17.7°, 15.2 Nm [289]

	• lower cervical spine - flexion compression 12.1 Nm, 2158 N [289] • trauma initiation, 9 kN normal spine, 4.4 kN degnerated spine [82] • compressive strength 11 kN normal spine, 5.3 kN degenerated spine [82] • > 50 km/h vertebral injury AIS 2 [223] • cervical spinal cord injury 0.35 Mpa [354] • cervical spine forward flexion: 170 Nm / 80° [TUV] • cervical spine backward flexion: 57 Nm / 90° [TUV] • cervical spine lateral flexion: 60 Nm / 50° [TUV] • cervical spine tension: 1,1 kN / t > 50 ms [TUV] • cervical spine compression: 1,1 kN / t > 30 ms [TUV] • cervical spine shearing: 1,1 kN / t > 35 ms [TUV] • lumbar spine bending compression moment: 4,67 – 7,14 kN [TUV] • lumbar spine shearing: 400 – 480 N [TUV] • lumbar spine flexion: 12 – 17° [TUV]
upper extremity	• airbag induced injury, distal forearm speed 15.2 m/s peak, and 11.7 m/s average [99] • humerus, shearing force Fx=Fy=2.5 kN, bending moment Mx=My=230 Nm (50 % male); 1.7 kN, 130 Nm (5 % female) [143]
lower extremity	• dynamic, midshaft, tibia bending 270-1200 N [Rabl] • tibia torsion 320 to 1455 kpcm, bending 1465 - 3550 kpcm [7] • ankle 45 deg of dorsiflexion [14] • frontal crash, tibia axial compressive load 4.4 kN- 23.7 kN [68] • compression load tibia (femur) 0.8 - 3.6 kN (0.5 - 3.2 kN) [48] • bending tibia 40.8 - 99.2 Nm [48] • femur proximal, 5.441 N (male), 4.273 N (female) [75] • distal femurshaft axial forces 4.050 - 5.330 lb (18.015 - 23.720 N), impact velocities of 34-38 ft/sec [71] • foot, ankle peak contact force < 4.2 kN [145] • foot in plantarflexion 2 kN, dorsiflexion 11 kN [145] • femur axial 8.730 to 11.570 N [110, 249] • femur axial 10 kN, 549 J [250] • femur 7560 N/ 30-50 ms [142] • 50 % injuries, 9.3 kN plantar contact force, 5 kN/msec contact force onset rate, 216 g heel acceleration [145] • tibia 6.5 m/s (23 km/h), 17 g, 4300 N, <5 ms [148] • femur dynamic loading 6.464 N [151] • femur tolerance: 23.4 - 0,72 T when T < 21 ms, F = 8,3 kN when T >= 21 ms

	[160] • torsional stiffness tibia (femur) 326 Nm/r (562 Nm/r), torsional rigidity 95 Nm^2/r (192 Nm^2/r), maximum torque 101 Nm (183 Nm), energy absorption 25 J (35 J), angle of deformation (ultimate deflection) 23.7° (20°) [170] • knee impact 1400 lb [228] • femur and knee 50 kph [264] • 50 % injury, tibia 55.26 foot-lb [292] • femur load limit 7.6 kN (10kN) [314] • static femur fracture force 8.90 kN [314] • foot-ankle 4.3 - 11.4 kN, foot-ankle 6.9 - 8.7 kN, foot-ankle 7.8 - 13.0 kN [350] • upper leg bending 220 Nm, 4 kN [356] • femur direct fracture (indirect), maximum bending load 6.410 N (4.879 N), bending moment 373 Nm (275 Nm), energy 36.8 J (17.7 J) [171] • tibia bending 304 - 330 Nm (male), 264 - 288 (female) [213] • pedestrian 15 km/h [218] • knee, quasistatic shearing 0.75 - 3 kN, lateral displacement 22 mm, bending: rotation $>16^{o}$, 100 Nm [252] • patella fractures 1300/950 kN [327] • lower leg 212 g [284] • side collision, fibular fracture <20 km/h [359] • femur load: 8,9 kN for t < 20 ms [TUV] • knee load: 2,5 – 5,8 kN [TUV] • tibia flexion: 165 – 200 Nm [TUV] • tibia torsion: 50 – 90 Nm [TUV] • tibia compression: 7 – 10 kN [TUV]

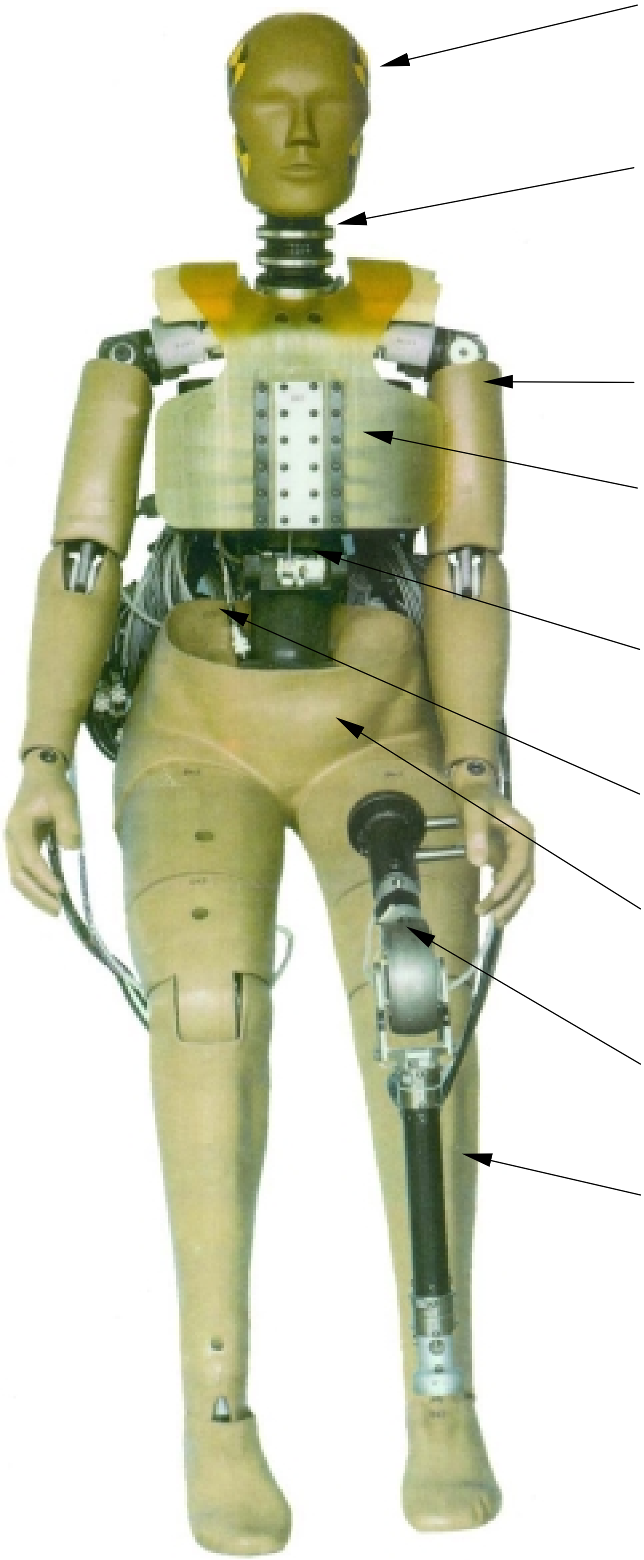
5.5.3 Human Tolerances

After a “survivable“ aircraft crash, it is of integral importance for passengers to evacuate the aircraft on their own, without external aid, as quickly as possible. This is required particularly in view of the considerable fire hazard during a crash. Accident injuries cannot be generally ruled out, but it should be possible with biomechanic tolerance data to assess the risks of injury. The basic idea in the development of tolerance data is to make sure that passengers are able to evacuate themselves after an accident, without external aid. The risk of injury should generally be as small as possible.

First of all, passengers must be able to act, i. e. they must not be unconscious, in order to evacuate themselves from the aircraft. Furthermore, they must be able to use their hands e.g. for unfastening their safety belts. In addition, they must be able to get out of the aircraft on their own. To increase passive safety in aircraft cabins, it is necessary to determine tolerance data for all body regions, including extremities, i. e. arms/hands and legs. Internal injuries are relevant here insofar as they may considerably restrict the passengers’ ability to act.

The compilation of biomechanic tolerance limits of the human body in aircraft seats shows Figure 5.5-1 before this background.

Figure 5.5-1 Selected tolerance limits per body region



5.6 Injury criteria for enhanced passive safety in aircraft cabins

5.6.1 Objective and basis of WP 6

The objective of workpackage 6 is the development of new, improved evaluation criteria for an enhancement of passive safety in aircraft cabins in order to increase aircraft passenger survivability in an emergency landing or in a crash.

The injury criteria determined in workpackage 3 and the correlation of injuries and evaluation criteria set-up in workpackage 4 serve as the basis for this workpackage.

The tests required for the approval of aircraft passenger seats in accordance with JAR 25.562 "Emergency landing conditions" cover passive safety of aircraft passengers in a crash to an insufficient extent only. To enhance passive safety, passengers' survival space, as outlined in Chapter 5.3.2, must be considered as well. The new injury criteria will then be applied for the evaluation of passive safety in the aircraft cabin, both in tests with interior parts and dummy tests, aimed at developing tests based upon each other, which first of all consider individual critical components / parts of the aircraft interior. Tests with entire structural components will be performed only in a second step, encompassing e. g. two passenger seat rows with dummies.

The central idea in the definition of protection criteria is the passengers' ability to evacuate the aircraft on their own after an accident. To meet this requirement, passengers must

- be in a state of consciousness,
- be able to free themselves and
- be able to evacuate the aircraft on their own.

5.6.2 Overview

The injury criteria used in the automotive sector were reviewed as regards the question of whether they are already used in aviation or whether the injury criteria are applicable also in the aviation sector. The comparison of the actual injuries and the injury criteria demonstrates that for particular body regions, injury criteria are not available. Thus, e.g. the feet, the lower arms and hands are not taken into consideration.

5.6.3 Injury Criterias

5.6.3.1 Interieur

"Interior" includes individual elements of the interior panelling, I. e. the doors in the exit areas, or individual parts of the aircraft passenger seats. The criteria suggested here are based on ECE-R 17 and 21, and were applied to the conditions in an aircraft. It is possible with these criteria to consider not only possible head injuries but also the injury risks of all other body regions such as legs, arms, torso etc., compare Chapter 5.3.

Table 5.6-1 shows an overview of applicable criteria. Figure 5.6-1 represents the impact areas related to the seatback of an aircraft passenger seat.

Table 5.6-1 Overview of the requirements for impact areas of seats

impact area	minimum requirements for radii of curvature (mm)	energy absorption test	padding / covering
1	> 2.5 mm	< 80 g over 3 ms, after test no sharp edges	
2	> 5.0 mm	---	structural components shall be covered with an energy-absorption material. If the covering is softer than 50 Shore(A) the radii shall be > 5.0
	2.5 - 5.0 mm	< 80 g over 3 ms. after test no sharp edges	
3	> 3.2 mm	---	

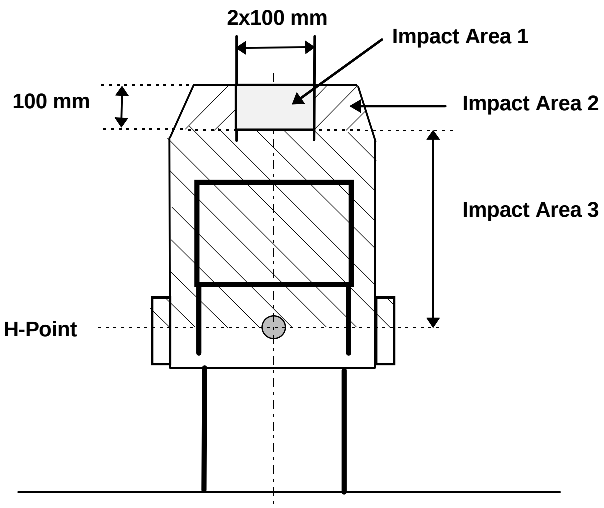


Figure 5.6-1 Impact Areas of Seats (rear view of a passenger seat)

Table 5.6-2 compiles the requirements for evaluating in particular protruding parts, also compare Figure 5.6-2, and padded components:

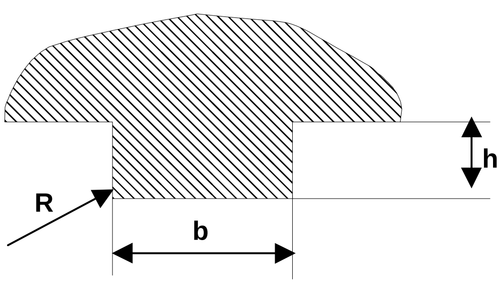


Figure 5.6-2 vorstehende Teile

Table 5.6-2 Overview of the requirements for interior:

IMPACT AREAS	REQUIREMENTS
"head impact area“ in the cabin above reference level	Dangerous uneven surfaces and sharp edges shall be avoided. The edge radii shall be at minimum 2.5 mm. Excepted from this are protrusions projecting by less than 3.2 mm as well as such protrusions which are twice as long as wide and the edges of which are broken. The level of switches, knobs, handles, levers etc. shall be determined with a test device. If these components protrude between 3.2 mm and 9.5 mm, they shall have a surface not smaller than 2.0 cm^2, measured at 2.5 mm from the most protruding part. The edge radii shall be at least 2.5 mm. If parts protrude by more than 9.5 mm from the surface, they must be compressible or breakable. The test is performed with a horizontal longitudinal force of 37.8 daN in a forward direction, which is applied with a stamp having a plane pressure surface and a diameter of not more than 50 mm. It must be possible to press the parts into the surface, and they must not protrude by more than 9.5 mm or must otherwise dissolve. If the parts dissolve, there shall not be hazardous protrusions of more than 9.5 mm left; the cross section at a distance of at maximum 6.5 mm from the most protruding point shall have a surface of at least 6.5 cm^2. For switches, knobs, handles, levers etc. which are covered with a material softer than 50 Shore A, such soft material shall be removed. If rigid carriers etc. are covered with a material softer than 50 Shore A, the test, as outlined above, shall be performed directly at the rigid carrier. If one or more critical points are found, an energy-absorption test shall be performed at those points.
impact area in the cabin below reference level	Any protruding components which can be reached by the test wedge, shall be tested, such as switches, knobs etc. (see above). Storage shelves shall have no sharp edges. Storage shelves pointing to the interior shall • have a front height of at least 25 mm; their edge radius shall not be smaller than 3.2 mm, and an energy absorption test shall be made, or • substantially deform or evade under a longitudinal force of 37.8 daN without leaving dangerous edges at the borders. The test is performed under a horizontal longitudinal force of 37.8 daN in a

IMPACT AREAS	REQUIREMENTS
	forward direction, applied with a cylinder with perpendicular axis and a diameter of 110 mm. The force shall be applied to the resistant part of the storage shelve or similar parts. • If part of a component is made of materials which are softer than 50 Shore A, such material shall be removed, and the storage shall be tested as outlined above. It is not necessary to perform an energy absorption test. • If one or more critical points are found, an energy-absorption test shall be performed at those points.
roof area	The roof shall have no sharp edges nor dangerous uneven surfaces. Any components which can be touched by a test sphere with a diameter of 165 mm shall meet the following requirements: • The width of protruding components shall not be smaller than their vertical height. Their edge radius shall be at least 5 mm. • Any rigid protrusions or rips shall not project by more than 19 mm downwards unless they pass the energy absorption test. • If one or more critical points are found, an energy-absorption test shall be performed at those points.

5.6.3.2 Dummy-Test´s

In contrast to the tests of individual components, the tests of structural components show the injury risk to be expected under the specific test conditions. These include e. g. the emergency landing conditions in accordance with JAR 25.562, see Chapter 5.3.4.1.

According to the findings of the accident analysis in Chapter 5.2, the dynamic tests with aircraft passenger seats outlined in JAR 25.562 give a good representation of the loads effective in the aircraft cabin during an accident. Particularly the load level and the load direction in the forward and downward tests can be transferred with sufficient accuracy to the accidents in Kegworth and Warsaw.

Accordingly, it is recommended to keep the dynamic impact test parameters in accordance with SAE AS 8049A.

A **Hybrid III 50 percentile** male dummy is recommended for passenger simulation, the decisive factor being its far better biofidelity to man compared to the Hybrid II, and on the other hand, it allows measuring especially in biomechanically sensitive regions such as neck, thorax and lower legs.

For the Hybrid III, the following injury criteria are recommended before the background of the examined accidents in Kegworth and Warsaw:

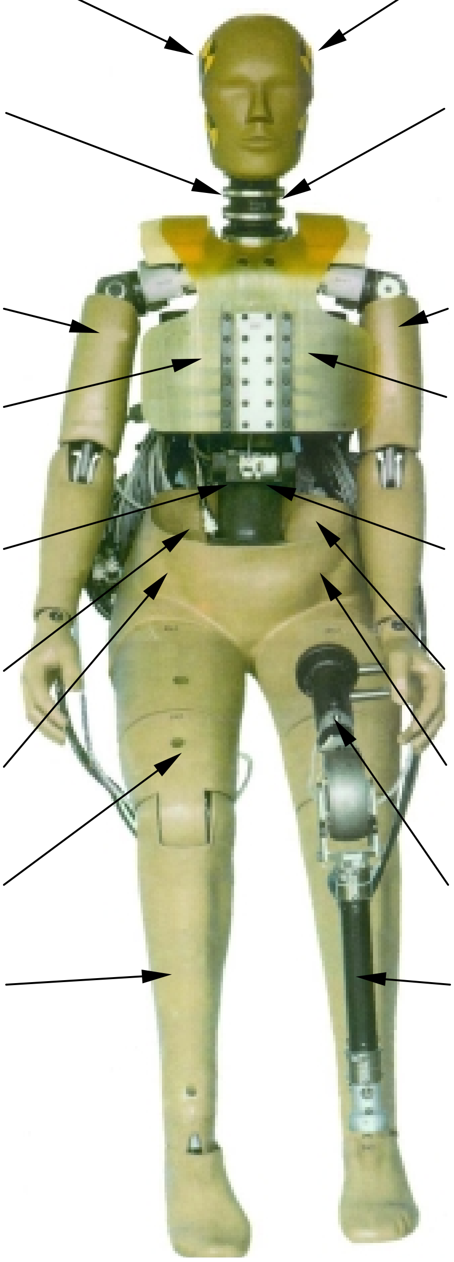
- The accelerations measured in the centre of the dummy head shall not exceed the acceleration of 80 g measured cumulatively over 3 ms.
- The HIC measured in a head impact shall not exceed a value of 1000.
- The compression forces measured in the neck in an axial direction of the vertebral spine shall not exceed the time-based tolerance curve, compare Chapter 5.3.5.2.2..
- The tractive forces measured in the neck in an axial direction of the vertebral spine shall not exceed the time-based tolerance curve, compare Chapter 5.3.5.2.2.
- The bending moment measured in the neck around the y-axis shall not exceed the value of 57 Nm.
- The velocity of compression (Viscous Criterion) measured in the thorax shall not exceed the value of 1.0 m/s.
- The deceleration measured in the upper thorax shall, cumulated over 3 ms, not exceed the value of 60 g.
- The thoracic compression measured in the chest shall not exceed 50 mm.
- The maximal compression in the lumbar spine shall not exceed 6.67 kN.
- The femur loads measured in the femurs shall be smaller or equal to 10 kN.
- The tibia index (TI), measured at the top and bottom of each tibia, must not exceed 1.3 at either location tibia. The tibia compression force criterion (TCFC) must not exceed 8 kN.

Furthermore, the following criteria shall be complied with during or after the dynamic test respectively:

- The safety belts shall ensure safe restraint of the dummy during the entire test.
- Safety belts shall not slip to the soft part region of the dummy during the test.
- The integrity of the test set-up simulating the aircraft interior shall remain during the test.
- Buckles shall easily open after a dynamic test (without applying any aids).

Figure 5.6-3 shows the comparison between the enhanced dummy injury criteria and the results of Chapter 5.5, Biomechanics.

Figure 5.6-3 Injury Criterias for Dummy-Test´s



Human
Tolerance limits per body region

Head
a_{res} = 200g / t = 2ms
a_{res} = 80g / t = 6ms
Gambit- Wert g = 1
HIC < 1000 / t < 50ms

Cervical spine
forward flexion: 170Nm / 80°
backward flexion: 57Nm / 90°
lateral flexion: 60Nm / 50°
tension: 1,1kN / t > 50ms
compression: 1,1kN / t > 30ms
shearing: 1,1kN / t > 35ms

Upper Extremeties (Humerus PRV)
shearing: 1,7 - 2,5kN
flexion: 130 - 230Nm

Thorax
rib deflection: 45 - 65mm
rib fracture: 6 - 8kN
deceleration: 40 - 60g / t < 45ms
VC criterion: 2,5m/s

Lumbar Spine
compression: 4,67 - 7,14kN
shearing: 400 - 480N
flexion: 12 - 17°

Abdomen (Liver)
impact force: 1,7 - 1,8kN
pressure: 300N/m²

Pelvis
deceleration: 60g
impact force: 10kN
VC criterion: 2,5m/s

Lower Extremeties
femur load: 8,9kN / t < 20ms
knee load: 2,5- 5,8kN

Lower leg (Tibia)
flexion: 165 - 200Nm
torsion: 50 - 90Nm
compression: 7 - 10kN

Dummy
Injury Criteria

Head
head injury criterion (HIC) ≤ 1000
head acceleration a_{res3ms} ≤ 80g

Cervical spine
neck injury criterion (NIC)
tension:
3,3kN \ 0ms; 2,9kN \ 35ms; 1,1kN \ ≥ 60ms
shearing:
3,1kN \ 0ms; 1,5kN \ 25-35ms; 1,1kN \ ≥ 45ms
backward flexion ≤ 57Nm

Upper Extremeties

Thorax
thoracic compression criterion (ThCC)
deflection: ≤ 50mm
viscous criterion (VC) ≤ 1,0m/s
chest acceleration (xms) a_{res3ms} ≤ 60g

Lumbar Spine
compression ≤ 6,67kN

Abdomen
no submarining

Pelvis

Lower Extremeties
femur force criterion (FFC)
9,07kN \ 0ms; 7,58kN \ ≥ 10ms

Lower leg (Tibia)
tibia index (TI) ≤ 1,3
tibia compression force criterion (TCFC) ≤ 8kN

5.6.4 Example for ECE Regualtions in Aircrafts

Based on the ECE-R 17 and ECE-R 21 (see Section 5.3.2.6 and 5.3.2.7), cabins were examined at the example of the aircraft types :

A310-200/300 (D-AHLC) and
B737-400 (D-AHLU)

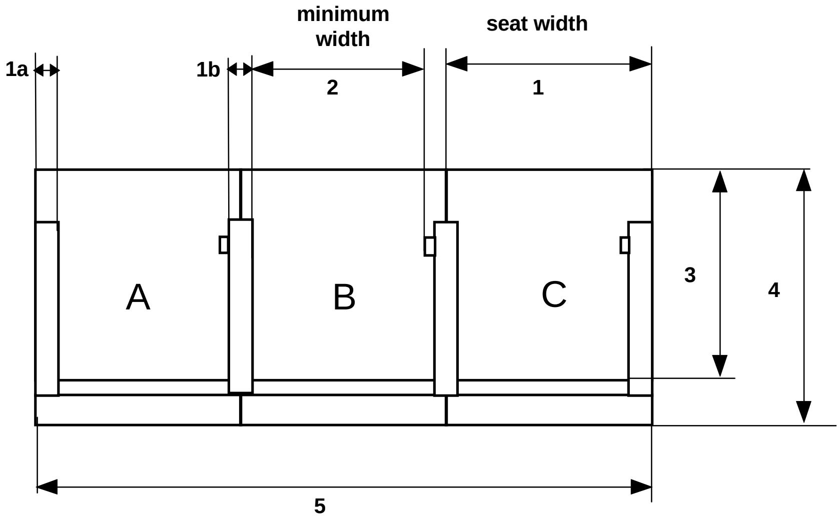
of Hapag Lloyd.

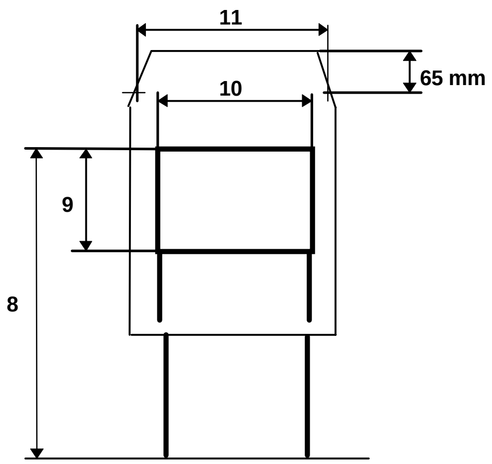
5.6.4.1 Determined Values

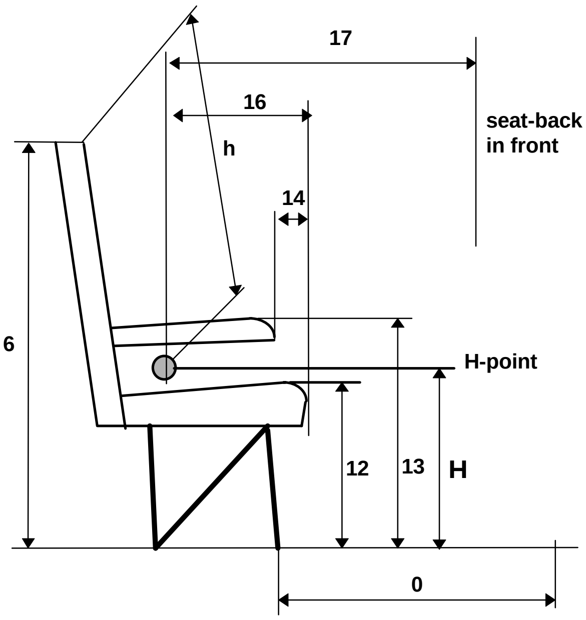
For the evaluation of the passenger compartment in view of its passive safety, both the surfaces and edges, and possible impact areas of the aircraft occupant seated in the passenger seat were considered. For this purpose, the passenger seats were measured as shown below. The H-point of the built-in seats was used as reference point for the examination, see Section 5.3.2.

The seat space available for the aircraft passengers is due to the seat pitch, the thickness of the seat-backs and the distance between the armrests. This available space again has an impact on the passive safety.

The following overviews show, for each aircraft, the different minimum distances between the armrests. They furthermore indicate the minimum distances between the H-point and the front limitation. The front limitation of the aircraft passengers' space is either made up by the seat-back in front or a bulkhead. Backwards, the space is limited by the seat-back of the passenger seat.







dimension	definition
0	seat pitch
1	seat width
1a	width of the left armrest
1b	width of the right armrest
2	minimum width between the armrests
3	depth of the seat area
4	total depth of the seat (max.)
5	total width of the seat row (max.)
6	total height of the seat (max.)

dimension	definition
8	height up to the upper edge of the folding table (max.) in a folded-up position, measured from the floor.
9	height of the folding table
10	width of the folding table
11	width of the head restraint at 65 mm
12	height of the seat area (max.)
13	height of the upper edge of the armrest
14	displacement of the armrest towards the seat front edge
16	H-point position towards the seat front edge
17	distance between the H-point and the rear edge of the front seat or a bulkhead in front
h	height of the head restraint
H	height of the H-point above the floor

5.6.4.2 Passenger seats

Hapag Lloyd mounts Keiper Recaro passenger seats of the model 4340 in the aircraft types A 310-200/300 and Boeing 737-400. The passenger seats in the Airbus and Boeing mainly differ in the shape of the seat-backs (see Figure 5.6-4)

A 310 B 737

Figure 5.6-4 view of A310 and B737 passenger seats

5.6.4.3 A310-200/300

5.6.4.3.1 Passenger seat types

In the A310, 26 different aircraft passenger seats were installed at the time of examination (different PartNo.). As regards the evaluation of the passenger compartment, the following passenger seats can be distinguished:

seat rows	seat types	minimum distance between the armrests (mm)	
centre	triple-seat row	standard seat:	402
lateral LH	triple-seat row	standard seat:	402
		rows 2 and 26 :	392
		row 27:	379

seat rows	seat types	minimum distance between the armrests (mm)	
	double-seat row	standard seat:	402
		row 33:	392
Lateral RH	triple-seat row	standard seat:	402
		rows 2 and 26 :	392
		row 27:	379
	double-seat row	standard seat:	402
		row 33:	392
summary	5 different seat types	3 different widths	

Further differences in passenger seats, which are not relevant in this context, are due, among other things, to their limited breakover, limited recline, emergency lights mounted to the seats as well as to handicapped seats.

The position of the **H-point** results from the measurements of seat G of row 4, and seat G of row 6 of the A310 as follows:

distance of the H-point to the front seat foot point = 293 mm
height of the H-point = 460 and 470 mm

The different height of the H-point reflects its range depending mainly upon the condition of the seat padding.

The length of the seat-back measured from the H-point was 685 mm (seat 4G) and 680 mm (seat 6G). Here, too, the different measuring results are due to the different compression of the seat padding.

5.6.4.3.2 Impact of the Seat Pitch

Depending on the seat pitch and the respective passenger seat, there are different minimum distances between the H-point and the passenger seat in front or the bulkheads. The following table lists the distances in the cabin of the A310:

seat rows	seat types	distance to the wall (inches)	seat pitch (inches)	minimum distances between the H-point and the limitation in front (mm)
centre	triple-seat row, first row (row 1)	30	---	997
	triple-seat row, second row (rows 2, 3)	---	30	389
	triple-seat row, second row (row 6)	---	31	440
	triple-seat row, first row (row 15)	20.5	---	756
	triple-seat row, second row (rows 4, 5, 7 to 14, 16 to 33)	---	31	415
lateral LH and RH	triple-seat row, first row (row 2)	21.5	---	781
	triple-seat row, second row (rows 3 to 8, 11, 12, 19 to 27)	---	32	440
	triple-seat row, second row (row 9)	---	33	465
	triple-seat row, second row (rows 10, 16 to 18)	---	31	415
	triple-seat row, first row (row 15)	40.5	---	1264
	double-seat row, second row, (mounted at an angle) (row 28)	---	32 to approx. 34	440 to 490
	double-seat row, second row (rows 29 to 33)	---	32	440

For passenger seats in the A310 with a bulkhead in front, distances between the H-point and the bulkhead were measured ranging from 756 to 1264 mm. The distances between the aircraft passenger seats ranged from 389 to 490 mm.

5.6.4.4 B737-400

5.6.4.4.1 Passenger seat types

In the B737-400, 24 different types of aircraft passenger seats were installed at the time of examination (different PartNo.). The mounted triple passenger seats have different distances between the armrests; for this reason, it must be differentiated between the inboard/outboard place and the centre-place.

seat rows	seat type	minimum distance between the armrests (mm)	
		inboard / outboard place	centre place
lateral LH	triple-seat row		
	standard seat:	412	432
	rows 1 and 27:	402	402
	row 13:	412 / 461	432
	row 14	412 / 451	432
	row 26:	412	417
	row 28:	392	392
	double-seat row (no outboard place)		
	row 12:	412 / ---	432
lateral RH	triple-seat row		
	standard seat:	412	432
	rows 1 and 27:	402	402
	row 13:	412 / 461	432
	row 14	412 / 451	432
	row 26:	412	417
	row 28:	392	392
summary	7 different seat types	5 different widths	4 different widths

Further differences between passenger seats examined here result, among other things, from a lack of or a limited seat-back breakover, a lack of recline, a seat cushion reduced in height, an integrated in-arm food tray and handicapped seats.

The position of the **H-point** results from the measurement of seat C of row 14 and of seat C of row 15 as follows:

distance of the H-point to the front seat foot point = 288 mm
height of the H-point = 475 and 480 mm

The different heights of the H-point reflects its range which is mainly due to the condition of the seat padding.

The length of the seat-back, measured from the H-point, was 640 mm (seat 14C) and 645 mm (seat 15C). Here, too, the different measuring results are due to the different compressions of the seat padding.

5.6.4.4.2 Impact of the seat pitch

Depending on the seat pitch and the respective passenger seat, there are different minimum distances in the B737-400between the H-point and the passenger seat in front or the bulkheads. The following table lists the minimum distances

seat rows	seat types	distance to the wall (inches)	seat-pitch (inches)	distances between the H-point and the limitation in front (mm)
lateral LH	triple-seat row, first row (row 1)	19.95	---	747
	triple-seat row, second row (rows 2 to 8, 16 to 23, 25 to 28)	---	30	394
	triple-seat row, second row (rows 9 to 11, 15, 24)	---	29	369
	triple-seat row, second row (row 14)	---	32	445
	triple-seat row, first row (row 13)	---	34	496
	double-seat row, second row (row 12)	---	29	369
lateral RH	triple-seat row, first row (row 1)	19.95	---	747
	triple-seat row, second row (rows 2 to 12, 16 to 23, 25 to 28)	---	30	394
	triple-seat row, second row (rows 15, 24)	---	29	369
	triple-seat row, second row (row 13) longer seat padding due to in-arm tray -> distance between the front edge of the seat padding and the front seat is smaller than in row 14	---	35	521
	triple-seat row, second row (row 14)	---	35	521

For passenger seats with a bulkhead in front the distances between the H-point and the bulkhead vary between 496 and 747 mm. Among the passenger seats, the minimum distances from the H-point and the seat in front ranged from 369 to 521 mm.

5.6.4.5 Evaluation of the Aircraft Passenger Cabin on the Basis of the ECE-R 17 and 21

5.6.4.5.1 ECE-R 17

The impact areas were measured in the **Airbus A 310** at the example of the passenger seats 4G and 6G (see Figure 5.6-5).

Figure 5.6-5 impact areas in the A310

In the **Boeing 737**, the impact areas were measured at the example of the passenger seats 14C and 15C (see Figure 5.6-6).

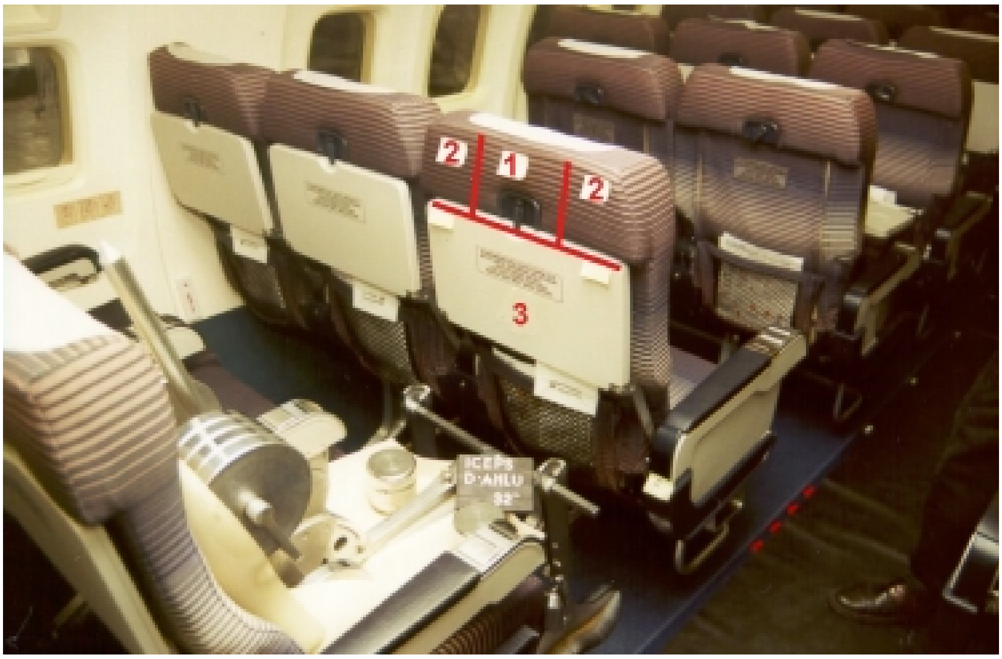


Figure 5.6-6 impact areas in the B737

Examination results in accordance with the ECE-R 17

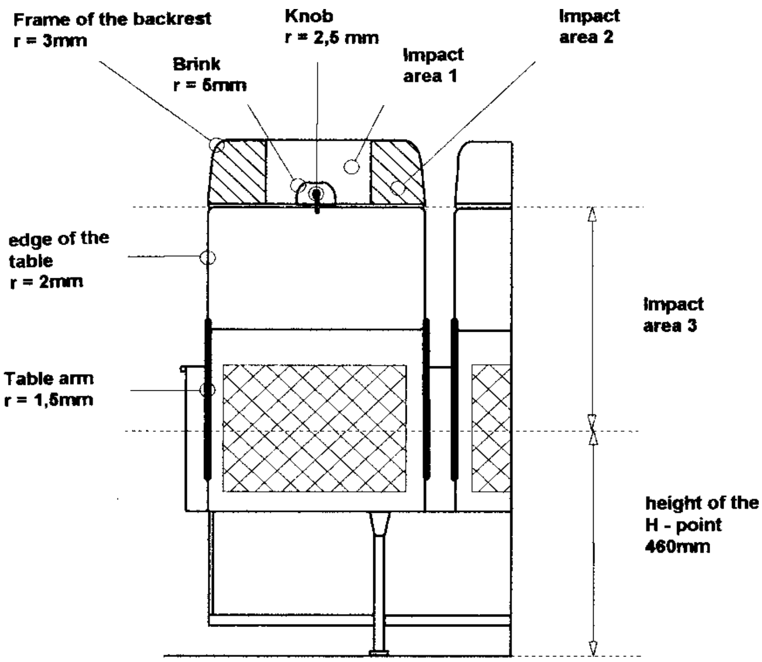
It must be stated that the line separating the impact areas 1, 2 and 3 passes through the upper area of the folded-up table.

More than one components were determined within the impact areas which project by more than 3.2 mm from the seat surface. These include, among other things, the knob which locks the folding table, the upper and lower edges of the folded-up table, the backward components of the armrests etc.

The radii of curvature of the components were determined in accordance with the ECE-R 17. The following figures depict the backward view of the aircraft passenger seats of the Airbus (see Figures 5.6-7) and the Boeing (see Figure 5.6-8) The radii (r) of curvature of the components and of the seat-back frame are indicated in millimetres. The minimum radii of 2.5 mm in the impact area 1, of 5.0 mm in the impact area 2, and of 3.2 mm in the impact area 3 were only partly reached in the measurements.

Following the ECE-R 17, the upper edge of the head restraint should have a height of at least 750 mm. The seat-backs of the Airbus passenger seats have a length between 680 and 685 mm, and those of the Boeing between 640 and 645 mm. According to the ECE-R 17, this means that there is no head restraint.

It is not possible to give a statement about the energy absorption capacity of structural elements, since such examination was not part of the research project.



Figures 5.6-7 determined radii of the Airbus passenger seat

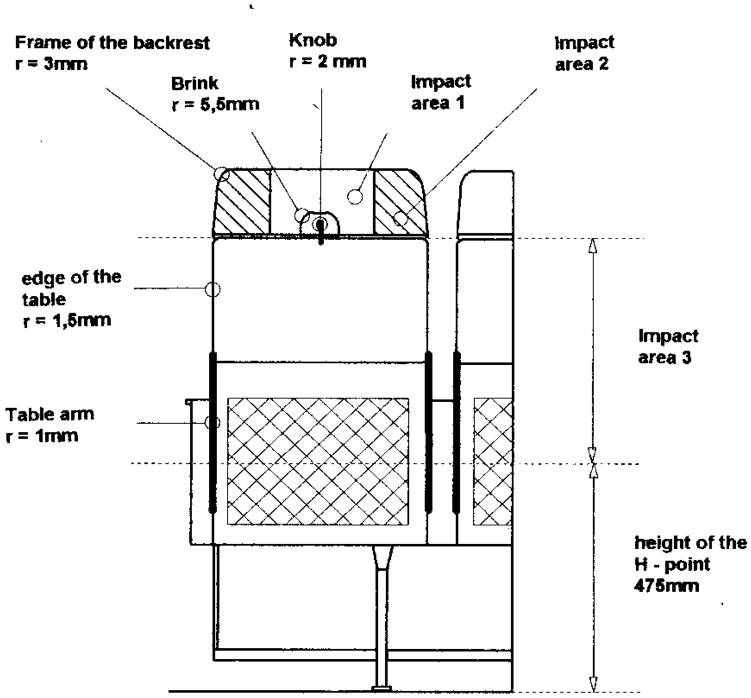


Figure 5.6-8 determined radii of the Boeing passenger seat

5.6.4.5.2 ECE-R 21

Impact Area above the Reference Height

In the Airbus A310, the seats 6G and 6E were examined (seat pitch = 31 inches). In the Boeing B737, the seat 15C was examined (seat pitch = 29 inches) (see Figure 5.6-9).

At first, the head impact area was determined as defined in the ECE-R 21, with the head test disc fixed with a thread to the H-point in the seat centre. The photograph (Figure 5.6-9) gives an example of the measurement of the head impact area of 840 mm between the H-point and the vertex of the test disc.

The upper edge of the seat-back lies within the head impact area. In the centre seats, the head impact area passes through the folding table of the right or left neighbouring seat up to the outboard armrest of these seats. For the seat at the aisle, the head impact area also includes the armrest of the seat of the same row on the other side of the aisle (compare photographs in the Appendix A4).

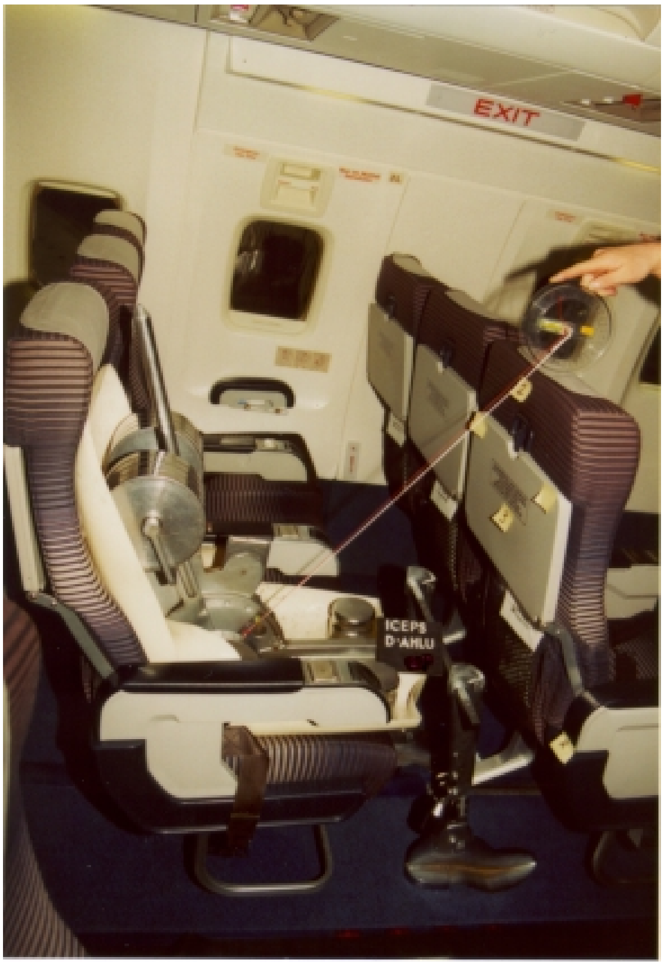


Figure 5.6-9 determination of the head impact area

Contact areas below the reference height

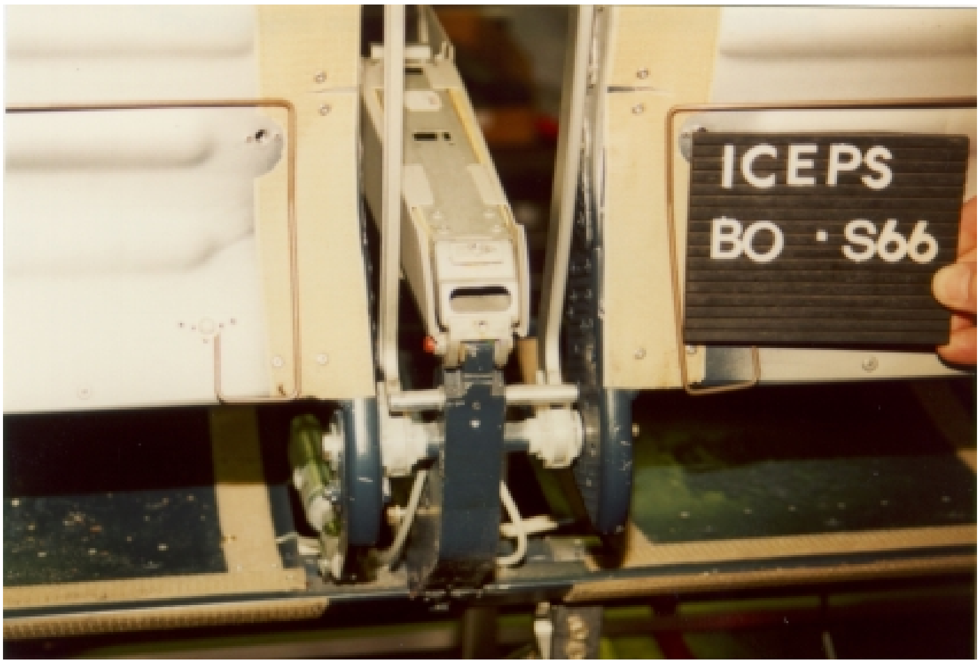
The components in the area below the H-point were determined with the knee test disc illustrated in Figure 5.6-10. This area is upwards and rearwards limited by the H-point.

Figure 5.6-10 knee test disc

The knee test disc contacts the seat feet of the seat row in front. The knee test disc also contacts the rear edge of the aluminium seat pans, since the seat covering had to be removed according to the Regulation. The hardness of the seat covering is less than 50 Shore A. Furthermore, the lower area of the links to which the seat-backs and armrests are attached, are reached with the knee test disc. The knee test disc also contacts the baggage bar, which is pulled backward from under the aisleward seat in its lower area (compare photographs in the Appendix A5).

The links to which the seat-backs and armrest are attached, are provided with coverings in the visible area, the hardness of which is more than 50 Shore A (see Figure 5.6-11, Figures 5.6-12 and Figure 5.6-13). For the links of the centre seat and the seat of a triple seat row at the board wall, there is no covering in the lower area.

Figure 5.6-11 Passenger seat without padding, total view



Figures 5.6-12 passenger seat without padding, armrest detail

Figure 5.6-13 seat feet of the passenger seat

Roof area

The control elements and components located above the passengers' heads include push buttons for lighting and call knobs, ventilation nozzles, reading lamps as well as indication lamps (Figure 5.6-14 and Figure 5.6-15).

The projections determined in the roof area of the A310 and B737 are less than 19 mm. The width of the control elements is larger than their height, so this criterion has been complied with. However, the push buttons as well as the ventilation nozzles have radii of curvature which are less than 5 mm. Their energy absorption capacity has not been checked within the framework of these examinations.

Figure 5.6-14 roof view of the Airbus

Figure 5.6-15 roof view of the Boeing

Results of the examination in accordance with the ECE-R 21

The seat-backs of the passenger seats are completely covered with fabric on their rear side. In the upper area, the seat-back is furnished with a foam padding (see Figure 5.6-16). The knob for fixing the folded-up table is surrounded by this padding.

The foam padding has a hardness of less than 50 Shore A. The padding goes up to an aluminium link perpendicular from the left to the right and is riveted on the seat-back. The sharp-edged link with a width of approx. 1.5 mm is 20 mm high and is covered when the table is folded up.

Figure 5.6-16 folding table knob

The lower part of the seat-backs is not additionally padded and has a hardness of less than 50 Shore A.

Above and below the reference height

Above (head impact area) and below the reference height (foot space), the criteria for projecting components were applied. The following components do not comply with the criteria:

criterion:	components not complying with the components
height: 3.2 to 9.5 mm radius > 2.5 mm surface > 2 cm²	• upper edge of the seat frame • knob of the folding table • edges of the folding table • front and rear area of the armrest • the seat feet of the passenger seats are sharp-edged • screws below the H-point are higher than 3.2 mm and their surfaces are smaller than 2 cm² • seat adjustment components are higher than 3.2 mm and are sharp-edged
height: more than 9.5 mm component compressible or breakable	Since this criterion is applicable for switches, levers etc. it was not examined here.

Roof area

The control elements and components fixed above the passenger seats are contacted by the spherical headform apparatus, however, the projection is smaller than 19 mm. It was established in the examination that the width of the components is larger than their height. The following criteria were not complied with:

criteria for the roof area:	components do not comply with the criterion
radius of curvatures > 5 mm	• push-button switch for the reading lamp • call knob • ventilation nozzles • control panel in the Airbus (see Figure 5.6-14)

Overview of the radii

At the example of the passenger seats installed in the Airbus A 310-200/300 and the Boeing 737-400, Figure 5.6-17 gives an overview of the radii of curvature of the components and hardness of coverings, following the ECE-R 17 and 21. In accordance with these regulations, coverings or paddings with a hardness of less than 50 Shore A were removed, such as the seat padding and seat covering.

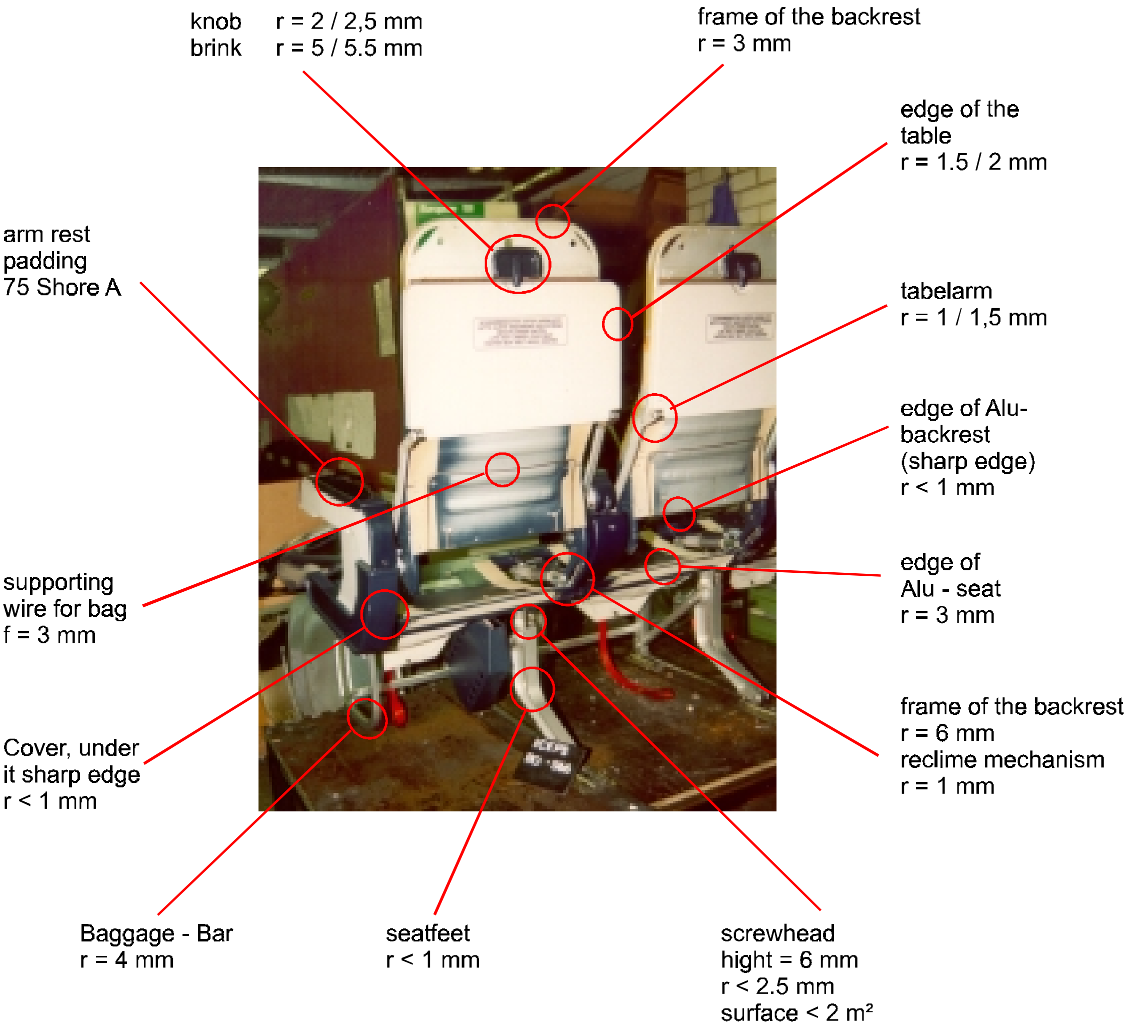


Figure 5.6-17 rear view of the seat row, radii

Head impact areas at the doors / exits

Figure 5.6-18 depicts the "over-wing exit" of the A310 with the seat row located behind it. An examination of the head impact areas in the aircraft could not be carried out within the framework of these examinations.

Figure 5.6-18 passenger seat behind the over-wing exits in the Airbus

Figure 5.6-19 depicts the fuselage of the Airbus in the area of seat 7A without the panelling. The figure shows the area of two windows. The heat insulation of the fuselage can be seen, among other things, which also covers the fuselage rips. Figure 5.6-20 depicts the rear view of the panelling in the area of the windows.

Comprehensive examinations of the fuselage structures, e. g. on the basis of the ECE-R 17 and 21, could not be carried out within this research project.

Figure 5.6-19 fuselage structure

Figure 5.6-20 rear view of the interior panelling

Examination of the energy absorption

The determination of the energy absorption of materials in accordance with the ECR-R 17 and 21 was not part of this ICEPS-examination programme. Since it is not always possible to avoid e. g. edges, the components should be furnished with energy-dissipating coverings. In this context, furthergoing examinations may render a contribution for increasing the passive safety in aircraft.

As becomes evident e. g. from the examination of the Kegworth accident, a large part of severe passenger injuries can be avoided if the injury hazard in the aircraft cabin is evaluated with suitable testing and checking procedures and methods. In the examinations already carried out, a potential for reducing the injury hazard became evident. In this context, a targeted determination of sharp edges and projections can be suggested in particular. Paddings and coverings could furthermore be determined, requiring an examination of energy-dissipating materials.

5.7 Proposals for European airworthiness requirements (WP 7)

5.7.1 Objective and basis of WP 7

Work package 7 will provide proposals for the further development of European airworthiness requirements and prepare an exploitation of the main project deliverables. It will submit the final contribution of work package 6. The proposed criteria will be discussed and agreed with the representatives of European aviation authorities (Luftfahrt-Bundesamt and Austro Control GmbH).

5.7.2 Contact partners

We contacted the members of the JAA working groups of the Luftfahrt-Bundesamt (LBA) as well as Austro Control GmbH (ACG) and informed them about the ICEPS Project. We also took part in the meetings of two employees of the German federal Bureau of Aircraft Accidents Investigation:

Christian-Heinz Schuberdt, Captain

Lothar Müller, Captain

JAA groups	tasks / members
JAR-25 Large Aeroplanes: Cabin Safety Study Group	The purpose of the Cabin Safety Study Group is to consider the Cabin Safety Requirements related to the design & construction and equipment requirements necessary for JAR-25. Mrs Kleinhammer - LBA Mr Markus - ACG
JAR-OPS: Aircraft Operations, Equipment Sub-Committee	The primary purpose of the Equipment Sub-Committee is to propose, when requested, draft material for the consideration of the Operations Committee, and similarly to consider proposed amendments relating to the contents of JAR-OPS Subpart K & L. Mrs Kleinhammer - LBA
JAA: Regulation Advisory Panel (RAP)	The RAP is an adviser to the JAA Regulations Division on matters dealing with the whole rulemaking process, the structure and layout of the set of JAR codes and the content and form of changes proposed. Dr Lhotsky - ACG
JAA: Human Factors Steering Group	The purpose of the Human Factors Steering Group is to coordinate activities relating to the Human Factors aspects of JAA rulemaking. Dr Lhotsky - ACG

There was also a meeting with representatives of DaimlerChrysler Aerospace Airbus GmbH in Hamburg-Finkenwerder, with Dr.-Ing. Hachenberger and Mr. Fitzsimmons participating from the Structural Mechanics / Analysis Techniques unit.

5.7.3 Results of the meetings

In February 1999, a meeting was held with DaimlerChrysler Aerospace focusing on the results of the technical examination of the Kegworth and Warsaw accidents performed within the ICEPS project. The employees of DaimlerChrysler Aerospace explained the building regulations as well as criteria for the layout of the aircraft fuselage in case of a crash. Also the results of crash tests were discussed.

In March 1999, we had the opportunity to present the ICEPS project to the members of the JAA groups appointed by ACG, and to discuss the results.

In April 1999, we presented the ICEPS project to the members of the JAA groups appointed by the LBA and employees of the German Federal Bureau of Aircraft Accidents Investigation, and discussed the results.

The following aspects of the ICEPS project were explained and discussed, among other aspects, in the meetings:

- Explanation of the Kegworth and Warsaw accident whereabouts;
- representation of the damages of the aircraft cabin as well as of the aircraft seats and the overhead bins;
- report about the injured passengers;
- exemplified explanation of the reasons for the passenger injuries;
- explanation of backgrounds, on the basis of which the passenger protection criteria will be developed further. The injuries caused by the accidents (Kegworth and Warsaw) and the already available injury criteria will be correlated. Furthermore, additional injury criteria will be determined, if adequate, for individual body regions. This is aimed at describing criteria which enhance the passive safety of aircraft passengers to such an extent that the passengers are able to leave the aircraft on their own after a crash. This requires an evaluation of the injury criteria, which also includes the passengers' state of consciousness and their ability to free themselves and to walk.
- Some protection criteria for the enhancement of passive safety in aircraft cabins were explained, e. g. criteria for the elimination of sharp edges, means to determine leg injuries etc.

The results of the conversations can be summarised as follows:

- The events explaining why the accident occurred are generally well documented. The crash, during which strong decelerations stop the aircraft, is very scarcely documented. As a rule, there are no data available on the deceleration level and the direction of deceleration, or on statements of passengers and flight attendants explaining what happened in the cabin.

- Registration and documentation of passenger injuries is insufficient. Results are set up, which are important e. g. for paying out life insurances or helping to answer the question of guilt. Based on such findings, e.g. passengers' time of death is determined, or the results serve insurance companies and lawyers to process passengers' claims for damages. There is very little documentation about Injuries which give some hints for passive safety in the cabin. There is no or only a very vague documentation of passenger injuries before the background of injury causes. Passenger seat-related injury patterns can generally not be determined.

- Harmonised European action and development of foundations, or the development of methods for a comprehensive registration of accidents with passenger aircraft is proposed.

- The presented results for the enhancement of passive safety in aircraft cabins were found very helpful. The proposals concern most different JAR requirements, such as the requirements for the licensing of aircraft passenger seats, the evacuation of passengers, the installation of wall panelling etc. Accordingly, different working groups of the JAA and the national authorities have to be included in further meetings. The question as to which working groups are concerned, could not yet be finally clarified. It has been found that additional meetings and discussions are necessary to represent the ICEPS results.

6 Conclusion

The proposed injury criteria serve to enhance passive safety in aircraft. In complying with the building regulations in accordance with JAR 25.562 "Emergency Landing Conditions“, only the integrity of the aircraft passenger seat as well as the compliance with the injury criteria Head Injury Criterion (HIC), lumbar loads and femur forces are presently proven and the correct position of the pelvic belt strap (submarining) evaluated. The analysis of the Kegworth and Warsaw accidents, however, demonstrate that the presently applied criteria cover the real-world accident situation only to a very insufficient extent. The criteria are by far not sufficient to identify injuries and mechanisms.

To define protection criteria, this study developed the main idea that passengers must be able, after an accident, to evacuate themselves from the aircraft within the shortest possible time. For this purpose, the passengers must

- be conscious,
- be able to evacuate themselves and
- be able to leave the aircraft on their own.

The injury criteria derived from this main idea serve to directly evaluate measures aimed to provide the chances to survive and to minimise the severity of injuries in the aircraft cabin, with the passengers' survival area to be taken into consideration (see figure 6-1).

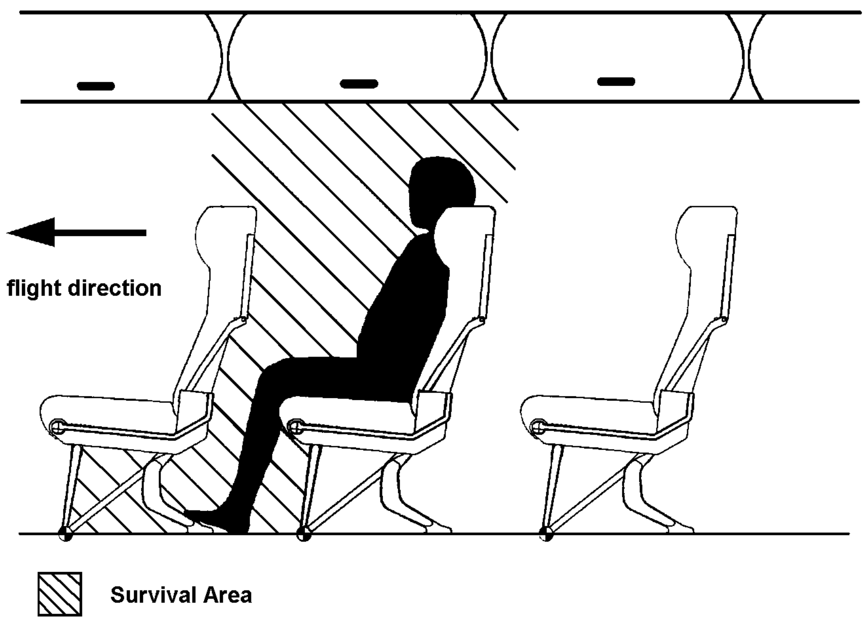


figure 6-1 survival area

On the one hand, the proposed, prospectively enhanced criteria include the consideration of injury risks for all body regions, i. e. injury criteria are defined for the head/face/brain, neck/cervical spine, chest, pelvis/vertebral spine, upper extremities and lower extremities.

On the other hand, the passengers' survival area must be examined with regard to sharp edges and the energy absorption capacity of covered structures.

The level of passive passenger safety can only be enhanced by a comprehensive consideration and examination of the aircraft interior, i. e. by:

- the evaluation of the survival area, e. g. by tests with interior parts, with aircraft passenger seat;
- determination of the energy absorption capacity of covered rigid structures in the survival area;
- application of dummies of the Hybrid III series in dynamic tests;
- application of extended dummy protection criteria.

This project, however, found that further research is necessary beyond this project.

It was found that not all useful injury criteria are biomechanically verified, and partly no suitable dummy protection criteria are available either. The analysis of the Kegworth and Warsaw accidents shows that for some body regions, biomechanic tolerance limits are not known (see table below).

Criteria required due to accident analysis and main idea	Known biomechanic tolerance limits	dummy protection criteria
head	head	head
cervical spine	cervical spine	cervical spine
upper arms	upper arms	-
forearms	-	-
hands	-	-
thorax	thorax	thorax
lumbar spine	lumbar spine	lumbar spine
abdomen	abdomen	abdomen
femurs	femurs	femurs
lower legs	lower legs	lower legs
feet	-	-

The accident analyses performed in this research project demonstrate that presently, aircraft accidents are mainly and almost exclusively examined to answer the question why the accident with the air carrier happened. Was it technical or human failure or both? There are very few data or even no information at all on what happened to the passengers during the crash, what decelerations were effective in the aircraft cabin and how the interior behaved.

For a continuous enhancement of passive safety in aircraft cabins, further analysis of aircraft accidents is useful. Thus, each aircraft crash should be examined with regard to the correlations of the accident mechanisms and injury mechanisms. However, this requires new means of information gathering to perform the respective analysis, such as:

- new sensor technology;
- new film technology in the cabin;
- additional black box;
- development of new accident questionnaire forms;
- additional training of aircraft crash researchers;
- development of new evaluation strategies;
- exchange of information with the crashworthiness divisions of aircraft manufacturers;
- exchange of information between the doctors treating the accident victims and the technicians analysing the accident;
- determination of the correlations between cabin layout, seat layout, survival area, restraint systems, decelerations effective during the crash and occurred injuries.