Examination on the
Enhancement of Cabin Safety for Infants

Research Order No.:
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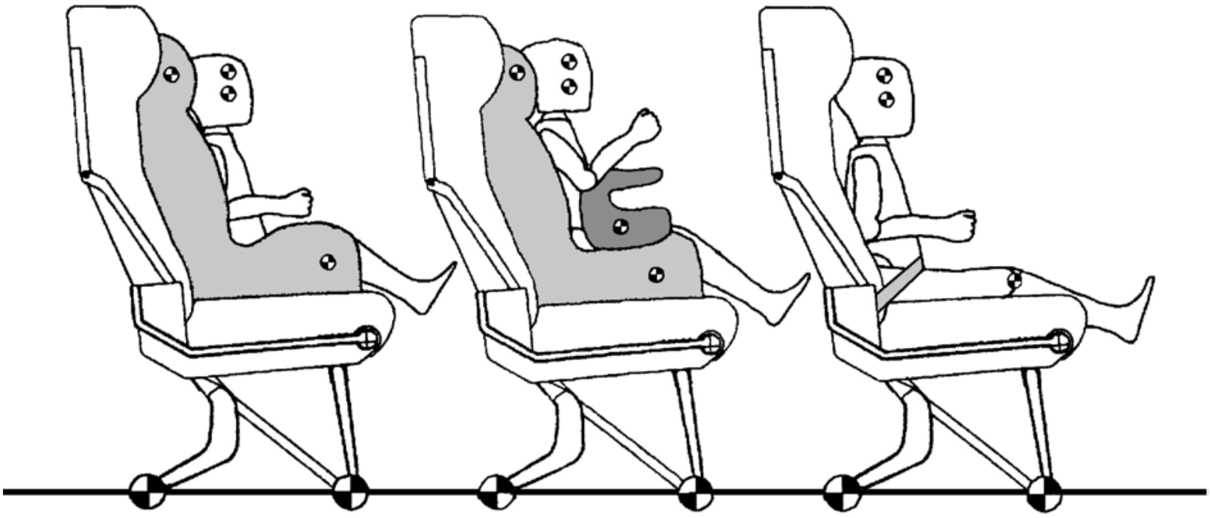

BRIEF REPORT

Brief Report

1 Initial Situation

Since September 1998, the provisions of the Joint Aviation Requirements-Operations 1 (JAR-OPS 1) on the "Commercial Air Transportation" apply in Germany as well as in the other JAA member states. JAR-OPS 1.320 and 1.730 outline, among other things, the transportation of infants and children. The provisions allow multiple occupancy of aircraft passenger seats. Accordingly, infants (< 2 years) are properly transported on an adult's lap. JAR OPS 1.730 further regulates that an operator is only allowed to operate an aircraft if he or she provides an additional loop belt or other restraint device for each infant.

However, the research results achieved so far show that the safety measures for infants outlined in JAR-OPS 1 are insufficient. Due to this situation, JAR-OPS 1.320 and 1.730 were suspended by the *5. Durchführungsverordnung zur Betriebsordnung für Luftfahrtgerät (5. DV LuftBO)* [Fifth implementing order on the operating regulation for aircraft] effective up to 31 August 2003.

For the transportation of infants on an adult's lap, the adult is restrained with a pelvic belt, and the infant is fixed on the adult's lap with an additional loop belt (see figure 1).

Figure 1
Infant restrained with a loop belt

In a suddenly occurring deceleration in the longitudinal aircraft axis, the adult and the infant show a pronounced jack-knife effect. The upper torso and the lower extremities of the infant as well as of the adult sitting behind the infant fold up in a forward direction, with the loop belt restraining the infant. Finally, the loop belt drives into the infant's abdomen and only stops at his or her vertebral spine. From the technical point of view, the infant acts like an energy absorption element for the adult; the crash loads acting on the adult are thus reduced, and the infant fixed with the loop belt thus suffers most serious up to fatal injuries.

The research projects implemented by the TÜV by order of the German Transportation Ministry in 1992 and 1995 demonstrate that passive safety for infants and children adequate to adult's passive safety can only be achieved with an own seat and a suitable restraint system.

In contrast to the situation in aircraft, there are comprehensive regulations on the transportation of infants and children in motor cars providing suitable child restraint systems (CRS). World-wide, there are regulations such as FMVSS 213 for the USA and the ECE-Regulation 44 being applied in Europe and in Germany, encompassing, among other things, requirements for CRS regarding

- suitable restraint principles
- adequate classification of CRS for children
- inflammability
- corrosion
- toxicity
- energy absorption
- roll-over test
- dynamic test (crash test)

2 Aircraft Passenger Survey

In the holiday period of July to September 1997, an aircraft passenger survey was performed on the airports of Cologne/Bonn, Frankfurt and Dusseldorf. 365 families were interviewed with their children up to an age of 14 years, among other things, on the following points:

- Data on the interviewed persons and on the family's income
- Number and age of the children
- Joint flight frequency with children
- Annual travelling habits
- Transportation of children in aircraft
- Willingness to pay extra for an own seat for children younger than two years

69% of the 536 covered children were younger than 2 years.

Regarding their willingness to pay extra for an own seat for children younger than 2 years, 79% of the interviewed persons stated that a seat price of 50% would have no effect on their flight behaviour.

3 Survival Space

The passenger's individual survival space is the basic requirement for their passive safety in aircraft. In a crash, the aircraft fuselage must on the one hand absorb energy, and on the other hand, there must be a survival space. The survival space consists of the cabin floor, fuselage wall, ceiling, overhead bins, the passenger's own seat as well as the seats or bulkheads in front of it. Like for adults, an individual survival space is the basic requirement for an enhancement of passive safety of infants and children in aircraft.

4 Biomechanics

Given normal development, the development of children is concluded as late as approx. with the 21st year. Figure 2 depicts the change of the body proportions of a newborn (4 head levels) up to an adult (9 head levels). The ratio of the head levels to the entire body demonstrates the fundamental differences to be considered in the design of restraint systems adapted to the development of man. Furthermore, the skeleton of infants and children is partly still chondroid which makes it impossible to introduce forces like an adult. Furthermore it is important to protect the head in a crash according to children's development stage.

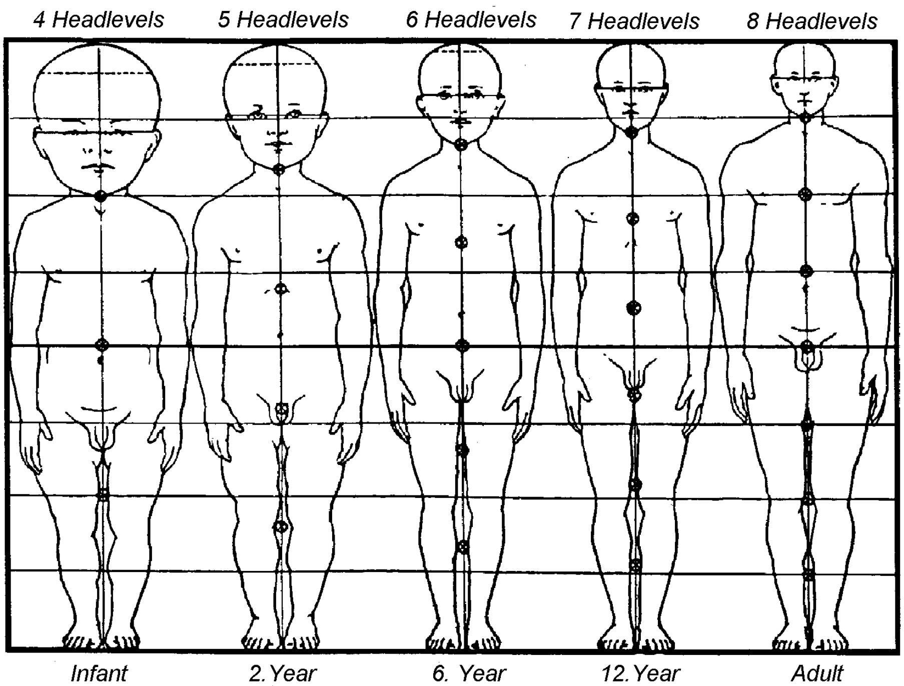

Figure 2
Changes of the body proportions during growth

The generally accepted "biomechanic" tolerance is determined for the assessment of the loads acting on infants and children in child restraint systems (CRS) in crash situations,. The evaluation of dynamic tests with dummies is based on protection criteria derived from literature and the regulations on the certification of CRS in passenger cars.

head:	HIC <1000
	a_{3ms}, resultant < 80 g
cervical spine:	a_{3ms}, vertical < 30 g
thorax:	a_{3ms}, resultant < 55 g
abdomen:	modelling mass in the vertebral spine region must not be damaged

5 Restraint principles

The research project examined and outlined the general principles of restraint systems for children up to a weight of approx. 36 kg. It must generally be differentiated between forward and backward-facing systems. Forward-facing systems are e.g.:

Lap belts, child pelvic belts or pelvic belt guides which restrain the child's pelvic; however, there is no restraint of the upper torso and the head. For infants, the belt runs over the abdomen which is from a biomechanic point of view not acceptable as a restraint principle.

In child restraint systems with impact shields, the child is restrained by the impact shield over the pelvis and the thorax. The examination was based on four generally different systems.

CRS with integrated belt system restrain both the pelvis and the upper torso.

Backward-facing CRS, which are normally intended for infants up to approx. 10 or 13 months, support the child in a large area with the seat-pan. The belts integrated in the CRS protect the infant against slipping out as well as during the rebound phase.

6 Means of Adaptation / Installation Tests

The examined CRS were selected, among other things, under the aspect that they are only adaptable to a seat with a pelvic belt. Aircraft passenger seats are as a standard equipped with a pelvic belt (see figure 3). The difference to the pelvic belt in passenger cars is the centrally located lift-lever buckle with which lap belts are equipped in aircraft, rather than a lateral push-button release.

The installation tests with CRS were implemented in the "window seat" of a double-seat mounted with a seat pitch of 28 inches to the aircraft passenger seat in front. The following aspects were examined: the adaptation of the CRS to the aircraft passenger seat, the restraint of dummies (P3/4 [9 months], P3 [3 years], P6 [6 years], P10 [10 years) in a CRS as well as the dismounting of the CRS.

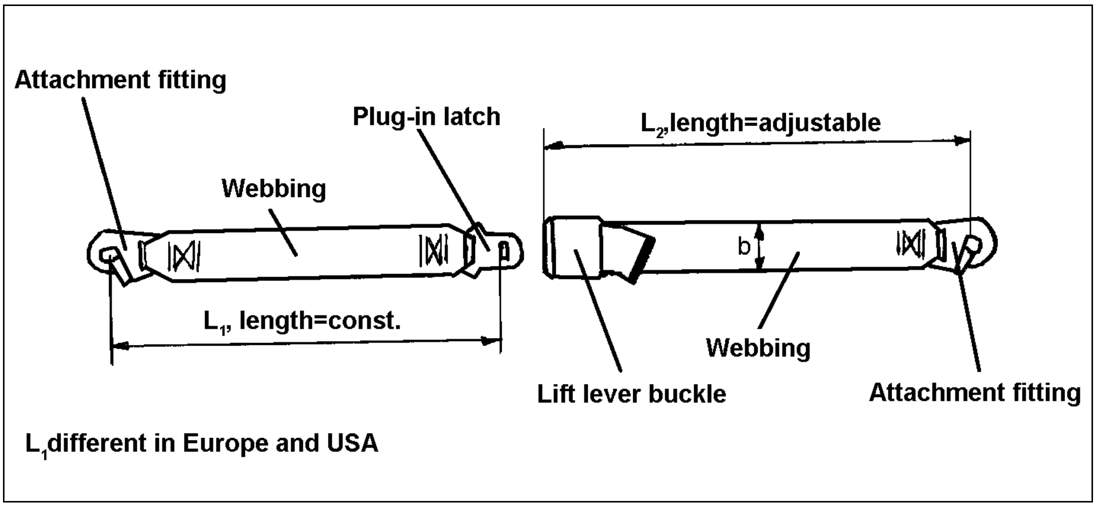

Figure 3:
Sketch of an aircraft passenger seat pelvic belt

The examined CRS were in most systems adapted with the pelvic belt to the aircraft passenger seat. The impact shield as well as the seat pan of the impact shield systems is normally held by the pelvic belt A problem was the position of the central lift-lever buckle of the CRS developed for passenger cars. Some impact shields had to be modified in order to use the lap belt. Though others did not have to be modified, the opening of the lift-lever buckle was problematic.

CRS with an integrated belt system are also designed for safety belts equipped with lateral push-button release. Belt guides are normally available behind the seat-back to adapt a CRS. In one system, the belt runs over the seat-back. The lift-lever buckle of these CRS rests on the seat-back and presses against the child's back. Other systems posed the difficulty that the lift-lever buckle is not positioned centrally behind the seat-back of the CRS but in the area of the belt guide, where the belt is normally diverted. In these cases, it was necessary to use lap belts with different belt strap lengths. After the adaptation of some CRS, the lift-lever buckle did not open, since the available space behind the seat-back of the CRS was too small. Here, the belt strap had to be dismounted and turned round to fold up the lift-lever and open the buckle.

One CRS was equipped with an ISO-FIX adaptation. Additional supports had to be mounted to the aircraft passenger seat. The adaptation of the CRS to the prepared aircraft passenger seat could then be done without difficulty.

None of the examined CRS is adaptable to an aircraft passenger seat without restrictions. Either the systems had to be modified, or other pelvic belts had to be used. In the ISO-FIX system, additional adaptation points had to be mounted to the aircraft passenger seat.

7 Roll-Over Tests

Roll-over tests were performed to examine the behaviour of CRS in negative accelerations, based on ECE Regulation 44. Aircraft passenger seats were mounted to a rotating stand and CRS equipped with dummies rotated around the lateral and longitudinal axes. The aircraft passenger seats were rotated around the lateral axis in a forward and backward direction by 360° each. They were rotated around the longitudinal axis to the right and to the left, also by 360°. At 180°, the displacement of the dummy head was measured (see figure 4). All systems gave significantly lower values than the tolerance limits for the head displacement in accordance with ECE Regulation 44. None of the systems can be seen as critical or striking in this regard.

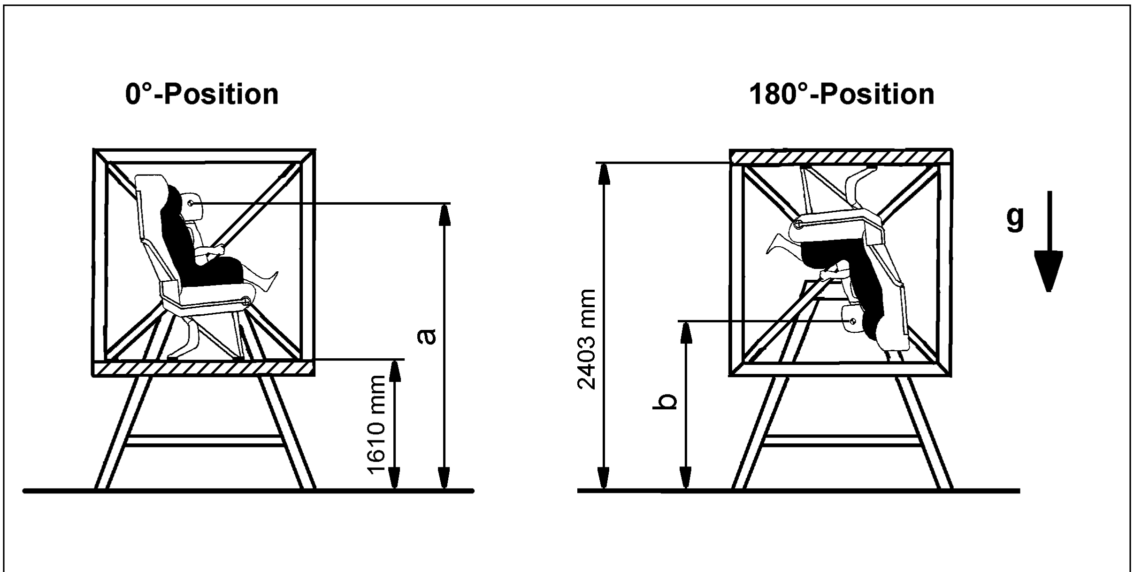

Figure 4:
Determination of the vertical head displacement

8 Dynamic Tests

The dynamic tests were performed in accordance with SAE AS 8049a, 16g forward Tests. The test configuration consisted of 3 aircraft passenger seat rows mounted one behind the other with a seat pitch of 29 inches and 32 inches respectively. 24 test situations were examined with 12 different CRS types and dummies for the age groups of 9 months, 3 years, 6 years, and 10 years. It was also examined, which effect the CRS adaptation to the aircraft passenger seat (recline method) had on the dummy loads during a crash. The lap belts which adapted the CRS to the aircraft passenger seat were as a standard fastened at a force of 200 N.

In the recline method, the seat-back is first put in the recline position and then, the lap belt is fastened. Thereupon, the seat-back is again put in an upright position. The recline method produces a firmer adaptation of the CRS to the aircraft passenger seat.

In the examination, a forward-facing CRS was considered for the age group of 9 months and up. The adaptation of the system with the recline method shows a significant decrease of the head load (approx. 1/3) compared to the normally adapted CRS. During the crash, critical loads of the examined body regions of the P3/4 dummies were generally not found. Only in the rebound, the lumbar spine is exposed to a higher load since the CRS was not laid out for a use of belts with central lift-lever buckle (the lift-lever buckle is located on the seat-back).

The findings with P3 dummies of the age group of 3 years show that both the CRS with integrated belt system and with impact shields give comparably favourable results. In contrast to this, the exclusive restraint of the P3 dummy with a pelvic belt (child belt) shows a generally critical load.

The tests implemented with a P6 dummy of the age group of 6 years show that the examined impact shield systems and the systems with integrated belt generate almost identical loads in a crash. One system was assessed as critical, all other systems as higher loaded. In the systems with pelvic belt only, the effect of the seat position of the first row, i. e. with no aircraft passenger seat in front of the dummy, as well as of the second row, i. e. with an aircraft passenger seat in front of the dummy, were examined. Here, the measured values for the head loads in the second row showed lower values, which, however, always remain in the critical range. The load acting on the thorax in the first row was evaluated as higher loaded and is lower than in the second row. The use of a pelvic belt must be assessed as critical for the age group of 6 years.

The loads of the P10 dummy of the age group of 10 years were examined for the first and the second row. The loads must generally be assessed as critical, especially the head loads are significantly above the tolerance limit (HIC > 1000). Only the thorax and in some tests also the lumbar spine are higher loaded.

It is generally found that the examined CRS are applicable in aircraft, even under simulated crash conditions, for the age groups of 9 months to approx. 6 to 7 years. However, a safe adaptation of the CRS to the aircraft passenger seat must be ensured. For this purpose, the examined CRS were adapted to the conditions in the aircraft fuselage. It is possible with suitable systems to provide for a safety for infants and children which is equivalent to that of adults.

Thus, CRS for infants adapted to the development of children (for children up to approx. 13 kg) should be selected according to the respective weight, and for taller children (up to approx. 125 cm), CRS should be chosen according to the body height. Infants must generally be transported in backward-facing CRS.

9 Requirements to Child Restraint Systems

The dynamic crash tests with CRS of different principles show that the loads acting on the children are significantly lower with a suitable CRS than by transporting infants on the lap of an adult and by restraining children with a loop belt or a pelvic belt only.

The safety achievable with a suitable CRS increases for infants (0 to 2 years) and children (2 to 7 years) to a similar level of a 50 percentile adult. The safety level for infants and children is thus equivalent to an adult.

Due to their body height, (> 125 cm), older children represent the transition to adults (e.g. a 5 percentile female).

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Figure 5
Sensible Requirements for CRS

The following requirements must be met for the use of CRS in aircraft (see figure 5):

- ECE-R44 or comparable regulations

  These include the evaluation of the applied restraint principles, biomechanics and constructive provisions.

- Aviation-specific requirements

  These include the adaptation of CRS to the aircraft passenger seat or to the aircraft structure as well as the handling of the CRS in the aircraft.