Study on Child Restraint Systems

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Final Report

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Acronyms

ACJ-OPS	Advisory Circular Joint Operations (JAA)
AEA	Association of European Airlines
ARP	Aerospace Recommendet Practice (SAE)
BDF	Bundesverband der Deutschen Fluggesellschaften
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung, Federal Ministry of Transport, Building and Urban Affairs
CFR	Code of Federal Regulations
CMVSS	Canadian Motor Vehicle Safety Standard
CRD	Child Restraint Device
CRP	Cushion Reference Point
CRS	Child Restraint System
CS	Certification Specification
CSSG	Cabin Safety Steering Group
DOT	Department of Transportation
EASA	European Aviation Safety Agency
EBAA	European Business Aviation Association
ECE-R	Economic Commission for Europe Regulation
ELFAA	European Low Fares Airline Association
ELOS	Equivalent level of safety
ERAA	European Regions Airline Association
ETSO	European Technical Specification Order
EU-OPS	Council Regulation (EEC) No 3922/91 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FMVSS	Federal Motor Vehicle Safety Standard
g	Gravity, 9,81 m/s^2
HIC	Head Injury Criterion
IACA	International Air Carrier Association
IATA	International Air Transport Association

ICAO	International Civil Aviation Organization
ICEPS	Research Project by European Commission: "Injury Criteria for Enhanced Passive Safety in Aircraft"
IEM-OPS	Interpretative/Explanatory Material Operation
IMPCHRESS	Study: "Improved Child Restraint System Safety"
ISO	International Organization for Standardization
ISOFIX	International standard for attachment points for child safety seats in cars
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
JAR-OPS	Joint Aviation Requirements: Operation
LATCH	Lower Anchors and Tethers for CHildren
NTSB	National Transportation Safety Board
P10 Dummy	Child Dummy, 10 years
P3 Dummy	Child-Dummy, 3 years
P3/4 Dummy	Child-Dummy, 9 month
P6 Dummy	Child Dummy, 6 years
Pax	Passengers
RIA	Regulatory impact assessment
SAE	Society of Automotive Engineers
TSO	Technical standard order
WG	Working Group

1 Introduction

This Study on Child Restraint Systems was carried out by TÜV Rheinland Kraftfahrt GmbH, Team Aviation, by order of the European Aviation Safety Agency (EASA).

The issue to be addressed by this study is the protection from injuries caused by turbulence, aborted take-off, hard landings and/or in emergency landing conditions, of children, particularly those 2 or less years old (infants), on board aircraft used for commercial transport of passengers. There are recognized concerns that the current regulations and operational practice may not provide such children with the level of impact protection equivalent to that provided to the other passengers.

The study is subdivided into the following three focal points:

Phase I: Literature and data search and review

The "Literature and data search and review" of this study gives an overview of relevant research papers as well as of applicable regulations of the major aviation authorities regarding the transport of infants in aircraft and also includes the regulations for the approval of child restraint systems for motor vehicles with their main specifications for Europe and the USA. The accident analysis reviews accidents involving infants at specific examples.

Phase II: Evaluation of available solutions

The "Evaluation of available solutions" outlines the solutions which are already used and those which are in development, and analyses them in view of safety, operational practicality and costs.

Phase III: Evaluation of possible regulatory and non-regulatory options

The solutions to be analysed can be subdivided into three categories:

- approval standards / provisions for child restraint systems
- child restraint systems
- procedures for the transport of infants / children in aircraft.

The "Evaluation of possible regulatory and non-regulatory options" analyses possible amendments regarding the restraint of infants and children in aircraft specifying possible amendments within the fields of airworthiness and operational impacts. The impacts of these possible amendments are analysed for aviation and passengers with the "Regulatory Impact Assessment (RIA)".

2 Literature and data search and review (Phase I)

The "Literature and data search and review" gives an overview of relevant research papers as well as of applicable regulations of the major aviation authorities regarding the transport of infants in aircraft and also includes the regulations for the approval of child restraint systems for motor vehicles with their main specifications for Europe and the USA. The accident analysis reviews accidents involving infants at specific examples.

2.1 Studies and Test Reports

2.1.1 Crash Safety in aircraft cabins

Ordered by: Federal Minister of Transport, Building and Urban Affairs (Germany); L - 8/91 - 50 103 / 91; 1992

Contractor: TÜV Rheinland Kraftfahrt GmbH (Germany)

Contents of the Research Project:

This research project dealt with the crash behaviour of aircraft passenger seats in “dynamic emergency landing conditions” focussing in particular on the accessibility of the overwing exit after a crash in deformed seat structures. The tests were carried out with different aircraft passenger seats which were approved on the one hand in accordance with JAR 25.561 (9g static test) and on the other hand additionally in accordance with JAR 25.562 (16g dynamic test).

For comparison, both seat types were tested in accordance with JAR 25.562 at 16 g. Two three-seat rows were mounted one behind the other and all seats were occupied with dummies.

These tests also considered children as passengers, amongst others. An infant dummy (P3/4) was placed on the lap of a 5 percentile female dummy who was fastened with a lap belt and the infant dummy was secured with a loop belt. A child dummy (P3) was placed next to them in a child restraint system (CRS) with an impact shield. The CRS was secured with a lap belt.

Results (related to the safety of children):

The adult-dummy and the lap-held infant-dummy secured with the loop belt show a pronounced jack-knife effect in sudden deceleration in the aircraft longitudinal axis. The loop belt fixes the infant in the abdominal region, the lap belt fixes the adult over the pelvis. In a crash, the upper torso and the lower extremities of the infant as well as of the adult sitting behind it break over. The infant moves forward due to its mass inertia forces. The jack-knife movement of the adult triggers so-called wedge expulsion forces which thrust the infant forward even more with the loop belt driving far into the infant’s abdomen until it gets hold at the vertebral spine.

The adult’s head hits against the back of the infant’s head, and the adult’s chest hits against the infant’s back. Due to the high compressive load effective on the child, the adult’s legs open and the infant hits onto the ground like a ping-pong ball.

In the transport of the lap-held infant secured with a loop belt, the infant acts as an ”energy absorption element” for the adult. The loop belt does not provide any safety to the infant.

The P3 dummy seated in the CRS is restrained by the impact shield. The measured dummy loads are significantly below the dummy protection criteria in accordance with ECE-R 44.

The former way of securing infants aged up to 2 years (with a loop belt) must be assessed as highly dangerous. This could be avoided with a suitable CRS.

2.1.2 The Performance of Child Restraint Devices in Transport Airplane Passenger Seats

Ordered by: Office of Aviation Medicine FAA (USA)
DOT/FAA/AAM-94/19; 1994

Contractor: FAA Civil Aeromedical Institute (USA)

Contents of the Research Project:

This research project dealt with the installability of child restraint systems (CRS) in aircraft passenger seats, the attachment, the child restraint and the analysis of injury potentials in a crash landing condition. 20 different CRS were tested as specific examples approved in accordance with American or European motor vehicle specifications (FMVSS 213, ECE-R 44) or in accordance with the American or British aviation standard.

Booster seats, forward-facing carriers, aft-facing carriers, a harness device, a belly belt, and passenger seat lap belts were evaluated. Dynamic impact tests, in accordance with FAR 25.562, were conducted with CRSs installed on airplane passenger seats. Four child-size anthropomorphic test dummies were utilised (2x 6 month, 24 month and 36 month-old dummys).

Results:

Some of the tested motor vehicle CRSs could not be used on aircraft passenger seats. CRSs wider than 17 inches did not fit in between the armrests of the aircraft passenger seat. Rearward-facing CRSs furthermore block the recline function of the backrest of the seat in front due to their forward overhang. Moreover, it was not in all cases possible to attach the CRS with an aircraft lap belt.

In approved forward-facing motor vehicle CRSs, the head may hit against the backrest of the aircraft passenger seat in front in a crash due to a small seat pitch (e.g. in economy class). FMVSS 213 specifies a front tolerance line which the dummy head must not exceed in the approval test. The seat pitch between the individual aircraft passenger seats, however, is often smaller than the distance to the tolerance line in accordance with FMVSS 213.

As a basic principle it is noted that motor vehicle CRSs did not yield satisfactory results. The main reason for this is the fact that the requirements specified in FMVSS 213 do not cover the conditions in an aircraft and on the aircraft passenger seat sufficiently. Thus, e.g. the installation situation of the CRD on the aircraft passenger seat clearly differs from the test set-up of FMVSS 213. The aircraft passenger seats (e.g. seating cushion) deviate from the test fixtures in accordance with FMVSS 213. The aircraft lap belt differs in the belt buckle and its means of adjustment. Also the position of the attachment points for the lap belt at the aircraft passenger seat differs from the position of the belt anchorage point at the test fixtures in accordance with FMVSS.

Notes on the different seat types:

The tested aft facing carriers provide an adequate means to enhance the protection of infants weighing up to 9 kg (infants aged approx. 9 months).

Forward facing carriers: In some CRDs, the use of the original belt anchorage points at the aircraft passenger seat leads to steep lap belt angles (85° up to 93°). The angle of the lap belt had a considerable effect on the forward displacement of the CRDs in the tests. The CRDs attached at a steep belt angle produced the largest forward displacement. The fastened 3-year-old dummies partly moved forward in the CRDs so far that their head hit against the backrest of the seat in front resulting in an HIC value of more than 1000 in six tests.

A lap-held child restraint, or belly belt, should not be considered as a means for protecting a child from injury during an accident.

Normal Lap Belt: The upper torso of the dummy (3-year-old dummy) hits against its femurs in the test. The head hits against the seat in front or the structure of its own seat. Head loads of an HIC value more than 1000 were measured.

Booster Seats (CRD without own backrest): The test results with the 3-year-old dummies showed a significantly higher forward-displacement of the head than it is admissible in accordance with FMVSS 213. Two aircraft passenger seat rows were set up one behind the other in the tests which were equipped with a break-over backrest. An adult dummy (50 percentile hybrid II) was seated behind the 3-year-old dummy. Due to the impact of the adult dummy against the backrest of the seat the backrest broke over resulting in a high forward-displacement of the head of the child dummy and in additional loads effective in the thorax. Compared with the tests where the child dummies were secured with a lap belt only, the tests with the booster seats produced less favourable test results. It is recommended not to use booster seats and to fasten 3-year-old children with the lap belt instead.

2.1.3 Requirements for Child Restraint Systems in Aircraft

Ordered by: Federal Minister of Transport, Building and Urban Affairs (Germany); L - 5/95 - 50 140 / 95; 1998

Contractor: TÜV Rheinland Kraftfahrt GmbH (Germany)

Contents of the Research Project:

This research project dealt with the specifications for child restraint systems for use in aircraft.

It performed 19 tests with rearward-facing CRS's which corresponded to group 0 (infants weighing up to 10 kg) and 0+ (infants weighing up to 13 kg) in accordance with ECE-R 44. The CRS's were attached on the aircraft passenger seats with the lap belt and tested dynamically at 16g.

The following aspects were tested:

- Installability of the CRS on the aircraft passenger seat.
- Attachment with the aircraft lap belt.
- Attachment with a lap belt with a lateral push-button buckle like in motor vehicles.
- Additional support of the CRS at the aircraft passenger seat.
- Investigation of the dynamic crash behaviour of the infant dummy in the CRS, the dummy loads and the effect of the lap belt angle.

Results:

It was possible to place the rearward-facing CRS on the aircraft passenger seats and to attach them with the lap belt and/or the motor vehicle lap belts. The belt routing over the CRS did not provide any difficulties. The belt routing under or behind the seat bucket caused problems with fastening and also with releasing the lap belt buckle.

A steep lap belt angle caused a larger forward displacement of the CRS than a flat angle. An additional support of the CRS for preventing the CRS from breaking over has a similar effect than a flat belt strap angle.

The dummy loads measured in the tests remained below the tolerance limits specified in ECE-R 44.

The transport of infants in a suitable CRS on their own aircraft passenger seat must be governed by law. Approval criteria for CRS for use in aircraft have been developed comprising the following aspects:

- The use of CRS in the take-off, in-flight and landing phases.

- Consideration of the cabin-specific needs and emergency evacuation.

- Approval criteria with the following aspects:
  - dummy protection criteria
  - classification of CRS
  - dimensions of CRS
  - testing of CRS
  - warnings and labelling at the CRS

2.1.4 ICEPS (Injury Criteria for Enhanced Passive Safety in Aircraft)

Ordered by: European Commission DGVII, Transport;
AI-97-AM.0235-ICEPS; 1999

Contractor: TÜV Rheinland Kraftfahrt GmbH (Germany)

<u>Contents of the Research Project:</u>

This research project pursued the following objectives:

- 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.

Two aircraft accidents (near Kegworth, 1989 and Warsaw, 1993) with Part 25 aircraft were analysed. The analyses were based on detailed test reports and interviews of persons involved in the accidents as well as persons who had conducted the accident investigation. The accident analyses focussed on the determination of the injury patterns of the passengers and of the injury causes taking account of the accelerations effective in the cabin during the crash, the destructions in the passengers' surroundings and the details on the design and approval of the aircraft passenger seats.

Dummy protection criteria were compiled on the basis of the known human biomechanic tolerances and the different approval specifications and were evaluated in terms of their applicability in aviation also taking the findings from the accident analysis into consideration. Furthermore, different criteria were determined for the evaluation of the passive safety of cabin installations and were applied in a cabin at a specific example. The applicability of the criteria was evaluated.

Results:

It is not possible with the presently applied approval criteria to improve passive safety in aircraft cabins in a comprehensive and targeted way. The comparison of the determined injuries with the approval criteria shows that only partial aspects of passive safety are reviewed. JAR 25.562 “emergency landing dynamic conditions“ for example only describes injury criteria for the head (HIC), lumbar spine and femurs.

The suggested improved dummy protection criteria take the injury risk of all human body regions into account. They specify injury criteria for the head/face/brain, neck/cervical spine, chest, pelvis/vertebral spine, upper extremities and lower extremities.

Furthermore they suggest criteria for the evaluation of the passengers' survival space. The survival space is intended to protect the passengers in a crash to such an effect that they remain capable of acting and walking after an accident in order to ensure independent evacuation. The criteria suggested included criteria for the evaluation of sharp edges or for the evaluation of the energy absorption capacity of covers for rigid structures.

There are also data available from the accident near Kegworth (B737-400) with regard to a lap-held infant who was secured with a loop belt. The chapter “Accident Analysis“ goes into further detail.

2.1.5 IMPCHRESS (Improved Child Restraint Systems – A study designed to assist progress in the matter of improving restraint standards for children in transport category aircraft)

Ordered by: European Commission DG VII, Air Transport Research; AI-97-RS-2183-IMPCHRESS; 1999

Contractor: Seatrac (Europe) Limited; H.R.F. Duffell; Cranfield Impact Centre Limited; Netherlands Organisation for Applied Scientific Research (TNO)

Contents of the Research Project:

This research project was intended to improve the safety of infants and children on an aircraft in emergency landing conditions.

The project surveyed aviation authorities, airlines, consumer groups and research institutes, amongst others, on practiced restraint methods and on their opinions. It evaluated travel and accident statistics, tests and reports on restraint systems for children as well as on specific aircraft restraint systems and summarised the relevant aviation regulations.

A Technical Reference Document outlines general requirements for child restraint systems for use in aviation. A proposal for a European Specification was drafted on the basis of this research.

Results:

Safe transport of infants is presently not provided. As a basic principle, there are neither technical nor practical reasons against providing an adequate and uniform safety standard for all passengers.

The Industry is aware of this situation but enhancements for infants in aircraft have not been implemented. The use of CRS in aircraft causes additional costs to the airlines. These costs could be reduced if not only the airlines were allowed to provide the CRS but if also the parents could bring suitable and approved CRS.

The evaluation of travel and accident statistics for 1997 showed that approx. 1522 million passengers travelled worldwide including approx. 13 million children aged less than 5 years and approx. 5.6 million infants (aged up to 2 years). Upon the evaluation of the worldwide accident statistics it is assumed that approx. 12 infants are involved in serious accidents every year. For Europe it is estimated that 3 to 4 infants are concerned.

The take-off, landing and in-flight risks were assessed differently deriving that different CRS can be used in the flight phases, where applicable: class A systems for all flight phases and class B systems only for the in-flight phase, e.g. in conditions of turbulence.

It is recommended to regulate the use of CRS in aircraft by the European Aviation Authority. For this purpose it is necessary to draw up a specification for CRS as a basis of subsequent approval.

A European Specification was suggested which is intended to achieve the following objectives:

- The safe restraint of infants at least to the standard of other passengers.
- Minimising any additional costs, particularly to the aviation industry.
- Compatibility where possible with ECE-R 44 (European) auto restrain specifications.
- Harmonisation with the USA proposed Standard (AS 5276/1).
- Not restricting CRS design flexibility.
- Differing risk profiles between "take-off and landing" and "in-flight" periods.
- CRSs only for passengers less than 18 kg.

The IMPRCHRESS study recommends that child restraint systems in accordance with the European Specification can also be brought on board by the passengers.

2.1.6 Examination of the enhancement of cabin safety for infants

Ordered by: Federal Minister of Transport, Building and Urban Affairs (Germany); L - 2/97 - 50 157 / 97; 2001

Contractor: TÜV Rheinland Kraftfahrt GmbH (Germany)

Contents of the Research Project:

This research project was intended to show different means of improving the passive safety of infants and children in emergency situations and furthermore to draw up recommendations for the transport of children in aircraft.

It investigated the biomechanic development of children e.g. with regard to their body proportions and means of protecting children in a restraint system during a crash. It compared the motor vehicle approval regulations for European and American child restraint systems in order to show differences and conformities. It also analysed the aviation regulations in view of the transport of infants and children.

It carried out installation tests on aircraft passenger seats, rollover tests and dynamic tests with forward-facing CRS testing 14 different child restraint systems for the age groups from 9 months to 10 years. The CRS were attached on the aircraft passenger seat with a lap belt. One CRS had an ISO-FIX attachment and was fixed on a modified aircraft passenger seat with ISO-FIX. ISO-FIX is an international standard anchorage system for child restraint systems in cars. A P3, P6 and P10 dummy were furthermore only fastened with a lap belt.

In addition, an aircraft passenger survey was conducted with 365 families with children aged up to 14 years asking, among other aspects, for their willingness to pay extra for an own seat for their child.

Results:

The requirements of the reviewed European and American motor vehicle approval regulations for child seats show good conformity. It must be noted that the roll-over test which is always required in the European regulation must be complied with in the American regulation only in those cases where the CRS can also be used in aircraft.

The installation and removal of the CRS on the aircraft passenger seat partly caused problems with the lap belt buckle. In some CRS, it was impossible to release the fastened lap belt since the buckle could not be opened for lack of space. In impact shield systems, e.g. additional recesses had to be made in order to accommodate the belt buckle.

The dynamic tests with the CRS show that the crash loads of the dummies (P3/4, P3 and P6) remain under the critical loads. Inacceptable loads, however, were determined for the P3, P6 and P10 dummies who were fastened with a lap belt only.

The tests show that suitable child restraint systems provide safety for children smaller than 125 cm and aged up to approx. 7 years which is equivalent to adults safety.

The child's development must be taken into account in the selection of the CRS, i. e. the CRS must correspond e.g. to the age, weight and height of the child.

Regarding the willingness to pay extra for an own seat for children younger than 2 years the aircraft passenger survey showed that 79 percent of the interviewed persons would accept a seat price of 50 percent and that this would not have any effect on their travel behaviour.

The recommendations for the use of CRS in aircraft comprise the following requirements:

- The CRS should meet ECE-R 44 or comparable regulations. These include an evaluation of the restraint principles, biomechanics and design rules to be applied.
- Additional aviation-specific requirements for the use of CRS in aircraft were set up. These include the installability, the attachment and the function of the CRS on the aircraft passenger seat as well as the handling of the CRS in the aircraft.

2.1.7 Child Restraint in Australian Commercial Aircraft

Ordered by: Australian Government, Australian Transport Safety Bureau; February 2006

Contractor: Human Impact Engineering and Britax Childcare Pty Ltd (Australia)

Contents of the Research Project:

This study tested the applicability of different Australian car seats for children aged 0 to approx. 7 years in aircraft.

It carried out installation tests with 20 Australian CRS on an eco-class aircraft passenger seat, it performed rollover tests with some CRS and dynamic 16g tests with 11 Australian CRS (in forward direction). As a basic principle, the tests dispensed with a top tether attachment. A modified top tether attachment was used only in few dynamic tests.

The tests furthermore reviewed the loop belt and four customary baby carriers regarding the protection of infants performing rollover tests and five dynamic 9g tests (in a forward-direction).

Results:

The use of car child seats for infants and children in aircraft is much safer than the lap-held transport (fastened or unfastened) or the use of the standard lap belt. However, there are many inconsistencies between Australian child seats and aircraft seat systems.

In the installation tests on the aircraft passenger seat, 14 out of 20 CRS caused problems regarding the CRS size (installation situation of the aircraft passenger seats: seat pitch 31 inches, distance between the armrests 450 mm) or with the lap-belt buckle of the aircraft passenger seat regarding its position and function.

The roll-over tests with the CRS did not constitute any problems.

In the dynamic tests, the dummies were restrained in the CRS but all CRS showed a significant forward movement, rotation and rebound movement. This is due to different causes:

- The top tether could not be used because in breakover backrests an attachment to the backrest is useless. Non-breakover backrests and/or attachment points for the top tether in the aircraft could remedy this problem which still has to be investigated.
- A very steep lap belt geometry on the aircraft passenger seat. This should be changed into an angle of 45 - 60°.
- It is difficult to fasten the belt due to the poor compatibility between the lap belt design and the belt routings over the CRS.
- Due to the limited depth of the seating platform the CRS performs a strong rotation and the lifting of the seat padding furthered the forward-movement of the CRS.

The Baby carrier systems are not suitable in dynamic crash loads. They could only protect the child dummies adequately in the rollover test.

It is recommended to design CRS either specifically for use in aircraft or to ensure an approved procedure to lay out car child seats to fit in aircraft passenger seats and fasten them with a lap belt.

The use of ISO-fix or latch systems which are spreading worldwide should be tested for use in aircraft.

2.1.8 An Investigation of Automotive Child Restraint Installation Methods in Transport Category Aircraft

Ordered by: Australian Government, Civil Aviation Safety Authority; 2007

Contractor: Airframe; Airworthiness Engineering Branch; Civil Aviation Safety Authority Australian

Contents of the Research Project:

The study investigated the possibility of using different car child seats on aircraft passenger seats and the contribution of a top tether to the restraint effect of child restraint systems (CRS).

Two CRS which are applicable both forward and rearward-facing were tested with a top tether and two ISO-fix systems without a top tether (one rearward-facing and one forward-facing system). Dynamic tests with 10 individual tests were carried out in total. The study furthermore investigated the effect of the ISO-fix CRS on the adult aircraft passenger sitting behind it.

Results:

A reduction of the forward displacement of the CRS by means of the top tether attachment was not found. The aircraft passenger seats had a limited breakover backrest over which the top tether strap was guided. The backrest broke over in the test. Due to the steep belt strap angle of the top tether, the CRS could not be restrained well either.

An additional belt around the backrest was investigated as an alternative to the top tether. Also in this case the limited breakover backrest broke over and failed to hold the CRS.

The lap belt attachment point of the aircraft passenger seat is generally positioned further in the front than in car seats partly resulting in steep lap belt angles (60 to 100°). Steep belt strap angles of the lap belt result in a large forward displacement of the CRS.

The ISO-fix attachment produced good results in the forward displacement and the biomechanic load of the child dummy. It could be shown that a child seat attached with the ISO-fix system provides a safety level to the child which equals that of an adult passenger.

The use of child seats for infants and small children generally provides a better chance to survive and a better protection from injuries than the lap-held transport (fastened or unfastened).

2.2 Accident Analysis

The accident analysis reviews four aircraft accidents involving infants. It gives a brief description of the circumstances of the accident, the sitting position of the infants in the aircraft, the restraint of the infants, the damage to the cabin in the surroundings of the infants, a description of the injuries and the causes of injuries.

2.2.1 Continental Airlines Flight 1713

Place:	Denver, Colorado	
Date.	15 November 1987	
Aircraft type:	DC 9 - 14	
Course of the accident:	Crash during take-off after stall on the left wing due to icing of the wings during the ground waiting time. The fuselage broke into three segments: front part, central part and rear part with empennage. The aircraft turned around its yaw axis by the airstrip during the crash, with its final position being approx. 166° against the flight direction, cf. Figure 2-2.	
Occupants:	77 passengers (2 infants) 5 crew	
Injuries:	Fatal injuries:	25 passengers (1 infant), 3 crew
	seriously injured:	27 passengers, 1 crew
	slightly injured:	24 passengers, 1 crew
	uninjured:	1 passenger (1 infant)

Figure 2-1: Front fuselage part (lateral position)

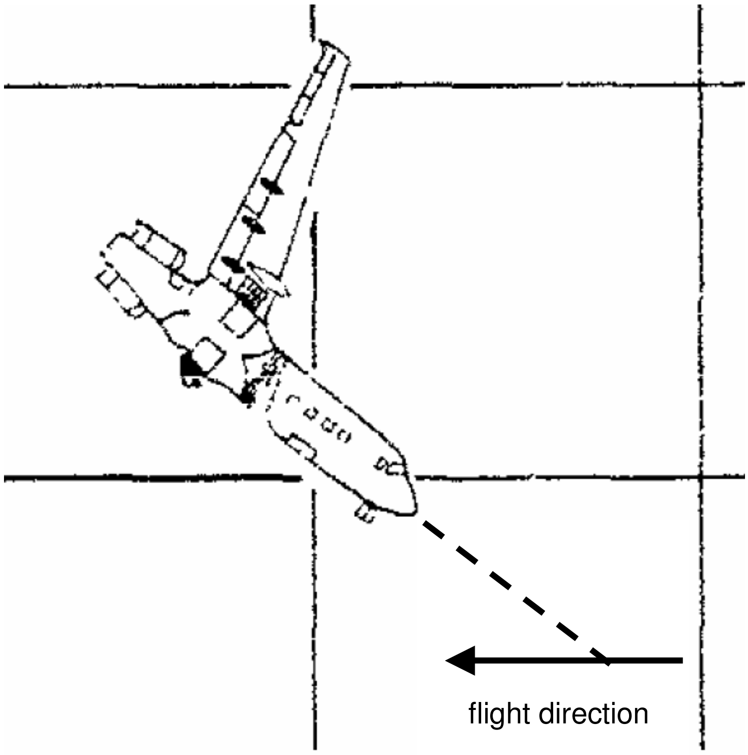


Figure 2-2: Final position of the front and central fuselage segment

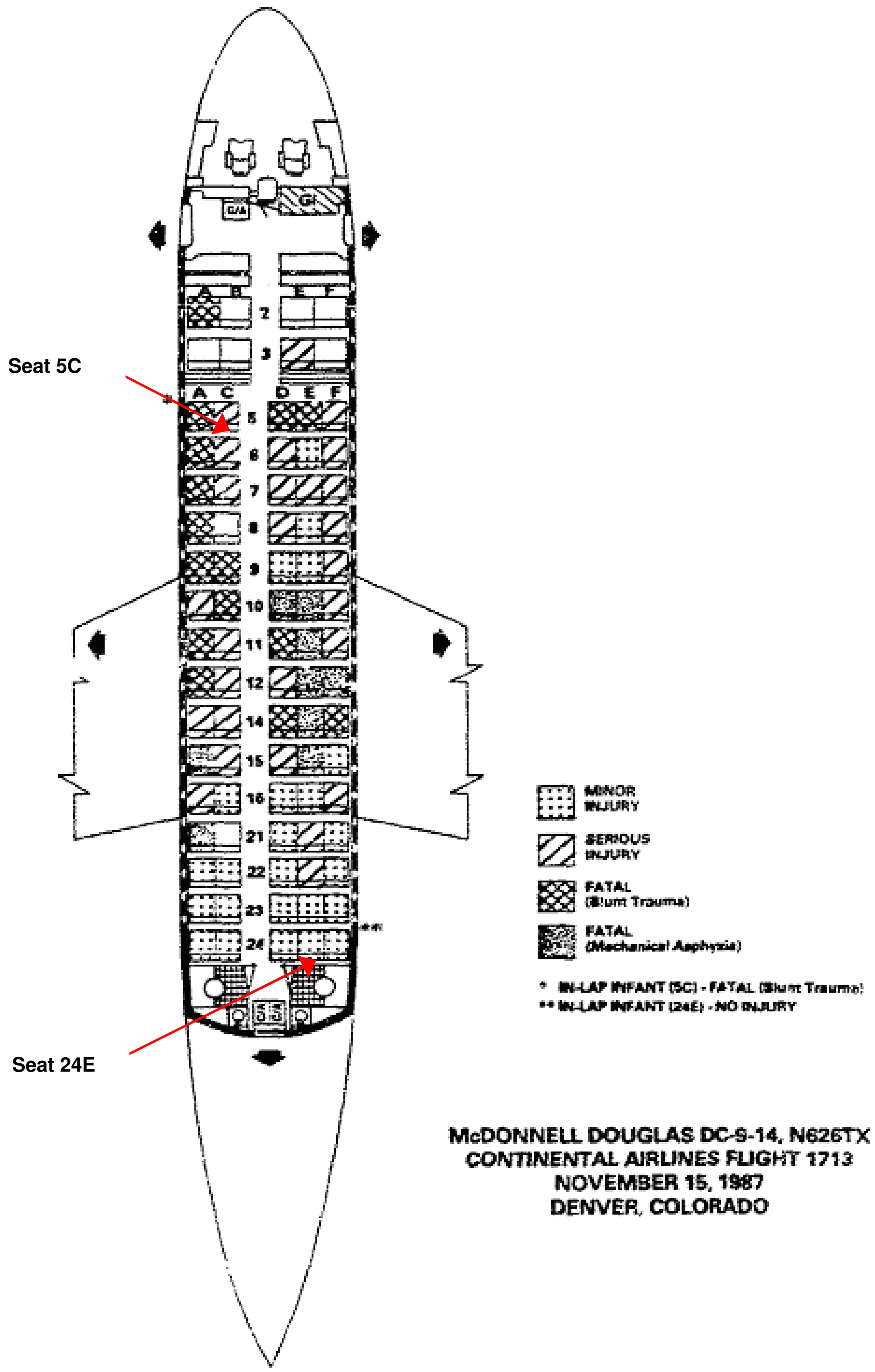


Figure 2-3: Cabin layout with sitting position of the infants

Passenger 5C, mother

Sitting position during the crash:	Upright sitting position, fastened with a lap belt, the infant was sitting on its mother's lap.
Surroundings in the crash:	The front section of the aircraft was strongly destroyed, with the left fuselage side being torn open. The seats were seriously damaged, cabin parts had been thrown out of the aircraft and had spread across the place of the accident. Seat 5C was directly behind the bulkhead to the first class. It was a seat on the aisle on the destroyed left-hand side of the cabin.
Injuries:	Serious injuries
Causes of injuries:	The passengers had been exposed to high loads, with the cabin being strongly destroyed. The seats by the windows were directly affected by the collapse of the left fuselage structure, with the passengers in the aisle seats still having a limited survival space. The passengers sitting in the aisle seats (C5 to C7) were seriously injured, but survived the accident. The passengers sitting by the windows suffered fatal injuries.

Passenger 5C, infant of 6 months

Sitting position during the crash:	Sitting on its mother’s lap
Surroundings in the crash:	See mother in 5C.
Injuries:	Fatal injuries, the infant died of multiple injuries from blunt force impact including basilar skull fractures and injuries to the thorax
Causes of injuries:	Due to the serious injuries suffered by the mother and the damage to the surroundings it can be assumed that high loads had been effective during the crash. The infant had no own survival space, it was sitting within its mother's survival space thus being exposed to an even additional load.

Passenger 24E, father

Sitting position during the crash:	Upright sitting position, fastened with a lap belt, the infant was sitting on its father's lap.
Surroundings in the crash:	The rear part of the central fuselage segment was relatively intact. In the final position it was upside down. The passengers of rows 22 to 24 only suffered slight injuries, with only one person being seriously injured.
Injuries:	Slight injuries
Causes of injuries:	The passenger was still sitting in an intact survival space both in view of the fuselage structure and the aircraft passenger seats. The loads effective especially in the flight direction had been relatively low, due to the fact, amongst other factors, that the aircraft fuselage had turned around its yaw axis and overturned in the crash.

Passenger 24E, infant of 6 weeks

Sitting position during the crash:	Sitting on its fathers lap, fastened with a supplementary loop belt.
Surroundings in the crash:	See father in 24E
Injuries:	not injured
Causes of injuries:	-----

2.2.2 Kegworth B737-400

Place:	Kegworth
Date.	8. January 1989
Aircraft type:	B737-400
Course of the accident:	Emergency landing after engine failure. Hard landing on a field and subsequent crash at a slope. The aircraft broke into three parts, cf. Figure 2-4.
Occupants:	118 passengers (1 infant) 8 crew

Injuries:	Fatal injuries:	47 passengers
	seriously injured:	67 passengers, 7 crew (1 infant)
	slightly injured:	4 passengers, 1 crew

Figure 2-4: Crash position of B737-400

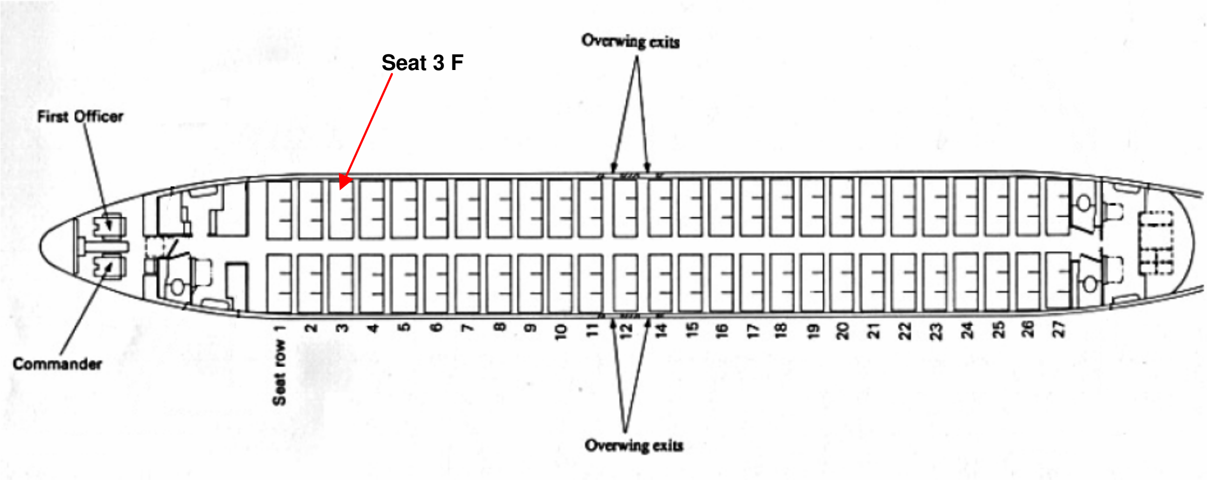


Figure 2-5: Cabin layout with sitting position of the infant

<u>Passenger 3F, mother</u>

Sitting position during the crash:	Upright sitting position, fastened with a lap belt, the infant was sitting on its mother's lap.
Damage to the seat:	The complete seat row had been pressed down to floor level. The backseat was torn off at the right joint. The seat was in the strongly destroyed front fuselage section.
Injuries:	Fracture of ribs on the right, fracture of the lumbar vertebrae, fracture of the left scapula, fracture of the right and left shinbone and fibula, fracture of the feet Rib fractures caused a heart contusion. The mother died in hospital.
Causes of injuries:	The mother suffered fatal injuries due to the effective decelerations and the strong destruction of the fuselage as well as of the seats. Due to the established deformations and structural damage to the seat and the injury of the lumbar spine it is assumed that high downward loads had been effective.

<u>Passenger 3F, infant</u>

Sitting position during the crash:	Sitting on its mother’s lap, fastened with a supplementary loop belt.
Damage to the seat:	See passenger 3F, mother
Injuries:	Haematoma and contusions at the left-hand side of the head as well as several fractures of the left and right shinbone and femur.
Causes of injuries:	It can be assumed due to the damage to the seat and the injuries that the infant had also been restrained by the rigid structures (e.g. by the seat in front). The vertical loads effective during the crash, see mother, were reducing for the infant because it was sitting on its mother's lap.

<u>Recommendations from the accident reports:</u>

The CAA implement a programme to require that all infants and young children, who would not be safely restrained by supplementary or standard lap belts, be placed in child-seats for take-off, landing and flight in turbulence.

2.2.3 United Airlines Flight 232

Place:	Sioux City	
Date.	19.07.1989	
Aircraft type:	DC 10 - 10	
Course of the accident:	Emergency landing after complete hydraulic failure. Hard landing on the airstrip. The aircraft fuselage broke into five parts, cf. Figure 2-6. The middle part burnt out.	
Occupants:	285 passengers (4 infants) 11 crew	
Injuries:	Fatally injured:	110 passengers, (1 infant), 1 crew
	Seriously injured:	41 passengers, 6 crew
	Slightly injured:	121 passengers, (3 infants), 4 crew
	uninjured:	13 passengers (1 child)

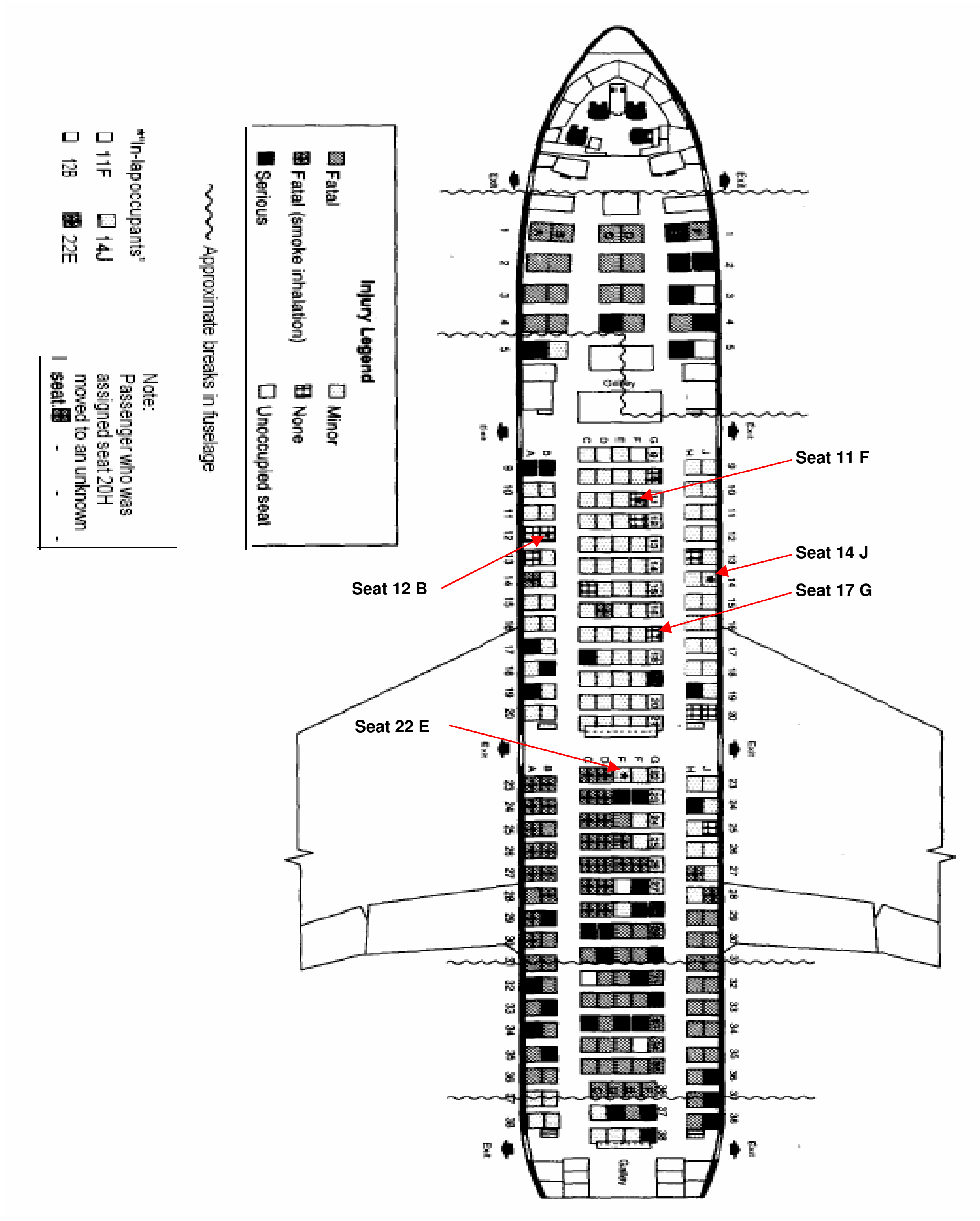


Figure 2-6: Cabin layout with sitting position of infants

Passenger 11F, infant of 11 months

Sitting position during the crash:	Lying on the floor in the foot space between seats 10F and 11F between its mother's legs. The mother had assumed the brace position.
Surroundings in the crash:	The middle section of the aircraft had turned upside down. The seat was in the front section of the fragment and had remained relatively intact.
Injuries:	Abrasion below the left eye.
Causes of injuries:	The slight injuries showed that lying in the foot space, the infant had been restrained by the surrounding seats. Presumably the mother had no longer been able to hold her infant and missed it when the central fuselage part overturned. The other passengers rescued it out of the wreck.

Passenger 12B, infant of 26 months

Sitting position during the crash:	Lying on the floor in the foot space between seats 11B and 12B between its father's legs. The father had assumed the brace position.
Surroundings in the crash:	The middle section of the aircraft had turned upside down. The seat was in the front section of the fragment and had remained relatively intact.
Injuries:	Abrasion at the left hand.
Causes of injuries:	Here as well the slight injuries showed that lying in the foot space, the infant had been restrained by the seats.

Passenger 14J, infant of 23 months

Sitting position during the crash:	Lying on the floor in the foot space between seats 13J and 14J between its mother's legs. The mother had assumed the brace position.
Surroundings in the crash:	The middle section of the aircraft turned upside down. The seat was in the front section of the fragment and had remained relatively intact.
Injuries:	Bruise at the head.

Causes of injuries:	The infant had initially been restrained by the surrounding seats. Presumably it had been thrown towards the ceiling only when the central fuselage part overturned. However, the mother had still been able to hold it, with the head hitting against the right board wall.

Passenger 17G, infant of 32 months

Sitting position during the crash:	Sitting in its own seat, restrained with the lap belt and additionally padded with cushions.
Surroundings in the crash:	The middle section of the aircraft turned upside down. The seat was in the central section of the fragment and had remained relatively intact.
Injuries:	uninjured
Causes of injuries:	The child's own seat as well as the "adaptation" of the restraint system for adults to the child provided enough protection.

Passenger 22E, infant of 23 months

Sitting position during the crash:	Lying on the floor between its mother's legs at the crossway in front of seat 22E. The mother had been able to assume the brace position.
Surroundings in the crash:	The central section of the aircraft turned upside down. The seat was in the central section of the fragment and had remained relatively intact. However, a fire had broken out in the rear part of the fuselage segment.
Injuries:	Smoke inhalation, dead.
Causes of injuries:	There was no further seat row in front of the child, the mother had not been able to hold her son during the crash. The child had been thrown backwards during the crash into the burning area. The mother had not been able to rescue her child from this area.

Recommendations from the accident reports:

The accident report recommends a review of 14CFR 91, 121 and 135 in view of the seatbelt law during take-off, landing and turbulence. It is required to fasten young children and infants with adequate child restraint systems whose weight is less than 40 lbs (18 kg) and whose size is less than 40 in (1m).

2.2.4 Aircraft accident Cessna 172 in British Columbia (Canada)

Place:	British Columbia
Date.	30 October 2007
Aircraft type:	Cessna 172
Course of the accident:	Crash at the Blaeberry River approx. one hour after take-off. Accident cause still unknown, cf. Figure 2-7.
Occupants:	3 passengers (1 child)
Injuries:	Fatally injured: Pilot and co-pilot Seriously injured: 0 Slightly injured: 1 passenger (child)

Figure 2-7: Final position of the aircraft

Passenger, child

Sitting position during the crash: The child was sitting in a child restraint system in the backseat.

Surroundings in the crash: The rear cabin section was relatively intact after the crash.

Injuries: Slight head injuries and contusions.

Causes of injuries: The slight injuries show that the child had been well restrained by the child restraint system during the crash.

Figure 2-8: Surviving three-year old girl.

2.2.5 Turbulence

Some examples:

Jan 4. 1972	National Airlines B747, Flight 041 went into turbulence during a routine flight from Miami to Los Angeles. Some passengers were not fastened even though the fasten seatbelt signs had been switched on. A child of six months was thrown upwards against the overhead compartment and suffered a slight head injury (facial contusion).
Jul 13. 1986	An Eastern Airlines A 300 was caught by a turbulence during its approach to Miami International Airport. The fasten seatbelt signs had been switched on. An infant of seven months could not be held by its already fastened parents and was thrown upwards over the seat of the passenger in front. The child suffered slight head injuries when it hit against the armrest of the seat with its left temple. 20 passengers and 8 cabin crew members sustained minor injuries and 2 passengers sustained serious injuries.
Jan 20 1990	An American Airlines DC 10 went into a serious turbulence in a thundery front shortly before approaching San Juan, Puerto Rico. The fasten seatbelt signs had been switched on and the cabin crew had called upon the passengers to fasten their seatbelts. An unfastened infant of seven weeks suffered most serious head injuries since its mother had not been able to hold it.

2.3 Regulation – Automotive

In Europe, child restraint systems are tested on the basis of the **E**conomic **C**ommission for **E**urope, Regulation no. 44 (ECE-R 44) and their use in motor vehicles is approved. In the USA, the regulations are applicable in accordance with the **F**ederal **M**otor **V**ehicle **S**afety **S**tandards 213 (FMVSS-213). Canada applies the **C**anadian **M**otor **V**ehicle **S**afety **S**tandards 213 (CMVSS-213) which follow the FMVSS-213.

The following chapters compare the specifications of ECE-R 44 and FMVSS 213.

2.3.1 Use of CRS depending on the children's physical development

CRS are classified according to children's weight. Furthermore, the child must not be too tall or too small for the CRS. As a basic principle, infants have to be transported in reward-facing CRS (up to 10 kg). Older children are also allowed to use forward-facing CRS.

weight categories	ECE-R 44	FMVSS 213
reward-facing CRS	< 10 kg	< 10 kg (22 lbs)
forward-facing CRS with/without integrated restraint system (belts and/or impact shield)	≥ 9 kg	≥ 10 kg (22 lbs)

2.3.2 Position and attachment of CRS in the vehicle

Depending on the certification, the use of a lap belt, a three-point-belt and/or an ISOfix attachment (with/without a top tether) can be admissible for attaching the CRS. The ECE and FMVSS/CMVSS include similar specifications in terms of the lap belt attachment. The use of CRS is partly limited to specific seats in the vehicle.

2.3.3 Properties and design of the CRS

The regulations of the ECE and FMVSS give general requirements for the design of CRS, e.g. regarding the minimum height of the backrest, belt dimensions, belt geometry, energy-absorbing materials at specific points, prevention of sharp edges.

2.3.4 Rollover test

In principle, ECE-R44 requires a rollover test. FMVSS 213 only requires a rollover test if the CRS is also to be used on an aircraft.

In the rollover test pursuant to FMVSS 213, the CRS is attached with an aircraft lap belt on aircraft passenger test fixtures. Pursuant to ECE-R4, the test is performed with the attachment being like in motor vehicles and on the motor vehicle test fixtures i. e. if the CRS is approved for lap belt attachment, the rollover test is performed with a lap belt, otherwise it is performed with a three-point-belt.

2.3.5 Dynamic test (crash test)

The regulations specify test set-ups (test fixtures, amongst others) which are used in dynamic tests with CRS and dummies to be used. ECE-R 44 defines two different test impulses for the simulation of a front impact and a rear impact. FMVSS/CMVSS – 213 specifies two different impulses as well as so-called misuse tests with regard to the attachment.

The test fixtures in the regulations specify typical motor vehicle seats. The test impulses are derived from the crash situation with motor vehicles. The differences have been reviewed in detail in various research studies. A comparison shows that the test velocities for the front impact are almost identical and thus, also the kinetic energy in the crash test is almost the same. The dynamic tests can be regarded as equivalent.

2.3.6 Protection criteria

In principle, both ECE and FMVSS define tolerance limits which the dummy must not exceed in the dynamic test. Furthermore, they define different limits for the head, neck and thorax for the evaluation of dummy loads. The following overview compares the protection criteria of ECE and FMVSS.

Protection Criteria		
	ECE-R44	FMVSS-213
Head	Specification of tolerance levels which must not be exceeded by the test dummy $V_{head} < 24\ ^{km}/_{h}$ with impact against the vehicle structure of special-purpose vehicles	Specification of tolerance limits which must not be exceeded by the test dummy. HIC(36) ≤ 1000, for children weighing > 10 kg
Cervical spine	Vertical thoracic acceleration $a_{vertical,\ 3\ ms} < 30$ g	Regarding the extension of the test dummy head, the angle between head and torso may deviate by 45° at the most in relation to the initial position
Thorax	Resulting thoracic acceleration: $a_{res,\ 3\ ms} < 55$ g	Resulting thoracic acceleration: $a_{res,\ 3\ ms} < 60$ g
Lumbar spine	A modelling mass attached to the abdomen must not show any visible damage caused by the restraint system.	———
Abdomen		———

Notes: The requirements for a CRS in accordance with ECE-R 44 and/or FMVSS-213 differ in individual points, e.g. with regard to the test impulse and dummy protection criteria. However, they are in principle comparable with regard to the passive safety specifications for the child.

2.3.7 Further test procedures

ECE and FMVSS specify further tests and test procedures:

- Flammability
- Corrosion
- Integrated belts and closing
- Toxicity of CRS parts accessible to children
  (The toxicity test is only required in the ECE.)

2.4 Regulation of major aviation authorities

The requirements for the safety of aircraft passengers in commercial transport aircraft are defined in the operational and design requirements. These specifications are aimed at providing an equal level of passive safety for all passengers.

The aviation regulations applicable in Europe and the USA are harmonised to a large extent.

2.4.1 Airworthiness requirements

The "Certification Specifications for Large Aeroplanes CS 25" specify in principle the requirements with regard to passive safety for passengers. Pursuant to CS 25.785 (a), a seat must be provided for each occupant from the age of 2. CS 25.785 (b) requires safety devices for emergency situations for each occupant in order to protect him or her from serious injuries. Furthermore, they require proof of compliance with static and dynamic tests (pursuant to CS 25.561 and CS 25.562) for aircraft passenger seats. The design of the seats and belt systems is based on a 77 kg occupant (50 percentile male).

2.4.2 Operational requirements

2.4.2.1 European regulations

2.4.2.1.1 JAR-OPS 1 (valid until 16 July 2008)

In Europe, JAR-OPS 1 for the transport of persons in aircraft was valid until 16 July 2008. On 16 July 2008 EU-OPS entered into effect.

JAR-OPS 1.607 classifies occupants according to their age:

Adults:	Persons of an age of 12 years and above
Children:	Persons of an age between 2 years and 12 years
Infants:	Less than 2 years of age

Pursuant to JAR-OPS 1.320 "Seats, safety belts and harnesses" it is permitted to occupy a seat with an adult and additionally with an infant. The adult is fastened with a lap belt and the infant is fastened with a supplementary loop belt or another restraint system.

JAR-OPS 1.730 "Seats, seat safety belts, harnesses and child restraint devices" specifies the term "child restraint devices" in more detail in section (a)(3) and in ACJ OPS 1.730 (a)(3):

- "supplementary loop belt" manufactured with the same techniques and the same materials of the approved safety belts.

- Child restraint devices approved for use in aircraft only by any JAA authority, FAA or Transport Canada and marked accordingly.

- Child restraint devices approved for use in motor vehicles according to the UN standard ECE-R 44, -03 or later series of Amendments.

- Child restraint devices approved for use in motor vehicles and aircraft according to Canadian CMVSS 213 / 213.1.

- Child restraint devices approved for use in motor vehicles and aircraft according to US FMVSS No 213 and are manufactured to these standards on or after February 26, 1985. US approved CRDs manufactured after this date must bear the following labels in red lettering:

  1) "THIS CHILD RESTRAINT SYSTEM CONFORMS TO ALL APPLICABLE FEDERAL MOTOR VEHICLE SAFETY STANDARDS" and

  2) "THIS RESTRAINT IS CERTIFIED FOR USE IN MOTOR VEHICLES AND AIRCRAFT".

- Child restraint devices qualified for use in aircraft according to the German "Qualification Procedure for Child Restraint Systems for Use in Aircraft" (TÜV Doc.: TÜV/958-01/2001).

The requirements for transportation of infants and children are differently in some European countries (until 16.07.2008), e.g.:

- In Germany, the supplementary loop belt is not permitted. Infants are either seated unfastened on the lap of adult (lap-held) or they are fastened in a child restraint system on their own seat. The CRS must be qualified for use in aircraft (pursuant to TÜV Doc.: TÜV/958-01/2001). It is also admissible for older children (up to approx. 7 years) to use qualified CRS in aircraft.

- Great Britain has the following regulation for infants and children:

  - Infants younger than 6 months (< 6 months) must be transported on the lap of their parents and be fastened with a supplementary loop belt.

  - Infants aged between 6 months and 2 years must either be transported like infants aged up to 6 months (cf. above) or have to be fastened on their own seat with a car safety seat.

  - Children from the age of 2 must be seated in their own seat. For children aged up to 3 years it is permitted to use a car safety seat.

  - Children from the age of 3 must be seated on an aircraft passenger seat of their own and be fastened with the standard lap belt.

2.4.2.1.2 EU-OPS 1 (valid from 16 July 2008)

On 16 July 2008 EU-OPS 1 entered into effect in Europe and replaced JAR-OPS 1.

Regarding the transport of children, EU-OPS has been strongly adapted to JAR-OPS. However, EU-OPS does not include any further explanations as are given in JAR-OPS by the ACJs.

EU-OPS reflect the following contents (in analogy to JAR-OPS):

EU-OPS 1.607 classifies occupants according to their age:

Adults:	Persons of an age of 12 years and above
Children:	Persons of an age between 2 years and 12 years
Infants:	Less than 2 years of age

Pursuant to EU-OPS 1.320 “Seats, safety belts and harnesses“ it is permitted to occupy a seat with an adult and additionally with an infant. The adult is fastened with a lap belt and the infant is fastened with a supplementary loop belt or another restraint system.

The EU-OPS 1.730 ”Seats, seat safety belts, harnesses and child restraint devices“ requires: “A child restraint device, acceptable to the Authority, for each infant”. It does not include further explanations as to which child seats can be accepted as well as regarding the positioning of the child restraint device within the cabin layout i. e. infants must be restrained in a child restraint device accepted by the national authority or be lap-held with the loop-belt.

Older children (>2 years) must obtain a seat of their own in accordance with EU-OPS 1.730; the EU-OPS does not include a regulation regarding the child restraint system.

2.4.2.2 American regulations

In the USA, FAR PART 121 “OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS “generally regulates the use of safety belts and child restraint systems in Section Sec. 121.311, amongst other sections. There are the following possibilities:

- The supplementary loop belt (belly belt) is not permitted.
- The child is seated on the lap of an adult without using any restraint device (lap-held).
- The child restraint systems used must be approved for aircraft in accordance with FMVSS 213 (incl. rollover test).
- It is allowed to use seats which are approved by a foreign government.
- It is allowed to use child seats which are approved in accordance with the standard of the United Nations (e.g. pursuant to ECE-R 44).
- Aerospace companies are allowed to offer and use seats and/or child restraint systems which are approved in accordance with a “Type Certificate or Supplemental Type Certificate”.
- Child restraint systems can also be approved by the FAA in accordance with §21.305(d) or TSO-C100b or a later version.
- Unless approved by the FAA or a certificate-holder, booster seats, vest- and harness-type restraints and lap held child restraint devices are not allowed.

The FAA recommends the following child restraint systems:

- Rearward-facing CRS for children weighing up to 20 lbs,
- Forward-facing CRS for children weighing between 20 and 40 lbs,
- Children weighing more than 40 lbs are fastened on the aircraft passenger seat with a lap belt.

In general airlines can provide appropriate CRS or appropriate CRS can be brought by the parents.

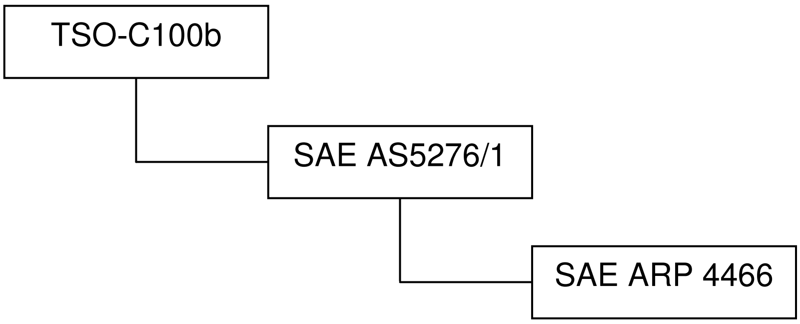
2.4.3 Aviation Requirements for CRS

2.4.3.1 Technical Standard Order for Child Restraint Systems (TSO-C100b)

The American TSO-C100b “Child Restraint Systems (CRS)“ specifies the minimum performance standards for CRS as regards the technical qualifications (functional qualification, environmental qualification) as well as the required labelling and documentation. The TSO is essentially based on the SAE Aerospace Standard

AS5276/1 in conjunction with the SAE Aerospace Recommended Practice ARP4466. SAE AS 5276/1 has partly been amended or changed by the TSO.

The following chart shows the connection between TSO C 100b, SAE AS 5276/1 and SAE ARP 4466.



Child restraint systems approved pursuant to TSO must be labelled with the following details, amongst others:

- Manufacturer's name as well as address of the production site
- Name and type of the CRS
- Serial number and/or manufacturing date
- Specification of the applied TSO for this system (e.g. TSO C100b for aviation CRS)

The following is a compilation of the SAE papers with their main aspects:

2.4.3.2 Performance Standard for Child Restraint Systems (SAE AS5276/1)

SAE AS5276/1 "Performance Standard for Child Restraint Systems in Transport Category Airplanes" applies to child restraint systems on forward-facing aircraft passenger seats. Airbags within the range of CRS are not admissible. It comprises the following requirements, amongst others:

- Definition of child classification / definition of CRS types

  The definitions correspond to those of PART 121.311.

- Compatibility of CRS and aircraft passenger seat

  This SAE refers to SAE ARP4466 which specifies the procedure for testing the installability and mountability of a CRS on a standard aircraft passenger seat, cf. below.

- Installability of CRS on aircraft passenger seats

  The CRS must be attached on the aircraft passenger seat with the existing lap belt only. Pursuant to TSO-C100B, a CRS may also be attached on the aircraft passenger seat with the so-called ISO-fix anchorage points if the seat is also equipped with it.

- Fire protection

  Pursuant to 14CFR25.853(c), fire tests must be performed as for aircraft passenger seats, however, with the restriction of TSO-C100b stating that “small parts” of the CRS do not have to be reviewed.

- Turbulence protection

  The rollover test pursuant to FMVSS 213 must be performed.

- Dynamic strength / occupant protection

  A dynamic forward test must be performed for each “child-occupant“ category of the CRS.

  A simulated aircraft passenger seat is used which corresponds to the test fixtures pursuant to FMVSS 213 to a large extent. The padding and the belt anchorage points, however, have been changed. Lap belts pursuant to TSO-C22 are used.

  It is possible to perform a 16g forward test (in accordance with SAE AS8049) or a test in accordance with FMVSS 213, figure 2.

  The pass / fail criteria correspond to those of FMVSS 213. The head injury criterion (HIC), however, is calculated in accordance with the former FMVSS-213 procedure.

- Labelling

  The label information comprises, amongst other data, the details about the manufacturer, instructions for the CRS use, for the installation and warnings.

Child restraint systems approved pursuant to SAE AS5276/1 bear the following information, amongst others:

- Model type and model number of the CRS
- Manufacturer’s name
- The expression: "Manufactured in “…“, (manufacturing date including month and year).
- Manufacturing site (city, federal state and/or country).

- The expression: "This child restraint system conforms to SAE Aerospace Standard AS5276/1".

- Specification of the weight and height of children for whom the CRS is provided.

2.4.3.3 Dimensional Compatibility of Child Restraint Systems and Passenger Seats (SAE ARP4466)

SAE ARP4466 specifies the "Dimensional Compatibility of Child Restraint Systems and Passenger Seat Systems in Civil Transport Airplanes", including the following aspects, amongst others:

- Specification of an aircraft passenger seat (test fixtures)

  Dimensions of the aircraft passenger seat for test purposes (e.g. seat geometry, width between the armrests (16 inch)), attachment points for the lap belt, padding type etc.

- Specification of a lap belt (test belt)

  Dimensions of the lap belt, specification of the fittings and the belt buckle.

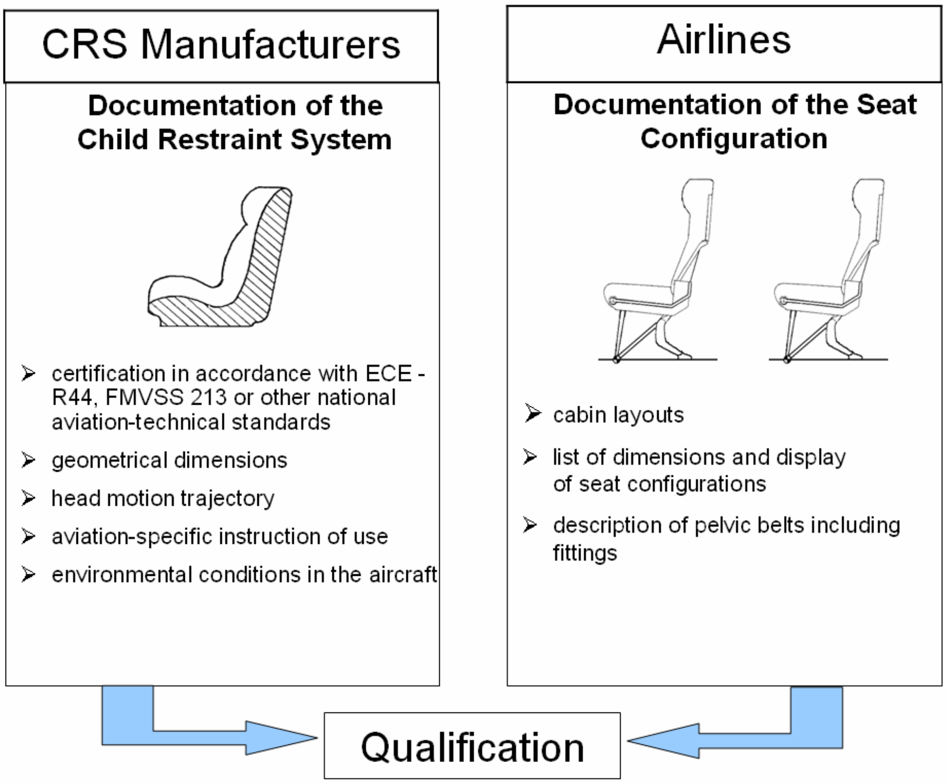
- Specification of installation and removal tests with the CRS on the test fixtures using the test belt:
  - Implementation of tests with a seat pitch of 30 inches between two aircraft passenger seats (test fixtures) placed ahead of each other.
  - Placing the CRS on the test fixtures.
  - Fastening the CRS with the test belt at different belt anchorage points.
  - Unfastening the CRS.

- Reviewing the edges within the range of the belt routing at the CRS.

2.4.3.4 Qualification Procedure for Child Restraint Systems (CRS) intended for Use in Aircraft (TÜV Doc.: TÜV / 958 – 01 / 2001)

An other option of the ACJ OPS 1.730 (a)(3) is the use of CRS qualified in according to this German procedure.

The qualification of a CRS is based on the proof of suitability of the CRS to be submitted by the manufacturer and the specification of seating configurations by the Airline. The objective of the qualification is to determine the seating positions in an aeroplane which are suited for the use of the qualified CRS.



<u>Child restraint systems:</u>

Child restraint systems which are approved in accordance with an aviation standard or e.g. in accordance with ECE-R 44 and FMVSS 213 are qualifiable. The following aspects have to be complied with in the compatibility test for the CRS:

- It must be possible to attach the CRS on the aircraft passenger seat with the lap belt used in aircraft.
- A proof of compliance regarding a safe and firm CRS attachment using a lap belt must be produced by means of a dynamic test.
- A head excursion must be determined for forward-facing CRS from the dynamic test with a two-point belt.
- Instructions for use in aircraft are required.

The CRS can be identified with the following label (incl. ID-Number) if the required evidence of compliance is submitted, see Figure 2-9.

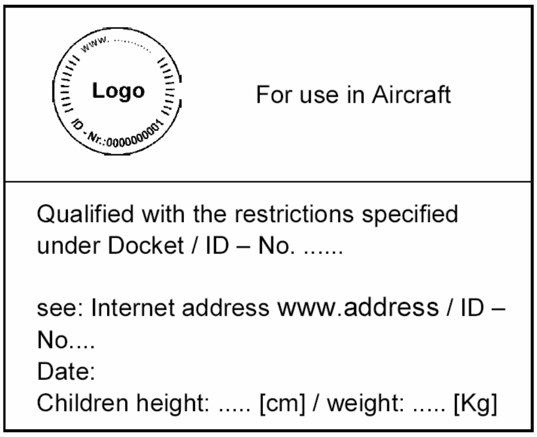


Figure 2-9: Example of a label for child restraint systems

<u>Airline:</u>

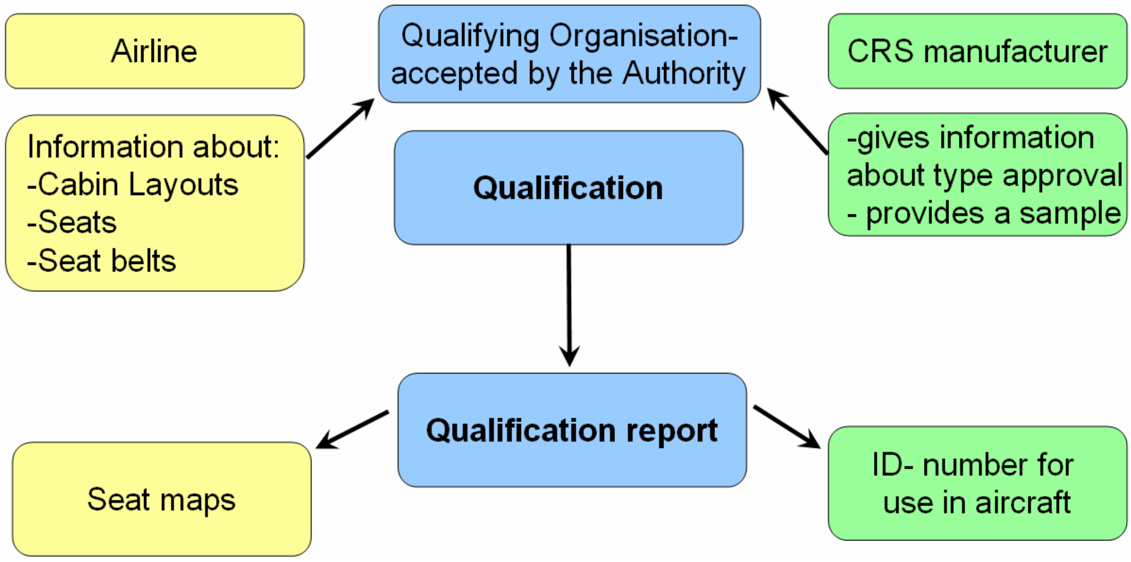
The following details on aircraft passenger seats are necessary for the use of child seats in aircraft:

- Dimensions of the different aircraft passenger seats installed in the respective cabin layout.
- Position of belt anchorage points for the different aircraft passenger seats.
- Dimensions of the lap belts and the belt buckles.
- Position of the different aircraft passenger seats in the cabin layout.

<u>Qualification:</u>

An independent organisation qualifies the CRS with the details about the CRS and the aircraft passenger seats according to the following steps:

- Correlation of the CRS dimensions with the seat configuration.
- Review of the CRS fixing by means of the test seat.
- Review of head contact and survival space.
- Review of the requirements for the evacuation of the aircraft cabin.
- Assignment of the CRS to specific aircraft seats (as a “seat map”).

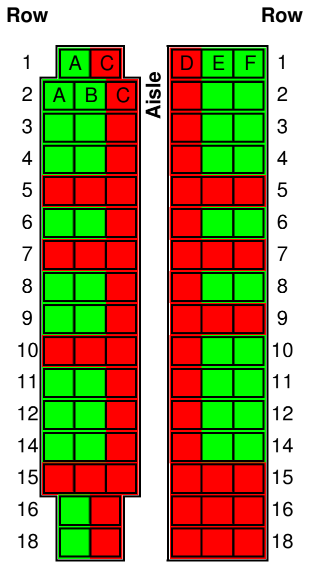


The qualification indicates suitable seats which the aerospace company is allowed to occupy with the respective CRS. The seat map depicts a simplified cabin layout, see Figure 2-10. The seat map identifies the usable seats and the appropriate CRS.

Seat Map for XXX (Airline)

Aircraft Type / Modell: XXX
Cabin Layout: YYY

Date of Issue: XX.XX.XXXX



Kinderrückhaltesysteme (KRS) /
Child Restraint Systems (CRS)

KRS Nr. 1 / CRS No. 1
ID-Nr.: XXXXXXXXXXXX
Kindergröße / Child height: XX - XX cm
Kindergewicht / Child weight: X - X kg

KRS Nr. 2 / CRS No. 2
ID-Nr.: XXXXXXXXXXXX
Kindergröße / Child height: XX - XX cm
Kindergewicht / Child weight: X - X kg

KRS Nr. 3 / CRS No. 3
ID-Nr.: XXXXXXXXXXXX
Kindergröße / Child height: XX - XX cm
Kindergewicht / Child weight: X - X kg

KRS Nr. ff. / CRS No. ff.
ID-Nr.: XXXXXXXXXXXX
Kindergröße / Child height: XX - XX cm
Kindergewicht / Child weight: X - X kg

Allgemein gilt / in General:
Für das Kinderrückhaltesystem ist der Fensterplatz zu bevorzugen !
Preferred seat for the child restraint system is the window seat !

Achtung / Attention:
Aus Evakuierungsgründen darf auf dem mittleren Sitzplatz nur dann ein Kinderrückhaltesystem montiert werden, wenn der Fensterplatz unbesetzt bleibt oder durch ein weiteres Kinderrückhaltesystem derselben Reisegruppe (Familie) belegt ist.
For evacuation reasons, the middle may only be occupied by a child restraint system if the window seat remains unoccupied or is occupied by another child restraint system of the same travel group (family).

KRS erlaubt / CRS allowed
KRS nicht erlaubt / CRS not allowed

Figure 2-10: Example of a seat map

2.5 Summary of "Literature and data search and review" (Phase I)

The transport of lap-held infants secured with or without a loop belt does not provide any protection to the infant. Being fixed with the loop belt, the infant acts as an energy absorbing element for the adult who performs a jack-knife movement over the infant in a crash. The crash loads are reduced for the adult, the crash loads for the infant, however, are massively increased. Without a loop belt it is not possible for an adult to hold and protect an infant sitting on his or her lap with the hands.

The reviewed studies and test reports show in principle that different motor vehicle child restraint systems are to be used also on aircraft passenger seats and have to be fastened with a lap belt. However, not all CRS approved for motor vehicles are suitable for use in aircraft. This both concerns systems approved in accordance with ECE-R 44 and FMVSS 213. One problem e.g. is that some CRS are too wide to be placed on the aircraft passenger seat in between the armrests. Furthermore, it is not possible with a number of CRS to fasten them with the aircraft lap belt, or to release the fastened lap belt since there is not enough space to open the belt buckle. On some aircraft passenger seat models the CRS can be placed and fastened, but the lap belt angle is so steep (up to over 90° to the horizontal) that the CRS can be moved forward even with very small effort. From this results an insufficient restraint effect of the CRS under emergency landing conditions

Procedures are specified for the USA and Europe in order to provide for the use of CRS in aircraft including:

- technical specifications for the CRS
- installability of CRS - aircraft passenger seat
- functionality of CRS - aircraft passenger seat in the cabin

The analysis of available accident reports and accident data dealing with four aircraft accidents - three accidents with passenger aircraft and one sports airplane accident. Furthermore, it considered incidents in conditions of turbulence.

The accident analyses show, and the accident reports recommend, that infants should be seated in a suitable child restraint system on a seat of their own. This is the only way to provide safety equivalent of adults safety.

Also conditions of turbulence during the flight involve a high injury risk for passengers with high vertical accelerations being effective in the aircraft cabin. Passengers should therefore fasten their seat-belts in conditions of turbulence. It is not possible for an adult to hold an infant sitting on his or her lap. Suitable child restraint systems provide safety for infants here as well.

The European and American specifications for the certification of automotive child restraint systems define requirements for the classification of child restraint systems (weight classes) as well as test requirements and protection criteria. The comparison of ECE-R 44 and FMVSS 213 shows comparable requirements for child restraint systems. According to the specifications, infants with a weighing up to 10 kg should be generally transported in rearward-facing CRS. For heavier infants and children, also forward-facing CRS are suitable.

The Certification Specification (CS 25) demand the consideration of all passengers in the configuration and certification of aircraft passenger seats, lap belts and cabin installations but several research projects shows that the specific physical features of infants and children are not sufficiently taken into account in the regulations.

In Europe and the USA, infants are presently transported in aircraft as follows:

- Lap-held by an adult.
- Lap-held by an adult and secured with a supplementary loop belt (not allowed in USA, Canada, Germany).
- Secured in a child restraint system, sitting in a seat of its own.

Equivalent safety for adults and infants or children is only possible with an own seat and a suitable CRS.

Application of a procedure for the use of CRS in aircraft, taking account of technical and operational specifications as well as specifications regarding the function of the CRS on the aircraft passenger seat.

3 Evaluation of available solutions (Phase II)

The "Evaluation of available solutions" outlines the solutions which are already used and those which are in development, and analyses them in view of safety, operational practicality and costs.

The solutions to be analysed can be subdivided into three categories:

- approval standards / provisions for child restraint devices
- child restraint devices
- procedures for the transport of infants / children in aircraft.

Approval standards / provisions for child restraint devices

- Child seats approved for use in motor vehicles according to the UN standard ECE R 44
- Child seats approved for use in motor vehicles and aircraft according to US FMVSS No 213. (or Canadian CMVSS 213/213.1)
- Child seats approved for use in aircraft according to TSO C-100b (referring to SAE AS5276/1 as amended by the FAA as a minimum performance standard).
- Dual child auto/aviation seat according to the draft IMPCHRESS CRD specification

Child restraint devices

- Infant restraint by a supplementary loop belt
- Aircraft passenger seat lap belt
- Child safety device CARES by AmSafe Aviation approved by the FAA for use in aircraft (in accordance with 14CFR 21.305(d))
- Design ideas for a passenger seat built-in child restraint device.

Procedures for the transport of infants / children in aircraft

- Unrestrained infant lap-holding
- Qualification Procedure for Child Restraint Systems for Use in Aeroplanes (TÜV/958-01/2001)

3.1 Basis of Evaluation

The following basis of evaluation is discussed to evaluate the solutions for the transport of infants and children in aircraft.

The basis of evaluation was developed with the results from the research projects and studies (cf. Phase I) and cover the following aspects:

- safety
- operational practicality

The cost aspect of the solutions is treated separately in chapter 4.

3.1.1 Safety

The following aspects are covered:

- The restraint of the infant / child by the CRD taking account of the child's development (biomechanics)
- The function of the CRD in case of a crash taking account of the specific installation.
- Evacuation aspects

3.1.1.1 Biomechanics

Infants / children differ significantly from adults in terms of size and weight, body proportions and anatomy.

The physique of a newborn child is marked by a disproportionately big and heavy head, with the length of the head accounting for approx. 1/4 of the entire body. In the course of the growth process, the corresponding ratio of adults decreases to up to 1/8, i.e. in the infant stadium up to the age of approx. two years, the head is disproportionately heavy compared to the body. The difference in the body proportions also entails a higher centre of gravity in children.

Figure 3-1 depicts the development of the body proportions on the basis of the head sizes in five growth phases.

The infant's cervical spine is exposed to a strong load in accelerating forces due to the disproportionately big and heavy head. In addition, the ligaments of the cervical spine have a higher elasticity than those of adults. In combination with the not yet fully developed vertebral joints, the vertebral spine has a higher flexibility, with the cervical spine of infants being less resistant against flectional and rotational loads.

This development of the head and cervical spine must be taken into account in the restraint of infants in CRD. It is therefore claimed that children up to a body mass of at least 9 kg are transported in backward-facing child seats in motor vehicles with the infant's head being directly restrained by the backrest of the child seat in an accident.

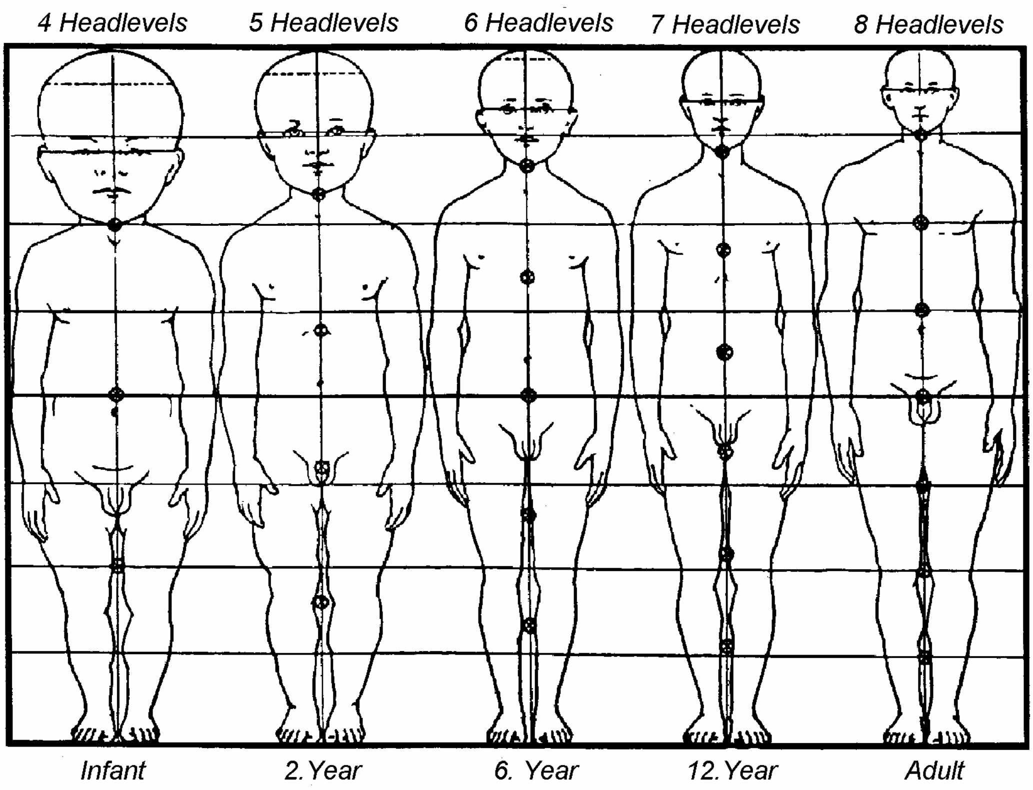


Figure 3-1: Changes in the body proportions during growth

The most frequent cause of contact injuries of the head is the head impact against rigid structures in an accident. Injuries are caused by head contact and by linear and rotational accelerations occurring in this impact, such as haemorrhages above and below the dura mater, cerebral contusions in the area of the external force, concussions.

During birth, the bony skullcap is made of bony scales which are still separated from each other by broad sutures and fontanelles (fibrous membrane). The thickness and strength of the infant / child skull is very different from that of adults. The skull of newborn children has a more viscoelastic property than the rigid skull of adults. The rigidity is a non-linear function of age - at the age of two years, children have reached approx. 45 percent of the adult's value, and at the age of six to nine years, they have reached approx. 75 percent of the adult's value.

At present, there is no detailed research of biomechanical tolerance for the head contact of infants / children in accidents available. However, since the bony skull structure of infants / children is not yet fully developed, the head is by far more damageable than the head of adults. Therefore, a head contact against rigid structures should be prevented at any rate during an accident.

Also the bony structures of the thorax, the pelvis and the extremities develop with increasing age. In contrast to adults, only a minor part of the infant's /child's abdomen is protected by the bony pelvis and the thorax.

There are vital internal organs in the thorax and abdomen such as the heart, lung, liver, spleen and kidneys. The major injury mechanisms in this region are based on the compression and penetration of the organs. High accelerations may also cause positional changes of individual organs due to inertia. As a consequence, major bloodstreams can tear or the organs can be compressed.

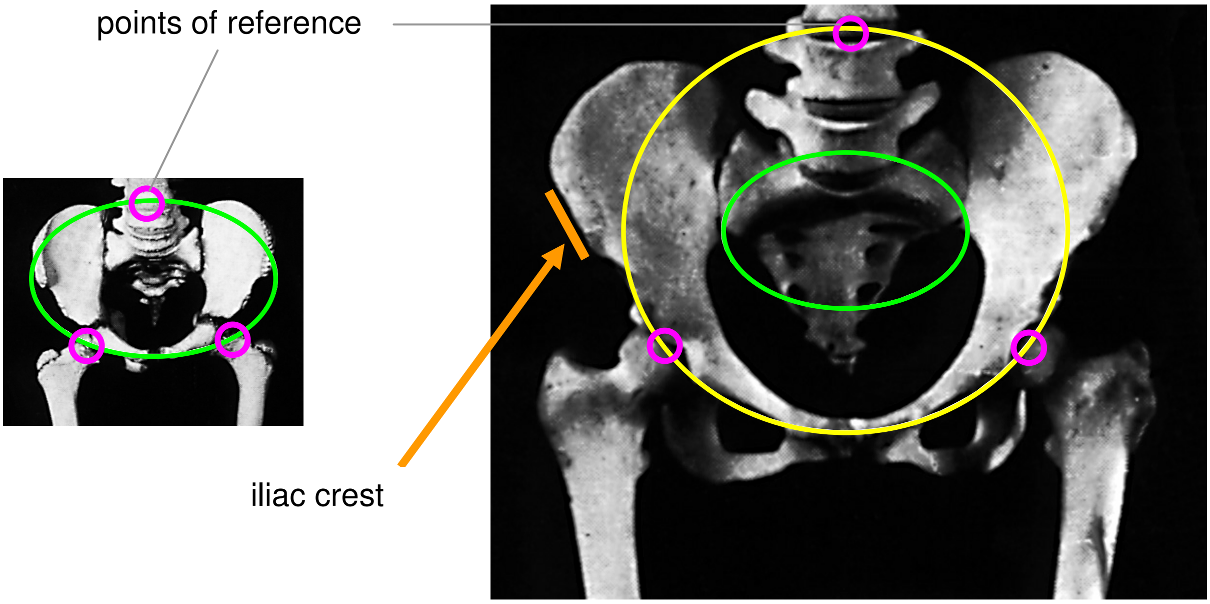


Figure 3-2: Comparison of an infant pelvis (left) and the pelvis of an adult woman

The pelvis is a link between the upper torso and the lower extremities and can be considered as a structure bearing the main load. The pelvis has a particular function in view of the aircraft passenger restraint with a two-point-belt. Given a correct belt routing, the 2-point belt runs in a tangent over the femurs in front of the pelvis and in adults is supported by the iliac crest. The inertial forces resulting from the deceleration are at first induced into the body by the pelvic bone. In biomechanical terms, the adult is restrained in an accident by the lap belt over his or her iliac crest bones. The development of the pelvic bones is relevant in view of an optimal belt geometry of the lap belt. Figure 3-2 depicts the pelvis structure of a child sized approx. 70 cm and of an adult woman sized approx. 160 cm. The figure gives an ellipse mostly enclosing the infant's pelvis which has been transferred into the figure of the adult (green). An ellipse is additionally drawn in there (yellow) which is almost shaped like a circle connecting more of less the same points of reference as those in the infant's pelvis (transverse processes of the 4th lumbar vertebra, hip joints) to illustrate that, besides the general pelvis growth, a significant enlargement of the ilium furthermore develops from the border cartilages of the hipbones, creating a pronounced iliac crest.

The standard lap belt is therefore not suited for a safe restraint of infants / children. The iliac crest of infants / children is not yet fully developed, there is the danger that the lap belt slips into the infant / child abdominal region in an accident or turbulences and the infant / child suffers severe internal injuries.

Biomechanical tolerance

Human biomechanical tolerance limits indicate physical loads (force, moment, acceleration, pressure etc.) which specific body regions or body parts can tolerate without major damage. This may be an individual load, e.g. a pure contact force, or a collective load in terms of a combination or overlap of individual loads, e.g. rotational and translational acceleration of the brain.

As a matter of fact it is impossible to indicate generally applicable biomechanical tolerance limits since these strongly depend on individual parameters (age, sex, constitution etc.) as well as on the peripheral conditions of the loads. It is therefore necessary to specify more than one tolerance for different load situations of a body region, strictly speaking depending on the above-mentioned individual parameters of the persons. It is almost impossible to determine such differentiated tolerance limits, nor were these practicable, especially in view of the set-up of general protection criteria. The tolerance limits indicated in literature are therefore only average values for specific groups of persons.

The experimental simulation of accident events and the loads effective in the accident uses physical or mathematic models in engineering with the dummy being the most popular physical human model. The dummy has an average body geometry and is representative for a specific group of persons. The group of persons is characterised by its age, size and sex as well as by physical parameters such as spring constants, attenuation key figures, mass distribution and moments of inertia.

Protection criteria were derived from the biomechanical tolerances. The loads determined in the simulation of the accident event can be assessed on the basis of the protection criteria. These are physical indicators which should not be exceeded in the tests.

There are presently no protection criteria for child dummies especially for the aeronautics sector which can be applied for the evaluation of the test results.

Relevant data are taken over from other sectors in order to define protection criteria using research of the automotive industry such as FMVSS-213 and ECE-R44 (cf. section 4.6 “Protection criteria” of Phase I).

Summing up, it can be stated that child seats must be adapted to the infant /child development in order to provide safe restraint. This results in fundamental requirements to be met by the CRD:

- Infants up to a weight of approx. 9 kg must be transported backward-facing in a CRD.
- Forward-facing CRD must be equipped with restraint systems which are appropriate for children, i. e. either with a belt restraint system or with an impact shield. A belt restraint system which is appropriate for children restrains

the pelvis and the upper torso safely in an accident and is adaptable to the infant's / child's size. In an impact shield system, the infant's / child's pelvis and thorax (sternum) are supported by the impact shield.

- The belt restraint system of forward-facing CRD must be equipped with an additional crotch belt preventing the Infant / child from slipping under the lap belt.

- A dynamic test in accordance with TSO C100b, ECE-R 44 or FMVSS 213 must be performed with the CRD and the dummy. The dummy protection criteria for infants / children must not be exceeded in this case.

3.1.1.2 Function of the CRD in a crash

Besides the biomechanical evaluation of CRD, the protective effect of CRD depends on the specific installation in the cabin layout. It must be possible to attach the CRD properly to an aircraft passenger seat. Furthermore, cabin installations may not cause additional injury potentials (e.g. protruding aircraft passenger seat, bulkheads etc.) within the infant's / child's excursion path. The following aspects must be taken into account:

- There must be a survival space for the infant / child in emergency landing conditions, i.e. the infant / child needs a seat of its own.

- There must be no head contact with the seat in front or with parts of the cabin layout.

- The structural stability of the CRD must be proven under crash conditions. The CRD must be attached like in an aircraft, i.e. normally by means of a lap belt attachment. The test conditions must be in line with TSO C100 b (FAR 25.562 or CS 25.562), ECE-R 44 or FMVSS 213.

- The belt angle (cf. Figure 3-3) of the CRD attached to the aircraft passenger seat must not become too large. The CRD must be safely restrained in the crash. Too large belt angles result in a strong forward movement of the CRD in a crash, resulting in a large forward displacement of the head. In extreme cases, the CRD can fall off the front edge of the aircraft passenger seat.

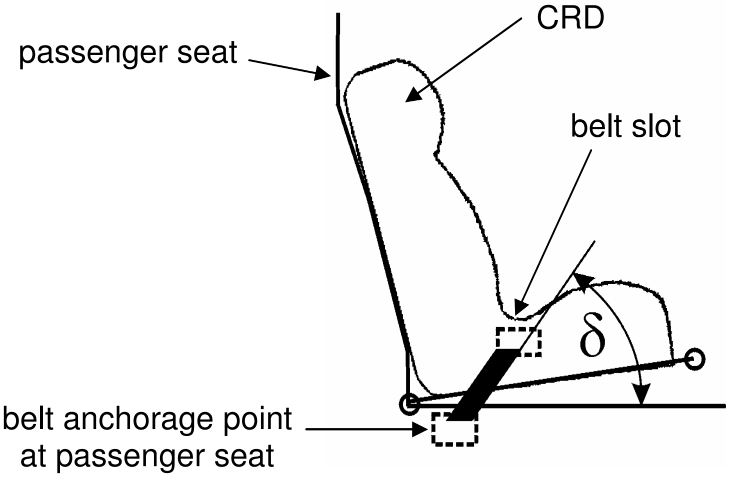


Figure 3-3: CRD on an aircraft passenger seat

- A roll-over test has to be performed pursuant to TSO C100b, ECE-R 44 or FMVSS 213.

3.1.1.3 Evacuation

The evacuation of infants / children and the other passengers must not be impaired by the use of CRD in the cabin layout.

Pursuant to the operating instructions, infants / children must not be placed at emergency exits. This is provided in JAR-OPS 1.280 in conjunction with ACJ OPS 1.280 and IEM OPS 1.280.

The EU-OPS effective as of 16 July 2008 defines in Art. 1.280 the same as the JAR-OPS: “An operator shall establish procedures to ensure that passengers are seated where, in the event that an emergency evacuation is required, they may best assist and not hinder evacuation from the aeroplane“. However, there are no further explanations about the EU-OPS as to which passenger groups are concerned. In this context, the EU-OPS is interpreted in the same way as the JAR-OPS, i.e. infants / children must not be placed at emergency exists.

The USA has adequate regulations in place (FAA regulations, see FAR Part 121, Section 585 “Exit Seating“).

The EU-OPS does presently not include standards regarding the positioning of child seats in the cabin layout.

In an evacuation, the infant / child must be released from the CRD by an attending person. However, this person must not hinder the evacuation of the other passengers, e.g. he or she must not stand in the aisle. Another situation is the attachment of the CRD to the middle seat of an outboard-triple seat bench. This may hinder the passenger sitting by the window. The EU-OPS should also consider the explanations relating to JAR-OPS 1.730, the ACJ OPS 1.730(a)(3), in order to take account of these issues. Regarding the seating under evacuation aspects they give the following details:

[ACJ OPS 1.730(a)(3) Seats, seat safety belts, harnesses and child restraint devices
…
3.Location
…
3.2 A child in a restraint device should be located as near to a floor level exit as feasible.
3.3 A child in a restraint device should be seated in accordance with JAR-OPS 1.280 and IEM OPS 1.280, “Passenger Seating“ so as to not hinder evacuation for any passenger.
3.4 A child in a restraint device should neither be located in the row leading to an emergency exit nor located in a row immediately forward or aft of an emergency exit. A window passenger seat is the preferred location. An aisle passenger seat or a cross aisle passenger seat is not recommended. Other locations may be acceptable provided the access of neighbour passengers to the nearest aisle is not obstructed by the CRD.

3.5 In general, only one CRD per row segment is recommended. More than one CRD per row segment is allowed if the children are from the same family or travelling group provided the children are accompanied by a responsible person sitting next to them.
3.6 A Row Segment is the fraction of a row separated by two aisles or by one aisle and the aircraft fuselage.

Since the above aspects regarding the evacuation must be equally taken into account for all solutions, these will not be further detailed in the following evaluation. It is assumed that the seating with regard to an evacuation is not dependent on the solution itself.

Regarding the evacuation, the CRD itself must provide a fast and easy means to release the infant / child from the CRD. During an evacuation, the restraint system should remain installed in the passenger seat and only the occupant should be removed from the aircraft.

3.1.2 Operational practicality

The following aspects fall under the basis of evaluation for the operational practicability:

- Compatibility of the geometric dimensions of the aircraft passenger seat and the child seat

- Practicable attachment and release of the CRD from the aircraft passenger seat

3.1.2.1 Compatibility aspects

Specific conditions must be considered in the use of CRD in the cabin layout which are on the one hand defined by the aircraft passenger seat and which on the other hand depend on the specific installation of the aircraft passenger seats in the cabin.

This section will deal with a “dimensional survey of existing aircraft seat configuration” as well as “installation problems and compatibility aspects of CRD”.

The following Figure 3-4 depicts an exemplary Eco-class passenger aircraft seat. The CRD (add- on system) is placed on the seat and is fastened with the lap belt. The space between the armrests, the distance to the seat in front and the safe attachment to the aircraft passenger seat are important for the evaluation of the installability of the CRD and the safe attachment to the aircraft passenger seat.

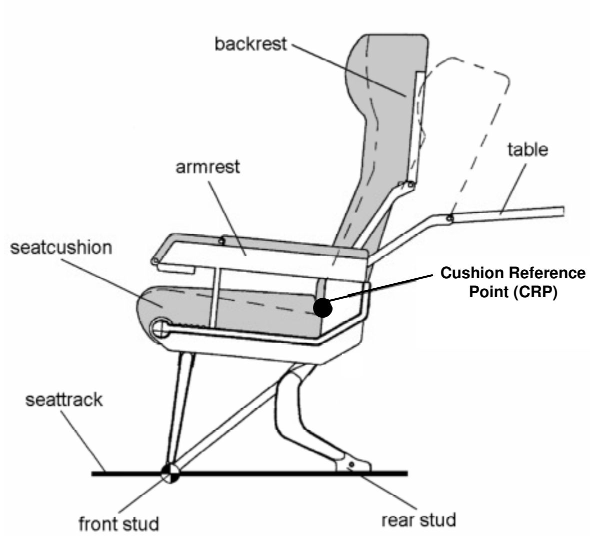


Figure 3-4: Example of Eco-Class Seat

3.1.2.1.1 Space on the aircraft passenger seat

The widths between the armrests differ significantly both between the individual classes in the cabin layout and in the different aircraft passenger seats. The width depends on the seat model and seat type, amongst others. Additionally, there are narrow and wide seats within the same seat type, depending on the position of installation:

- standard ECO Class seats:	approx. 400 to 450 mm,
- narrow ECO Class seats:	approx. 380 to 400 mm,
- Business / First Class seats:	approx. 430 to 550 mm (and more).

[Database: aircraft passenger seat measurements from 65 different cabin layouts]

If the width between the armrests is too small, the CRD cannot be used on the aircraft passenger seat (cf. Figure 3-5).

Figure 3-5: Distance between the armrests is too small

The distance to the seat in front depends on the seat pitch and the constructive design of the backrest of the aircraft passenger seat (width of the rest, contour of the backrest). The seat pitch in different cabin layouts varies as follows:

- ECO Class: approx. 28 to 34 inches,
- Business / First Class: approx. 41 to 60 inches (and more)

[Database: aircraft passenger seat measurements from 65 different cabin layouts]

If the distance to the seat in front is too small, the CRD e.g. cannot be placed properly; it stands too steep or cannot be installed (cf. Figure 3-6).

Figure 3-6: Too small distance to the seat in front (example, backward-facing CRD)

3.1.2.1.2 Lap belt attachment

The lap belt mainly consists of a rigid webbing, an adjustable webbing and the lift-lever buckle. The length dimensions of the webbing are not defined uniformly i.e. the length of the rigid webbing differs; so the position of the lift-lever buckle of a fastened and tightened lap belt can vary strongly.

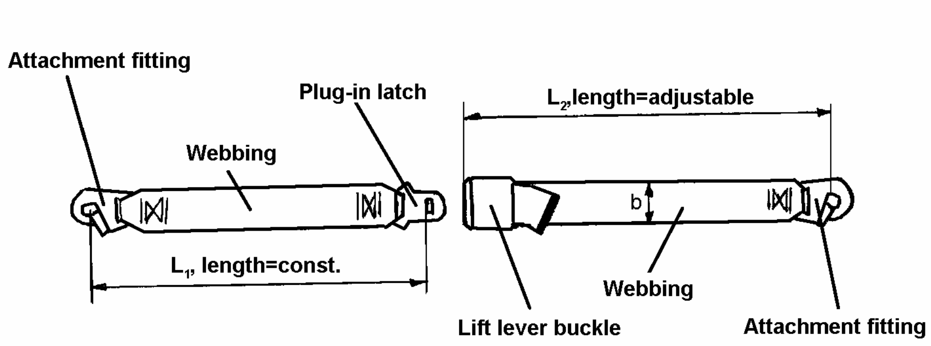


Figure 3-7: Lap belt

To attach a CRD with the lap belt, the belt must follow the belt routing defined by the CRD manufacturer. It must be possible to fasten and release the lap belt. It must furthermore be possible to pull the lap belt tight and it must not loosen independently. The following figures depict problematic installations of the lap belt attachment.

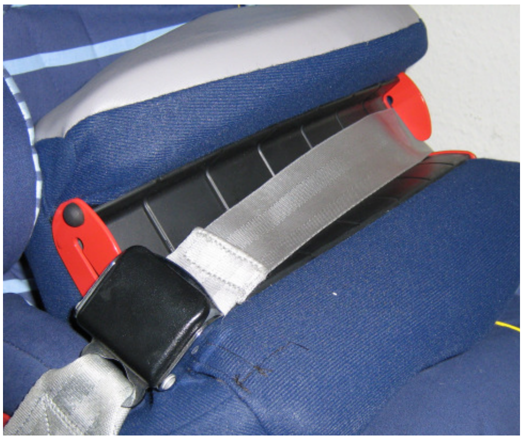
- The "rigid" webbing is very short, it is difficult or even impossible to lock the lap belt.

- The “rigid” webbing is very long. The lap belt can be locked but not pulled tight, since the lift-lever buckle contacts the CRD.

  Or the webbing is routed so steeply from the buckle that the webbing is not plugged in the attachment fitting and the belt can loosen.

- The lap belt runs through a "belt slot" in the CRD. After the lap belt has been locked, it cannot be re-opened since there is not enough space to lift the lift-lever.

- The lift-lever buckle does not fit into the guides for the webbing provided by the manufacturer.



The position of the lift-lever buckle does not exclusively depend on the length of the rigid webbing but also on the position of the belt anchorage points. The lap belt anchorage point (cf. Figure 3-8) varies very much in the different aircraft passenger seats. Related to the cushion reference point (CRP) e.g. between 120 mm forward and 50 mm backward as well as up to 15 mm above and 110 mm below the CRP [Database: aircraft passenger seat measurements from 65 different cabin lay-outs].

These different positions of the belt anchorages also lead to different belt angles in the attachment of the CRD. Too large angles result in the CRD moving too much forward in a crash (cf. paragraph 2.1.2).

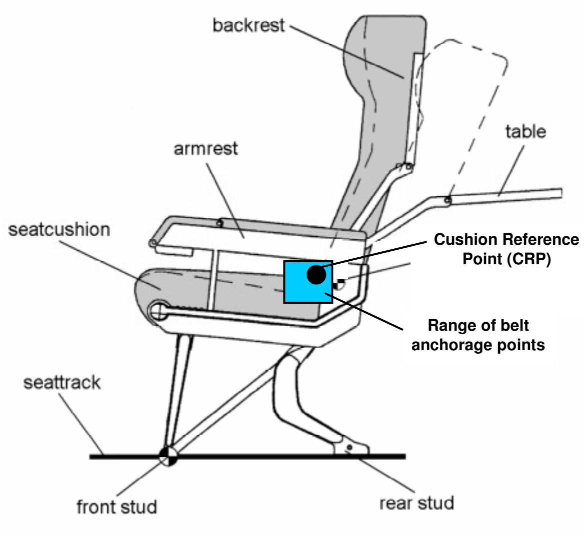


Figure 3-8: Range of belt anchorage points

3.1.2.2 Operational issues

There must be enough space available to use the CRD on an aircraft passenger seat. It must be possible to attach the CRD to the aircraft passenger seat and it must not endanger the safety of the other passengers additionally.

Geometric dimensions

- The CRD must fit between the armrests of the aircraft passenger seat. If the CRD broadens above the armrests, it must not endanger or excessively hinder the passenger sitting next to it.

- For backward-facing CRD the distance to the aircraft passenger seat in front must be large enough to be installed properly.

Attachment of the CRD to the aircraft passenger seat

- The attachment of the CRD to the aircraft passenger seat must be described clearly (e.g. in the operating instruction).

- Lap belt attachment:

  - It must be possible to fasten the CRD with the 2-point-lap belt of the aircraft passenger seat.

  - It must be possible to access, open and lock the buckle.

- It must be possible to pull the lap belt tight and it must not loosen independently.

- Other attachment systems

  If other attachment systems are used (e.g. ISOFIX), both the aircraft passenger seat and the CRD must have the respective attachment prerequisites to attach the CRD safely.

3.2 Evaluation of the Solutions

Taking account of the findings from Phase I “Studies and Reports”, the following describes and evaluates the solutions for the transport of infants / children in aircraft using the basis of evaluation (cf. chapter 2). A summarising evaluation for each solution outlines whether or not it is acceptable.

In principle, a solution is not acceptable if it meets the biomechanical aspects insufficiently. Where the solutions do not or only insufficiently take account of specific aspects of the basis of evaluation, an overview is given of the aspects which have to be additionally investigated for use in aircraft, i.e. it is described whether the solution shows potential, by supplementary measures, to ensure safe transport of infants / children.

3.2.1 Approval standards / provisions for child restraint devices

3.2.1.1 Child seats approved for use in motor vehicles according to the UN standard ECE R 44

The following examines child restraint devices which are approved for use in motor vehicles in accordance with the European Standard ECE R44. These are systems for infants / children which are added on the seat (add-on systems). The child restraint devices can be designed as follows:

Figure 3-9:
Backward-facing seat pan with integrated belt system

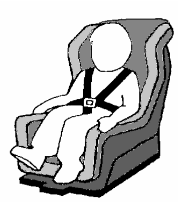


Figure 3-10:
Forward-facing seat pan with integrated 5-point belt

a) b)

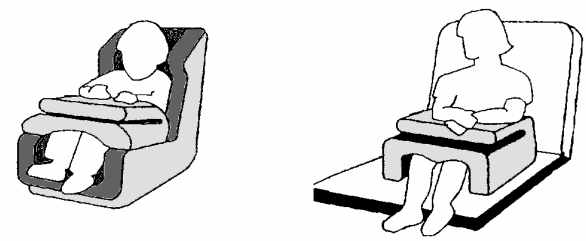


Figure 3-11:
Forward-facing impact shield systems with backrest (a)
and without backrest (b)

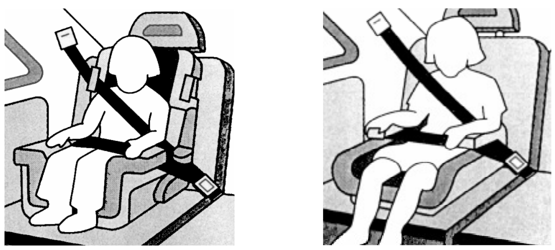


Figure 3-12:
Forward-facing booster seat with and without a backrest
(belt positioning systems)

These CRD are attached to motor vehicle seats with the existing 2 or 3-point belts. Since 2-point belts are used less and less in motor vehicles within the EU, motor vehicle child seats are frequently developed and approved only for use with 3-point belts.

Booster seats (see Figure 3-12) are not suitable for the restraint with 2-point belts (lap belts). They serve the correct positioning of the child on the adult three-point belt.

CRD are more and more equipped also with an ISOFIX attachment. ISOFIX is an internationally standardised attachment system for child seats. In the ISOFIX system, two fixing mechanisms are attached at the bottom of the child seat. The fixing mechanisms engage with plug-in latches in attachment points of the vehicle, cf. Figure 3-13 and Figure 3-14.

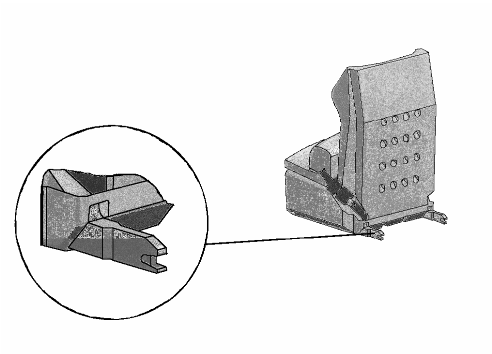


Figure 3-13: ISOFIX principle

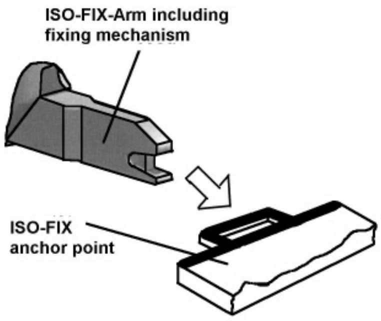


Figure 3-14: ISOFIX- attachement

To prevent an unwanted rotation of the CRD on the motor vehicle seat, ISOFIX child seats are equipped with a system to limit the nodding movement. In Europe, a floor support or an upper ISOFIX tether with a brace to the vehicle structure is mostly used.

ECE-R 44 approved CRD meet the biomechanical standards for the restraint of infants / children. The approval includes a roll-over test and dynamic tests with dummies as well as the evaluation of the test results by means of acknowledged dummy protection criteria. The dynamic tests are carried out on a test seat. The dummy head must not exceed a maximum forward displacement in the dynamic tests. The tests are carried out with a 2 and / or 3-point belt attachment, depending on the intended kind of CRD approval. If CRD with exclusive 3-point belt approval are to be attached only with the 2-point lap belt in the aircraft, the structural stability proof with lap belt attachment is absent.

ECE R44 does not take account of the specific installation of the CRD on an aircraft passenger seat in the cabin layout. The following open issues result from this:

- It is not ensured with the ECE R44 approval that there is no head contact with the seat in front or with components of the cabin layout.
- The belt anchorage points for the 2-point belt used in the ECE test seat are 20 mm behind and 80 mm below the Cushion Reference Point (CRP). In the aircraft passenger seat, the belt anchorage points can be positioned significantly further forward and also higher, resulting in a deterioration of the belt angle (cf. section 2.2.1.2). The belt angle should therefore be examined

additionally in the attachment of ECE R44 child seats to the respective aircraft passenger seat.

- The CRD with a seat pan attached to the aircraft passenger seat generally provides a survival space for the infant / child. If CRD are not equipped with a rigid backrest, the survival space can be reduced to an unacceptable degree by a "break-over" backrest of the aircraft passenger seat, e.g. in impact shield systems without a rigid backrest. If CRD without a rigid backrest are used on limited break-over aircraft passenger seats, it must therefore be investigated whether a sufficient survival space is left.

- There are no operating instructions for ECE R 44 approved CRD for use in aircraft.

- ECE R 44 approved CRD are designed for use in motor vehicles and do not take account of the conditions in respect of the geometric dimensions and the attachment of the CRD with the aircraft lap belt.
  The development of CRD for motor vehicles aims at an improved side-impact protection, with the CRD tending to become ever wider. Wide CRD, however, are not suitable on specific seats in aircraft (cf. section 2.2.1.1).
  Some ECE child seats are generally not suitable for installation on aircraft passenger seats, e.g. if the lift-lever buckle of the lap belt cannot be placed properly or if the locked lap belt cannot be opened (cf. chapter 2.2.1.2). If the ECE child seats are in principle suitable, it is not ensured due to the various aircraft passenger seat and belt dimensions that all ECE systems can be fastened safely and tightly with the lap belt (cf. chapter 2.2.1.2).
  The use of such systems causes problems and unforeseeable issues if the operational practicality of the CRD on the aircraft passenger seat is not investigated in advance.

Alternatively to the lap belt attachment of CRD, the evaluated studies and test reports (cf. Phase I) show the general possibility of using the ISOFIX attachment on aircraft passenger seats. Presently, however, this is impossible since aircraft passenger seats are not equipped with ISOFIX anchorage points.

<u>Summarising assessment</u>

ECE R44 approved child seats are suitable for the restraint of infants / children in aircraft only to a limited extent since they do not take the conditions in aircraft sufficiently into account. It is not ensured that the CRD can be used safely on the aircraft passenger seat. Taking the specific aeronautical standards into account additionally, the use of specific ECE R44 child seats is possible.

		Evaluation	Explanations
Current situation	**Safety**	-	+ The biomechanical standards for the restraint of infants / children are met. - It is not ensured with the ECE R44 approval that there is no head contact with the seat in front or with components of the cabin layout. - The belt anchorage points at the aircraft passenger seat can be positioned significantly further forward and also higher than at the ECE test seat, resulting in a deterioration of the belt angle and a bigger dynamic forward displacement. - If CRD are not equipped with a rigid backrest, the survival space can be reduced to an unacceptable extent by a "break-over" backrest of the aircraft passenger seat.
	Operational practicality	-	- There are no operating instructions for ECE R 44 approved CRD for use in aircraft. - The correlation of the geometric dimensions of the CRD and the aircraft passenger seat is not given. - The attachment of the CRD to the aircraft passenger seat cannot be ensured in principle.
Potential for safe transport		+	Taking account of the aircraft-specific peripheral conditions, it is possible to use ECE-R 44 approved CRD in aircraft. For this purpose, however, an additional procedure is required which ensures the practicality (geometric dimensions, attachment, functionality under emergency landing conditions) of the investigated CRD model on the respective aircraft passenger seat. The ISOFIX attachment could be an alternative to the lap belt attachment In the future. The ISOFIX attachment simplifies the attachment problem significantly.

[+ acceptable / - not acceptable]

3.2.1.2 Child seats approved for use in motor vehicles and aircraft according to US FMVSS No 213. (or Canadian CMVSS 213/213.1)

The following considers CRD which are approved for use in motor vehicles and aircraft in accordance with the American standard FMVSS no. 213 or in accordance with the Canadian standard CMVSS 213/213.1. These are systems for infants / children which are placed on the seat (add-on systems). The CRD are labelled as follows: “This Restraint is Certified for Use in Motor Vehicle and Aircraft”.

In accordance with FMVSS / CMVSS, it is principally impossible to use “belt-positioning seats, harnesses and backless child restraint systems“ in aircraft.

The design of FMVSS / CMVSS approved CRD in principle corresponds to ECE R 44 approved CRD (cf. chapter 3.2.1.1). In the USA, so-called “convertible” child restraint devices are widespread. Such CRD can be used backward-facing for infants of up to 10 kg and forward-facing for infants / children as of 10 kg. The principle design of the “convertible” CRD corresponds to a backward or forward-facing CRD with integrated belt system.

In the USA, more and more CRD can not only be attached by the safety belts built-in in the motor vehicle but also with a so-called LATCH system (Lower Anchors and Tether for Children). The system consists of the lower rigid attachment points in the vehicle and the flexible (A) or rigid (B) lower attachments at the CRD (cf. Figure 3-15). In flexible attachments (A) the CRD is connected with the attachment points in the aircraft by tight webbing; the rigid attachments (B) are comparable to the European ISOFIX attachment.

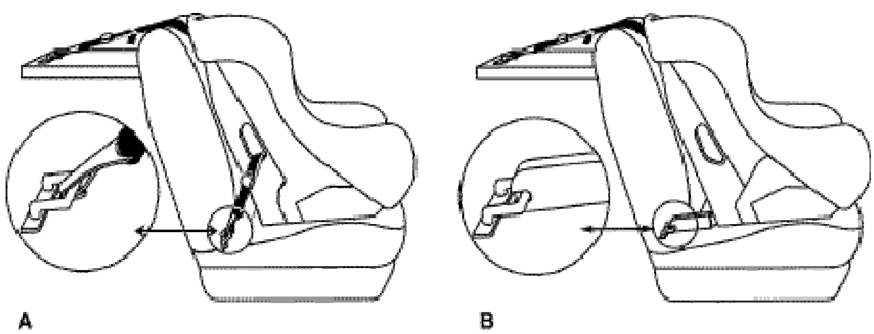


Figure 3-15: LATCH principle (lower attachment: A = flexible, B = rigid)

To prevent an unwanted rotation of the CRD on the motor vehicle seat, the “top tether” is used in America.

CRD which are approved in accordance with FMVSS No 213 or CMVSS 213/213.1 for use in motor vehicles and aircraft meet the biomechanical standards for the restraint of infants /children. The approval comprises a roll-over test and dynamic tests with dummies as well as the evaluation of the test results by means of acknowledged dummy protection criteria. The dynamic tests are carried out on a test seat and take account of the attachment with a 2-point lap belt. The dummy head must not exceed a maximum forward displacement in the dynamic tests.

Child seats without their own rigid backrest are not approved in accordance with FMVSS / CMVSS for use in aircraft.

FMVSS / CMVSS does not take account of the specific installation of the CRD in the cabin layout on an aircraft passenger seat. From this result the following open issues:

- The FMVSS / CMVSS approval does not ensure that there is no head contact with the seat in front or with components of the cabin layout.

- The belt anchorage points for the 2-point belt used for the FMVSS / CMVSS test seat are significantly behind and below the Cushion Reference Point (CRP). At the aircraft passenger seat, the belt anchorage points are positioned substantially further forward and also higher which leads to a deterioration of the belt angle (cf. section 2.2.1.2). The belt angle should therefore be investigated additionally for the attachment of FMVSS / CMVSS child seats to their respective aircraft passenger seat.

- FMVSS / CMVSS approved CRD are predominantly designed for use in motor vehicles and do not take account of the conditions in respect of the geometric dimensions and attachment of the CRD with the aircraft lap belt (cf. ECE R44-child seats).
  Due to the diverse aircraft passenger seat and belt dimensions, it is not ensured that all FMVSS / CMVSS systems can be safely and firmly fastened with the lap belt (cf. chapter 2.2.1.2).
  There are problems and unforeseeable issues in the use of these systems in the cabin layout if the operational practicality of the CRD on the aircraft passenger seat is not verified in advance.

Alternatively to the lap belt attachment of CRD, it is in principle possible to use the LATCH principle (cf. Figure 3-15) on aircraft passenger seats. However, this has not been possible so far since aircraft passenger seats do not yet have the required anchorage points (cf. European ISOFIX system).
The lower anchorage points of the LATCH principle and the ISOFIX system are compatible.

<u>Summarising assessment</u>

Child seats approved in accordance with FMVSS / CMVSS for motor vehicles and aircraft are suitable for the restraint of infants / children in aircraft only to a limited extent since they do not take the conditions in the aircraft sufficiently into account. It is not ensured that the CRD can be used safely on the aircraft passenger seat. Taking the aircraft-specific standards additionally into account, the use of specific FMVSS / CMVSS child seats in aircraft is possible.

		Evaluation	Explanations
Current situation	**Safety**	**-**	+ The biomechanical standards for the restraint of infants / children are met. - It is not ensured with the FMVSS approval that there is no head contact with the seat in front or with components of the cabin layout. - The belt anchorage points at the aircraft passenger seat can be positioned significantly further forward and also higher than at the FMVSS test seat, resulting in a deterioration of the belt angle and a bigger dynamic forward displacement.
	Operational practicality	**-**	- The correlation of the geometric dimensions of the CRD and the aircraft passenger seat is not given. - The attachment of the CRD to the aircraft passenger seat cannot be ensured in principle.
Potential for safe transport		+	Taking account of the aircraft-specific peripheral conditions, it is possible to use FMVSS 213 (or CMVSS 213/213.1) approved CRD in aircraft. For this purpose, however, an additional procedure is required which ensures the practicality (geometric dimensions, attachment, functionality under emergency landing conditions) of the investigated CRD model on the respective aircraft passenger seat. The LATCH attachment could be an alternative to the lap belt attachment In the future. The LATCH attachment simplifies the attachment problem significantly.

[+ acceptable / - not acceptable]

3.2.1.3 Child seats approved for use in aircraft according to TSO C-100b (referring to SAE AS5276/1 as amended by the FAA as a minimum performance standard).

TSO-C100b ”Child Restraint Systems (CRS)“ defines minimum performance standards for child seats regarding the technical qualifications (functional qualification, environmental qualification), as well as the labelling and documentation. The TSO relates to the SAE Aerospace Standard AS5276/1 in conjunction with the SAE Aerospace Recommended Practice ARP4466 (cf. Phase I, section 5.3).

The basic design of the TSO systems corresponds to the CRD design for road traffic, cf. chapter 3.3.

Most TSO systems can be used in a “convertible” way and can be applied backward-facing for infants of up to 10 kg and forward-facing for infants / children as of 10 kg. Furthermore, they are foldaway systems. An exclusive TSO approval only allows the use of such CRD in aircraft.

The following figures give an example of a TSO child seat:

Figure 3-16: CRD 2000 PlaneSeat, backward-facing configuration for infants of less than 10 kg

Figure 3-17: 2000 PlaneSeat, forward-facing configuration for infants / children of 10 kg to 18 kg

TSO-C100b approved CRD meet the biomechanical standards for the restraint of infants / children. The approval includes a roll-over test and dynamic tests with dummies as well as the evaluation of the test results by means of acknowledged dummy protection criteria. The dynamic tests are carried out on a test seat (in accordance with SAE AS5276/1) with a 2-point lap belt (aircraft lap belt).

The belt angle is not examined explicitly regarding the CRD forward displacement. The belt anchorage points, however, are positioned relatively far forward at the test seats for the dynamic test, 117 mm in front of the Cushion Reference Point and 76 mm below it. This means that a relatively unfavourable lap belt angle is taken into account in the dynamic tests (cf. chapter 2.2.2).

The dummy head must not exceed a maximum forward displacement in the dynamic tests. In the cabin layout, however, the distance to the seat in front can be smaller. In the use of TSO CRD in aircraft, it can therefore not be ensured in principle that there is no head contact with the seat in front or the components of the cabin layout in a crash.

In accordance with TSO-C-100b, child seats without an own rigid backrest are not approved.

The geometric dimensions regarding the width between the armrests and the space to the seat in front are assessed for a specific installation of the CRD in a test fixture (in accordance with SAE ARP 4466). This test fixture represents the following peripheral conditions by means of two test seats positioned one behind the other:
- The width of the armrests is 16 inches (406 mm).
- The seat pitch of the test seats is 30 inches.
The specific installation for the CRD depicts the situation on a standard aircraft passenger seat in the ECO class (cf. chapter 2.2). In today's cabin layouts, however, it is also possible to have smaller widths ("narrow ECO class seats") and smaller seat pitches. This means that it must be taken into account when placing TSO child seats that seats which do not correspond to the above peripheral conditions are not practicable in the cabin layout.

The attachment of the CRD is also investigated on the test seat (in accordance with SAE ARP 4466), using a defined lap belt with lift-lever buckle and checking two different belt anchorage points. One belt anchorage point is close to the Cushion Reference Point (approx. 23 mm in front of it and approx. 23 mm below it), and the second belt anchorage point is approx. 133 mm in front of, and 8 mm below the Cushion Reference Point). The lap belts in cabin layouts have different length dimensions; this is not taken into account in the TSO. The position of the lift-lever buckle on the CRD is affected by the position of the belt anchorage points and the belt length, i.e. in practise, there are different buckle positions (cf. chapter 2.2.1.2) which can lead to the situation that the CRD cannot be fastened.

<u>Summarising assessment</u>

TSO C-100b approved child seats are practicable for the restraint of infants / children in aircraft to a limited extent.
Installation tests are carried out for a "standard installation" in the ECO class regarding the geometric dimensions. It must be ensured in the respective cabin layouts that the available space is not smaller.

With regard to the lap belt attachment, it is not ensured that the CRD can be safely attached to different aircraft passenger seats. Different lap belt lengths and unfavourable belt anchorage point positions can cause problems in practise.
A head contact of the infant / child with aircraft parts cannot be precluded.

		Evaluation	Explanations
Current situation	Safety	-	+ The biomechanical standards for the restraint of infants / children are met. + A relatively unfavourable belt angle is taken into account at the TSO test seat for the dynamic test. - It is not ensured with the TSO approval that there is no head contact with the seat in front or with components of the cabin layout.
	Operational practicality	-	- The correlation of the geometric dimensions of the CRD and the aircraft passenger seat is only investigated for one aircraft passenger seat constellation (the variance of real aircraft passenger seats is not taken into account). - The attachment of the CRD is only investigated with one lap belt geometry (the variance of real lap belt lengths and anchorage point positions is not taken into account).
Potential for safe transport		+	It is possible to use TSO systems, taking account of the respective cabin situation. For this purpose, however, additional procedures are required which ensure the practicality (geometric dimensions, attachment, functionality under emergency landing conditions) of the investigated CRD model on the respective aircraft passenger seat.

[+ acceptable / - not acceptable]

3.2.1.4 Dual child auto/aviation seat according to the draft IMPCHRESS CRD specification

Pursuant to this draft proposal, it will be possible to qualify automotive child restraint devices for use in aircraft as well as CRD for exclusive use in aircraft.

This draft proposal distinguishes two types of CRD:

<u>Class A systems,</u> can be used in all flight phases, during take-off, landing and in turbulence,

<u>Class B systems,</u> must be used only during the flight, e.g. in turbulence.

<u>Class A systems</u> can be designed as backward-facing CRD or as forward-facing CRD.

Class A systems meet the biomechanical standards for the restraint of infants / children. A roll-over test and dynamic tests with dummies are carried out. It is not possible to evaluate the test results since there are no evaluation criteria available, and the protection criteria have been assigned incorrectly.

Class A systems are subdivided into child seats which are attached to the passenger seat (add-on child seats) and into child seats which are placed or attached in another way (e.g. a CRD attached to a bulkhead, CRD supported on a floor-mounted pedestal etc.).

Add-on CRDs are fastened with the lap belt to a test fixture in the dynamic test and are occupied by a child dummy. The test fixture consists of three test seats placed one behind the other (seat pitch 30 inches). The CRD is fastened on the test seat in the middle. An adult dummy (77 kg) is fastened with the lap belt on the test seat behind it. The specified test configuration is out of touch with reality and does not allow an objective evaluation of the CRD.

The belt angle is not examined explicitly. The belt anchorage points are 55 mm in front of the Cushion Reference Point (CRP) at the test fixture for the dynamic test. The belt anchorage point at the aircraft passenger seat, however, can be up to approx. 120 mm in front of the CRP (cf. chapter 2.1.2). The belt angle should therefore be investigated additionally on the respective aircraft passenger seat when attaching the child seats.

Such Class A systems with a seat pan in principle provide a survival space for the infant / child. If CRD are not equipped with a rigid backrest, the survival space can be reduced to an unacceptable extent by a "break-over" backrest of the aircraft passenger seat, e.g. in impact shield systems without a rigid backrest. If CRD without a rigid backrest are used on limited break-over aircraft passenger seats, it must therefore be investigated whether a sufficient survival space is left.

The geometric dimensions regarding the width between the armrests and the space to the seat in front are assessed for a specific installation of the CRD in a test fixture (in accordance with SAE ARP 4466). This test fixture represents the following peripheral conditions by means of two test seats positioned one behind the other:
- the width of the armrests is 16 inches (406 mm)
- the seat pitch of the test seats is 30 inches.

The specific installation of the CRD depicts the situation on a standard aircraft passenger seat in the ECO class (cf. chapter 2.2). In today’s cabin layouts, however, it is also possible to have smaller widths ("narrow ECO class seats") and smaller seat pitches. This means that it must be taken into account in the placing of child seats that seats which do not correspond to the above peripheral conditions are not practicable in the cabin layout.

The attachment of the CRD is also investigated on the test seat (in accordance with SAE ARP 4466), using a defined lap belt with lift-lever buckle and testing two different belt anchorage points. One belt anchorage point is close to the Cushion Reference Point (approx. 23 mm in front of it and approx. 23 mm below it), and the second belt anchorage point is approx. 133 mm in front of, and 8 mm below the Cushion Reference Point. The lap belts in cabin layouts have different length dimensions; this is not taken into account in this investigation. The position of the lift-lever buckle on the CRD is affected by the position of the belt anchorage points and the belt length, i.e. in practise, there are different buckle positions (cf. chapter 2.2.1.2) which can lead to the situation that the CRD cannot be fastened.

Class A child seats which are placed or attached in another way are additionally investigated in the study.
For the dynamic test, these systems are mounted on a test fixture as specified by the manufacturer. The head and knee excursion path is determined in the test with forward-facing CRD in order to define a required space envelope in the aircraft.

Class B systems can also be simple belt systems. It cannot be assumed in principle that Class B systems must be attached to an individual seat. An individual survival space for the infant / child is thus not ensured. Nor can a head contact with components in the cabin be precluded. A dynamic test with biomechanical protection criteria is not specified for Class B systems but only static tests with so-called “body blocks”. The specified “body blocks” do not correspond to the dimensions of infants / children and are therefore not suitable for the investigation of a restraint system for infants / children. The specification assumes that accelerations of up to 2g are effective in turbulence. In today’s passenger aircraft, accelerations of up to 6g are to be expected.
Class B systems must not be used during take-off and landing, they are only practicable during the flight (e.g. in turbulence).

Summarising assessment

Class A systems which are investigated in accordance with the IMPCHRESS study for aircraft use are not suitable with regard to a restraint effect on aircraft due to absent and incorrectly attributed protection criteria.
Installation tests are carried out for a "standard installation" in the ECO class regarding the geometric dimensions. It must be ensured in the cabin layout that the available space is not smaller.
As regards the attachment with the lap belt, it is not ensured that the CRD can be safely attached to different aircraft passenger seats. Different lap belt lengths and unfavourable belt anchorage point positions can cause problems in practise.

Class A system		**Evaluation**	**Explanations**
Current situation	**Safety**	**-**	+ The biomechanical standards for the restraint of infants / children are met. - It is not possible to evaluate the test results since there are no evaluation criteria available, and the protection criteria have been assigned incorrectly. - The test configuration is out of touch with reality.
	Operational practicality	**-**	- The correlation of the geometric dimensions of the CRD and the aircraft passenger seat is only investigated for one aircraft passenger seat constellation (the variance of real aircraft passenger seats is not taken into account). - The attachment of the CRD is only investigated with one lap belt geometry (the variance of real lap belt lengths and anchorage point positions is not taken into account).
Potential for safe transport		**-**	The study is not conclusive with respect to the test configuration and the protection criteria. This proposal for the qualification of child restraint seats is thus considered to be unsuitable.

[+ acceptable / - not acceptable]

Class B systems are not further examined here due to the limited operational practicality (not during take-off and landing).

3.2.2 Child Restraint Devices

3.2.2.1 Supplementary loop belt

The loop belt is a restraint system for infants (up to 2 years) used for double occupancy of the passenger seat. The infant is seated on the lap of an adult and is fastened with the “supplementary loop belt”. The loop belt is attached to the lap belt of the seat by means of a connecting loop before the adult fastens him or herself. Thereupon, the infant is seated on the lap of the adult and the loop belt is placed around the infant, is plugged together and pulled tight. The infant is fixed on the lap of the adult (cf. Figure 3-18).

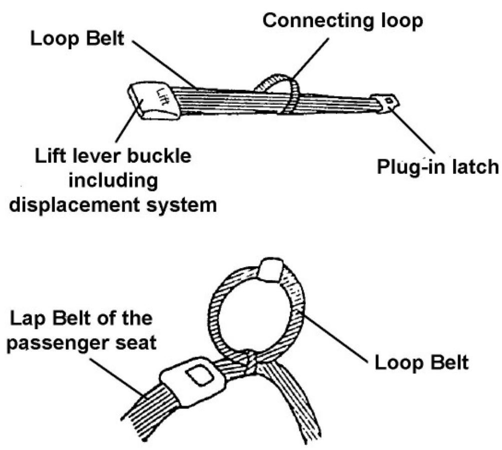


Figure 3-18: Infant seated on the lap of an adult
fixed with a "supplementary loop belt"

The loop belt is derived from the normal lap belt (width, material, buckle). The normal lap belt is designed to support the webbing on the iliac crest of the adult. In biomechanical terms, the adult is restrained by the lap belt over his or her iliac crest in an accident (cf. section 2.1.1). In infants, however, the iliac crest is not yet fully developed. The loop belt therefore rests by almost 100 percent within the infant’s abdominal region. The induction of forces into the abdominal region of the infant results in extremely serious internal injuries.

For this reason, the loop belt is <u>no</u> safety system for infants in turbulence, aborted take-off, hard landing, in emergency landing conditions and other accidents.

Furthermore, the infant is seated within the adult's excursion path. Dummy tests in emergency landing dynamic conditions illustrate the situation of an infant fixed with a loop belt on the lap of an adult. They show the following pattern:

Both occupants perform a translational forward movement towards the effective forces. 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 it fold up in a forward movement.

The inertia forces resulting from the mass of the infant and the effective accelerations affect the abdomen of the infant via the loop belt. Since the abdomen cannot induce exterior forces, the loop belt drives into the soft parts. The infant is additionally loaded by the pressure of the downward movement of the adult's upper torso and his or her femurs hitting upwards. The loop belt drives through the infant's abdomen and only stops at the vertebral spine.

The adult hits onto the infant. The infant is pushed through the legs of the adult and hits onto the floor.

Infants fixed with a loop belt suffer extremely serious to fatal injuries due to their position within the adult's excursion path and due to the restraint method

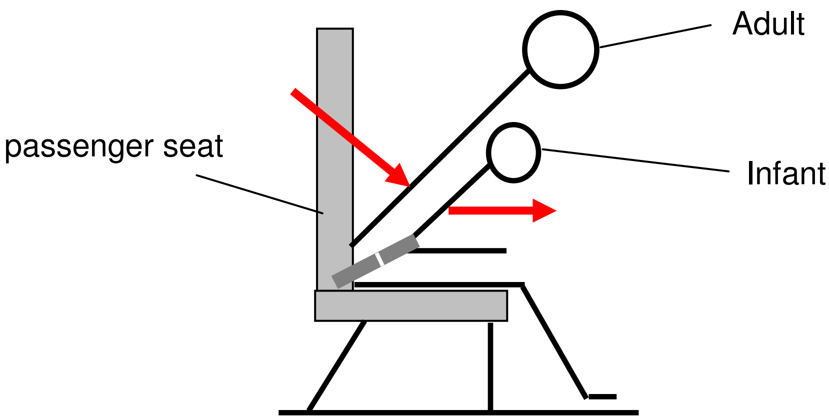


Figure 3-19: Movement pattern in an accident simulation

Summarising assessment

There are no restrictions for the loop belt in view of the operational practicality on different aircraft passenger seats (dimensions and attachment).

From the aspect of passive safety, however, the loop belt is not a suitable method to transport infants. In several countries such as e.g. the USA and Canada the loop belt is not permitted. Also e.g. in Germany, the use of the loop belt was not permitted before the introduction of EU-OPS (before 16 July 2008).

		Evaluation	Explanations
Current situation	**Safety**	-	- In biomechanical terms, the loop belt is not a suitable restraint system for infants. - The loop belt rests by 100 percent within the infant's abdominal region. The induction of forces into the abdominal region of the infant results in extremely serious internal injuries. - The infant is seated within the adult's excursion path; the adult folds up above the infant.
	Operational practicality	+	+ The infant does not require a seat of his or her own (double occupancy). + No booking expenditure (no special seat).
Potential for safe transport		-	The infant does not have his or her own survival space. The basic structure of the loop belt induces the forces directly into the infant's abdominal region, therefore there is no potential for an enhancement of the restraining effect.

[+ acceptable / - not acceptable]

3.2.2.2 Aircraft passenger seat lap belt

The aircraft passenger seat lap belt mainly consists of a rigid webbing, an adjustable webbing and the lift-lever buckle. The webbing has a width of approx. 50 mm. The length dimensions of the lap belts are not defined uniformly i.e. the length of the rigid webbing differs; so the position of the lift-lever buckle of a fastened and tightened lap belt can vary strongly.

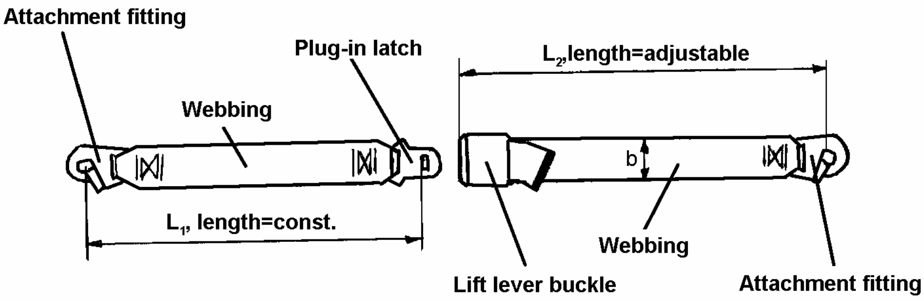


Figure 3-20: Aircraft passenger seat lap belt

The design specification demands for adults that the lift-lever buckle must be located in the centre, which means that the rigid part of the lap belt is relatively long. In practice, the following situation can arise for small / slender persons or children. It is possible to fasten the lap belt and to lock the buckle, then the belt is pulled tight, with the buckle moving to the side up to the stop. The lap belt is still not pulled tight, i. e. the belt lies loosely on the lap of the occupant who is not correctly fastened. In case of emergency, a loose belt leads to substantial additional loads on the occupant. Due to the lateral position of the lift-lever buckle, a life-threatening fracture of the iliac crest can be caused. The restraint effect is strongly dependant on the belt angle and thus on the position of the belt anchorage points in the x-direction.

If a lap belt is used, the upper torso is not restrained in a front impact. The child shows a pronounced jack-knife effect. The upper torso and the lower part of the body move relatively towards each other around a joint axis. In high decelerations the child can hit against his or her own extremities with his or her head. In the further course of the jack-knife movement, the head moves on between the opening legs and can hit against the rigid seat structure.

In children, the iliac crest is not fully developed; i.e. almost 2/3 of the belt width lies within the abdominal region of the child. In the course of an accident, the belt slips completely into the abdominal region which leads to severe internal injuries.

The aircraft passenger seat lap belt is not suitable for the restraint of infants / children for the specified reasons.

Figure 3-21: Child dummy (P6) fastened with an aircraft passenger seat lap belt

A restraint of children with a lap belt alone should only be used for children aged at least 7 years or with a body length of more than 125 cm. Regarding the body length, older and taller children constitute an interface to the adult. The starting point for an enhancement of passive safety is thus not the use of a child restraint device but rather the optimisation of the aircraft passenger seat especially for smaller occupants (belt geometry, head impact area etc.). The expression of "smaller occupants" does not only refer to children but also includes small adults.

Summarising assessment

There are no restrictions for the adult lap belt regarding its handling. However, it cannot be ensured that the lap belt can be pulled tight at all times.

From the aspect of passive safety, the adult lap belt is not a suitable method to restrain infants and smaller children. It should be used at the earliest for children aged approx. 7 years or with a body length above approx. 125 cm.

		Evaluation	Explanations
Current situation	**Safety**	-	- The standard lap belt is not suitable for the restraint of infants and smaller children; two thirds of the belt width lies within the abdominal region. It should be used at the earliest for children aged approx. 7 years or with a body length above approx. 125 cm. - The lap belt cannot be pulled tight sufficiently at all times.
	Operational practicality	+	+ No restrictions regarding the required space on an aircraft passenger seat.
Potential for safe transport		-	The aircraft passenger seat lap belt is not suitable for the restraint of infants / smaller children. It provides no potential for the safe restraint of infants and smaller children. Note: The lap belt can be used to fix / attach specific child seats to the aircraft passenger seat.

[+ acceptable / - not acceptable]

3.2.2.3 Child safety device CARES

CARES by the manufacturer AM Safe Aviation is an additional belt system for infants and children of 10 to 20 kg especially developed for aircraft use. It is allowed for all flight phases (take-off, landing and turbulence).

The device is approved in the USA in accordance with 14CFR 21.305 (d) and is furnished with the following label: “FAA approved in accordance with 14 CFR 21.305 (d) approved for aircraft use only“.

14 CFR 21.305 (d) reads as follows:

> **§ 21.305 Approval of materials, parts, processes, and appliances.**
> Whenever a material, part, process, or appliance is required to be approved under this chapter, it may be approved.
> (d) In any other manner approved by the Administrator.

14 CFR 21.305 does not define approval instructions for CRD; they are approved on the basis of tests and proofs which are agreed with the approval authority. The FAA certifies the CARES system as an "Equivalent Level of Safety (ELOS) to TSO-C100b”.

The use of CARES requires the infant / child to be seated on his or her own seat. The device consists of the shoulder belts, an additional belt around the aircraft passenger seat backrest and the lap belt of the aircraft passenger seat. The shoulder belts are sewn up with the additional belt and are looped in at the lap belt (cf. Figure 3-22).

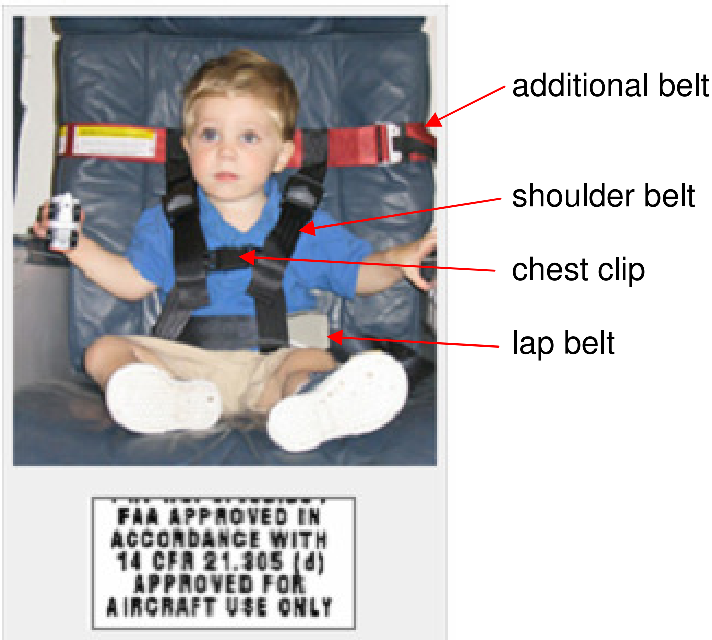


Figure 3-22: Child fastened with CARES

The infant / child is fastened according to the following steps:

- Place the additional belt around the backrest of the aircraft passenger seat and pull it tight.
- Place infant / child on the aircraft passenger seat.
- Thread in the standard lap belt of the aircraft passenger seat into the lower loops of the shoulder belts. Fasten the lap belt and pull it tight.
- Fasten the chest clip.
- Pull the shoulder belts tight.

The restraint is effected by the standard lap belt (available on the aircraft passenger seat) and an additional static shoulder belt part. The shoulder belt anchorage is a single belt which is laid around the backrest of the aircraft passenger seat above the infant's / child's shoulder level.

The standard lap belt is not suitable for the restraint of infants / children due to its belt width. In infants / children, the iliac crest is not fully developed; i.e. almost 2/3 of the belt width is within the abdominal region of the infant / child. In the course of an accident, the belt slips completely into the abdominal region which leads to severe internal injuries. The shoulder belts looped in at the lap belt facilitate the slipping up of the lap belt into the abdominal region additionally.

For the standard lap belt there are no specifications with regard to the lengths, neither for the rigid, non-adjustable part of the lap belt nor for the adjustable part facing the buckle. The design specification demands for adults that the lift-lever buckle must be located in the centre, which means that the rigid part of the lap belt is relatively long. Therefore, the belt can often be put on small, slim persons or infants / children, but it cannot be pulled tight, i.e. the belt remains loose. Due to the lateral position of the lift-lever buckle, there may be a life-threatening fracture of the iliac crest. The restraint effect is strongly dependant on the position of the belt anchorage points in the x-direction and thus on the belt angle.

The shoulder belt anchorage by the additional belt only works in non-breakover seats, since otherwise there is no rigid backrest available. In the height level in which the additional belt is laid around the aircraft passenger seat backrest, aircraft passenger seats are strongly contoured, which means that the additional belt does not contact the backrest. Due to the absent vertical fixing of the additional belt, it is pulled downward in deceleration. These effects cause a pronounced slack belt and thus a low restraint effect.

Summarising assessment

With respect to the required space on an aircraft passenger seat, there are no restrictions for CARES. However, it cannot be ensured that the adult lap belt can be pulled tight at all times. In strongly contoured backrests, the additional tether is spanned over the backrest and the infant / child lies with his or her head or neck region on the spanned belt and not on the backrest itself.

From the aspect of passive safety the CARES system is not a suitable method to restrain infants / children. The required belt geometry is not ensured and the adult lap belt, being a component of the CRD, is not suitable for the safe restraint of infants / smaller children.

		Evaluation	Explanations
Current situation	**Safety**	**-**	- The standard lap belt is not suitable for the restraint of infants / smaller children due to its belt width (two thirds of the belt width are within the abdominal region). - There is no vertical attachment for the additional belt around the backrest of the aircraft passenger seat which leads to a pronounced slack belt. - Aircraft passenger seats with a break-over backrest do not ensure the restraint effect by the shoulder belts.
	Operational practicality	**-**	+ With respect to the required space on an aircraft passenger seat, there are no restrictions. - The lap belt cannot be pulled tight sufficiently at all times. - In strongly contoured backrests, the additional tether is spanned over the backrest and the infant / child lies with his or her head or neck region on the spanned belt.
Potential for safe transport		**-**	The main component of the CRD is the adult lap belt which is not suitable for the restraint of infants / smaller children (cf. section 2.1.1).

[+ acceptable / - not acceptable]

3.2.2.4 Built-in Child Restraint Device

In contrast to CRD which are placed on an aircraft passenger seat (add-on systems), it is also possible to equip specific seats in the cabin layout with a so-called built-in CRD. The adult seat can be adapted to the specific needs regarding the restraint of infants / children. These concern e.g. a backward-facing seating position for infants and a belt restraint system adequate for infants / children. Figure 3-23 gives an example for a prototype of an aircraft passenger seat with a built-in CRD.

Figure 3-23: Functional model of a child restraint device integrated into an aircraft passenger seat by Lufthansa Technik
(source: Aircraft interiors Expo, Hamburg, 2008)

Built-in systems which have already been approved for aircraft use are not known so far. CRD integrated in the car seat are offered by various automotive manufacturers. These systems are forward-facing systems.

Built-in CRD are especially designed for the transport of infants /children and children in aircraft. The infant / child development must be taken into account with regard to biomechanics (restraint principle and protection criteria) and the function in the course of an accident (cf. section 2.1). The safe restraint of the infant /child must be proven by means of dynamic tests and be evaluated by means of acknowledged dummy protection criteria

At present, there are no approval provisions available for built-in CRD in aircraft. An approval could be achieved on the basis of the standards of TSO C-100b, ECE-R 44 or FMVSS 213. The respective standards must be defined in the EU-OPS for flight operation.

Since built-in CRD are designed in conjunction with the aircraft passenger seat, there are no problems of compatibility regarding the geometric dimensions and the attachment to the aircraft passenger seat.

Summarising assessment

Built-in CRD provide a high potential for a safe transport of children in aircraft and can be a good alternative to add-on CRD. At present, there are no approval and operating instructions for this type of systems available.

		Evaluation	Explanations
Current situation	**Safety**	**N/A**	A detailed system does presently not exist.
	Operational practicality	**N/A**	A detailed system does presently not exist.
Potential for safe transport	**Safety**	+	+ The prerequisite is the consideration of the biomechanical requirements for the restraint of infants / children and the respective approval criteria.
	Operational practicality	+	+ Due to the construction directly with/at the aircraft passenger seat, operational problems are not to be expected.

+ acceptable / - not acceptable / N/A not applicable]

3.2.3 Procedures for the transport of infants / children in aircraft

3.2.3.1 Lap Holding

In the “lap holding”, the infant (aged up to 2 years) is seated on the lap of an adult without restraint. The adult him or herself is fastened to the aircraft passenger seat with the lap belt and holds the infant with his or her hands.

Figure 3-24: Lap Holding

The underlying problem of the “lap holding” is the fact that the adult is not able to hold the infant in sudden accelerations. In a crash, the infant is weighing much more than it normally weighs (approx. 16 times more, cf. CS 25.562 “emergency landing dynamic conditions”), i.e. an infant of 11 kg is pulled out of the hands of an adult at a force of approx. 1730N (≈176kg).

In turbulence, accelerations in aircraft reach up to 6 g. Normally, the passengers are caught off guard. An infant of 11 kg is pulled out of the hands of an adult at a suddenly effective force of approx. 650N (≈66kg).

Even in prepared conditions, an adult is not able to hold the infant on his or her lap. The infant is thus not fixed on its seat and moves through the cabin without control. As a consequence, the infant is likely to suffer extremely serious injuries. Other passengers are endangered by the “freely flying” infant.

Also an evacuation by the adult can be problematic since the adult must look for the infant in the cabin. Other passengers can be obstructed in their evacuation.

<u>Summarising assessment</u>

Additional aids are not necessary for the “lap holding”, with no restrictions (dimensions and attachment) resulting from this in view of the practicality on different aircraft passenger seats.

From the aspect of passive safety the "lap holding" is not a suitable method to transport infants.

<table>
<tr><th colspan="2"></th><th>Evaluation</th><th>Explanations</th></tr>
<tr><td rowspan="2">Current situation</td><td>Safety</td><td>-</td><td>- No restraint device
- The infant is not restrained.
- The adult is not able to hold the infant in emergency landing conditions and in turbulence.</td></tr>
<tr><td>Operational practicality</td><td>+</td><td>+ The infant does not require a seat of his or her own (double occupancy)
+ No booking expenditure (special seat).
+ No additional aids needed</td></tr>
<tr><td colspan="2">Potential for safe transport</td><td>-</td><td>From the aspect of passive safety, the transport of infants without restraint cannot be tolerated.</td></tr>
</table>

[+ acceptable / - not acceptable]

3.2.3.2 Qualification Procedure for Child Restraint Systems for Use in Aeroplanes (TÜV/958-01/2001)

The procedure specified in the "Qualification Procedure for Child Restraint Systems for Use in Aeroplanes" serves the qualification of CRD for use on specific aircraft passenger seats in commercial aircraft.

The qualification of a CRD is based on the CRD verification of suitability by the manufacturer and the specification of seat configurations by the aerospace company. The qualification is aimed at defining the seats in an aircraft which are suitable for the use of the qualified CRD.

The qualification procedure is to ensure that the use and the function of the CRD on a specific aircraft passenger seat are guaranteed given proper use.

In accordance with this procedure, CRD are qualifiable which
- are approved for use in motor vehicles in accordance with ECE-R44
- are approved in accordance with FMVSS 213 for use in motor vehicles and aircraft
- or which are approved in accordance with an adequate aviation-specific CRD standard.

The qualification assesses each seat in a cabin layout with regard to the CRD practicality. The evaluation encompasses the following aspects:

- Additional proof of strength only using the lap belt for CRD which are approved only for anchorage by means of three-point seat belts.
- For inflatable CRD, proof that following a sudden cabin pressure loss at maximum altitude of the aeroplane, the function of the CRD is still ensured down to sea level.
- An aviation-specific installation and operational instruction for the CRD must be available.
- Correlation of the dimensions of the CRD with the characteristic dimensions of the seating configuration(s)
- Inspection of secured and fixed anchoring of the CRD on the (different) passenger seats by means of the adjustable test seat under consideration of the differences concerning the position of the belt anchoring points as well as the safety belt systems. It is also possible to use the ISOFIX attachment.
- Investigation concerning contact between the head of the dummy and the contour. For forward-facing CRD: Correlation between the head excursion path and the seating configuration(s) to preclude head contact with structural parts.
  For rearward-facing CRD: Contact of the head with the surrounding structure must be precluded.
- Assessment of the survival space for the use of a forward-facing CRD without a rigid backrest on a limited breakover passenger seat.

Technical CRD standards for use in aircraft are investigated within the qualification procedure. The CRD tested in this way receive a label with an unambiguous ID number. These CRD with their ID number are investigated with regard to their practicality in the respective cabin layouts of the airlines.

CRD which are qualified in accordance with the German procedure "Qualification Procedure for Child Restraint Systems for Use in Aeroplanes" meet the biomechanical standards for the restraint of infants / children. The qualification requires the proof of a roll-over test and dynamic tests with dummies as well as the evaluation of the test results by means of acknowledged dummy protection criteria.

To assess the function of the CRD in a crash, the specific installation of the CRD in the cabin layout is taken into account in the qualification. The airline obtains a “seat map” for each of their cabin layouts with the unambiguous allocation of seats on which the respective CRD can be used.

With respect to the evacuation, the qualification procedure in principle precludes specific seats in the cabin layout. These include the same exceptions as specified in the ACJ OPS 1.730 (a)(3) (cf. section 2.1.3).

Summarising assessment

The qualification investigates whether the tested CRD and the respective aircraft passenger seat are compatible. This encompasses, amongst others, the geometric dimensions, the attachment of the CRD to the aircraft passenger seat with the lap belt (or, if applicable, of another attachment system) as well as the infant / child head excursion path.

The qualification of the CRD with the respective seat map (cabin layout) ensures that such CRD can be used on specific seats safely and without problems.

		Evaluation	Explanations
Current situation	**Safety**	+	+ CRD qualified in accordance with this procedure meet the biomechanical standards for the restraint of infants / children. + The qualification requires the evidence of a roll-over test, dynamic tests with dummies and the evaluation of the test results by means of acknowledged dummy protection criteria. + It is ensured that there is no head contact within the installation.
	Operational practicality	+	+ The qualification assesses each seat in a cabin layout with regard to the operational practicality of the envisaged CRD (geometric dimensions, attachment, functionality in emergency landing conditions). + The tested CRD receive a label with an unambiguous ID number. + A seat map is prepared for the respective cabin layout. The seat map clearly indicates on which seats the respective CRD can be used.
Potential for safe transport		+	It is possible to derive specifications for building / operating instructions from this procedure.

[+ acceptable / - not acceptable]

3.2.4 Summarising evaluation of the solutions

The evaluation of the solutions with regard to safety and operational practicality provide the following picture:

The transport of unrestrained infant lap-holding and infant restraint by a supplementary loop belt is classified as unacceptable from a biomechanical point of view.

CRD approved for motor vehicles meet the biomechanical standards in principle. CRD approved in accordance with ECE-R 44, FMVSS 213 or CMVSS 213/213.1, however, do not take the aspects of the cabin layout into account to a sufficient extent. This concerns the function of the CRD in the course of the accident with regard to the forward displacement and the head contact as well as the operational peripheral conditions such as the correlation of the geometric dimensions and the attachment of the CRD to the aircraft passenger seat. As a consequence, it is not ensured that the CRD fit on the respective aircraft passenger seat and can be properly attached. If the aviation-specific peripheral conditions are additionally taken into account, however, it is possible to use specific automotive CRD also in aircraft.

There is a similar situation for TSO C-100b approved CRD. In principle, these meet the biomechanical standards, in the course of an accident, however, a head contact of the infant / child in the cabin layout is not precluded. Regarding the correlation of the geometric dimensions between the aircraft passenger seat and the CRD, the TSO investigates an "exemplary" installation within the cabin layout on the basis of a defined test fixture, i. e. aircraft passenger seats on which TSO CRD are to be used must meet at least these peripheral conditions. The TSO also investigates the attachment of the CRD to the aircraft passenger seat by means of a lap belt on a defined test seat with a defined lap belt. In the practice, however, the lap belt lengths and the position of the belt anchorage points vary. The test seat configuration does not reflect this variance. i.e. it is not ensured with the TSO CRD either that the CRD fit on the respective aircraft passenger seat and can be properly attached. If the aircraft-specific peripheral conditions are additionally taken into account, however, it is possible to use TSO CRD also in aircraft.

Regarding the operational peripheral conditions and function in the course of an accident, automotive CRD and TSO CRD are to be completed by procedures which ensure a smooth use in the cabin layout. This is intended by the “Qualification Procedure for Child Restraint Systems for Use in Aircraft“. It assesses approved child restraint devices (motor vehicle approval or aircraft approval) regarding their operational practicality in the cabin layout. This procedure requires CRD compliance with the safety standards (biomechanics and function in a crash) and takes account of the criteria of operational practicality (correlation of the geometric dimensions and attachment to the aircraft passenger seat). The procedure also takes account of the evacuation aspects. The possible seats for use of the respective CRD are defined for each cabin layout which enables a safe transport of the infant / child.

The IMPCHRESS proposal outlines specifications for two different restraint systems. Class A systems are practicable in all flight phases, Class B systems are only practicable during the flight, e.g. in turbulence. Class B systems are not assessed further in this context since they are not practicable during take-off and landing. Class A systems are not suitable for aircraft use due to absent and incorrectly attributed protection criteria with regard to a restraining effect in aircraft.

From the aspect of passive safety, the adult lap belt is not a suitable method to restrain infants and smaller children. It should be used at the earliest for children aged approx. 7 years or with a body length above approx. 125 cm.

The CARES system developed by the AM-Safe Aviation is not a suitable method to restrain infants / children in aircraft from the aspect of passive safety. The required belt geometry is not ensured and the adult lap belt, being a component of the CRD, is not suitable for the safe restraint of infants / children.

Built-in CRD provide a high potential for a safe transport of children in aircraft. There are, however, no approval and operating instructions available for these systems. An approval could be achieved on the basis of the standards of TSO C-100b, ECE-R 44 or FMVSS 213. For flight operation, the respective standards must be defined in the EU-OPS.

It is obvious that the investigated solutions alone do not provide a sufficient solution for the safe transport of children. The safe use of child seats can only be ensured in combination with a procedure taking account of the peripheral conditions (both in technical and operational terms) in the cabin layout. The following table depicts the result for the respective solution.

Regarding evacuation, there are no sufficient statutory regulations for the placing of infants / children in CRD. In an evacuation, the infant / child must be released from the CRD by an attending person. However, this person must not hinder the evacuation of the other passengers, e.g. he or she must not stand in the escape route. To take account of these issues, the explanations relating to JAR-OPS 1.730, ACJ OPS 1.730(a)(3), should be taken into account (see section 2.1.3). Regarding the evacuation, the CRD itself must provide a fast and easy means to release the infant / child from the CRD. During an evacuation, the restraint system should remain installed on the passenger seat and only the occupant should be removed from the aircraft.

Overview of the evaluation results:

Solution	Evaluation		
	Basis of Evaluation	**Current Situation**	**Potential for the Use of a Procedure**
Unrestrained infant lap-holding	Safety	-	-
	Operational practicality	+	+
Infant restraint by a supplementary loop belt	Safety	-	-
	Operational practicality	+	+
Child seats approved for use in motor vehicles according to the UN standard ECE R 44	Safety	-	+
	Operational practicality	-	+
Child seats approved for use in motor vehicles and aircraft according to US FMVSS No 213 (or Canadian CMVSS 213/213.1)	Safety	-	+
	Operational practicality	-	+
Child seats approved for use in aircraft according to TSO C-100b	Safety	-	+
	Operational practicality	-	+
Dual child auto/aviation seat according to the draft IMPCHRESS CRD specification <u>Class A Systems</u> for all phases of flight.	Safety	-	-
	Operational practicality	-	-
Aircraft passenger seat lap belt	Safety	-	-
	Operational practicality	+	+
Child safety device CARES	Safety	-	-
	Operational practicality	-	-
Design ideas for a passenger seat built-in child restraint device	Safety	**N/A**	+
	Operational practicality	**N/A**	+
Qualification Procedure for Child Restraint Systems for Use in Aeroplanes (TÜV/958-01/2001)	The “Qualification Procedure for Child Restraint Systems for Use in Aeroplanes” is a procedure and is only applicable with approved CRD		

+ acceptable / - not acceptable / N/A not applicable]

3.3 Costs

There are many different costs for the passengers and airlines arising from the use of CRD which depend on a large number of variable peripheral conditions. It is not possible to make a quantitative cost analysis within phase II of this study due to the complexity of the peripheral conditions and cost units specified below. It is, however, possible to make a qualitative analysis of the arising costs, taking account of the provision of the CRD by the passenger and / or the airline.

The lap holding or loop-belt respectively does not require an extra seat and therefore the costs incurred are insignificant. For this reason, we do not consider the lap holding and the loop belt further in the following analysis.

3.3.1 Peripheral conditions

1. Also infants aged up to 2 years get a seat of their own

2. All infants and children aged up to 7 years are transported in a suitable CRD

3. Provision of the CRD by the passenger or the airline

- The passenger brings an add-on CRD him or herself which is suitable in aircraft-passenger-seats and ensures its proper condition.
- The airline provides suitable CRD (add-on / built-in systems). The airline is in charge of the acquisition, availability, mounting / dismounting and the maintenance of the CRD.

4. Logistic and operational processes

The cost analysis of logistic and operational processes for the provision of child restraint devices by the airlines is very complex. It requires a broad database by airports and airlines as well as by their service partners. Furthermore, different scenarios must be set up for the solution of the logistic and operational tasks.

5. Ground times

It must be ensured with suitable procedures that a child restraint device fits on the aircraft passenger seat. Otherwise, there may be delays in boarding. Such delays would lead to an increase in costs.

3.3.2 Cost units

The cost units are subdivided into recurring and non-recurring costs.

3.3.2.1 Non-recurring costs

These cost units are subdivided into:

- Purchase (passenger / airline)

  Costs for the purchase of suitable CRD (add-on systems) by the parents or the airline.

- Fit check / qualification (Airline)

  Costs for a CRD fit check or qualification of cabin layouts with CRD (TÜV Qualification Procedure).

- Adaptation of the booking systems (Airline)

  Costs for changing the booking and operation software.

- Training (Airline)

  Costs for additional instructions or training of the cabin crew in the handling of child restraint devices.

- Infrastructure (Airline)

  Costs e.g. for means of storage and maintenance as well as for stowage or vehicles for the transport of child restraint devices to and from the aircraft.

3.3.2.2 Recurring costs

These cost units are subdivided into:

- Costs related to the seat (passenger)

  Costs for the seat to be additionally paid for infants aged up to 2 years.

- Rental costs for CRD (passenger)

  If no suitable CRD is available, it it possible to rent a CRD.

- Maintenance / repair (Airline)

  Costs for maintenance, repair and cleaning of child restraint devices (mainly personnel costs).

- Logistics (Airline)

  Depending on the operational process, logistic costs are incurred for providing the seat e.g. at the airport, in the cabin or at the stopover destinations.

- Additional weight (Airline)

  Depending on the operational process, costs due to additional weight are incurred. Firmly installed built-in systems or add-on systems which remain permanently in the aircraft increase fuel consumption.

3.3.3 Qualitative cost analysis

3.3.3.1 Provision of the CRD by the passenger:

Costs for the passenger

Non-recurring costs:	**Recurring costs:**
- Acquisition of a suitable CRD, if necessary	- Costs for a seat for infants aged up to 2 years - Rental costs for CRD, if necessary

Costs for the airline

Non-recurring costs:	**Recurring costs:**
- Fit check / qualification (if applicable) - Adaptation of the booking systems - Training of the cabin crew	- No costs

3.3.3.2 Provision of the CRD by the airline:

Costs for the passenger

Non-recurring costs:	**Recurring costs:**
- No costs	- Costs for a seat for infants aged up to 2 years

Costs for the airline

Non-recurring costs	**Recurring costs**
- Acquisition of suitable CRD - Fit check / qualification (if applicable) - Adaptation of the booking systems - Training of the cabin crew - Infrastructure	- Maintenance / repair - Logistics - Fuel costs (additional weight)

3.3.3.3 Result

<u>Provision of the CRD by the passenger:</u>

<u>Costs for the passenger:</u>

At present, it is possible to transport an infant aged up to 2 years on the lap of an adult at approx. 10 percent of the regular flight fare (infant ticket). If a CRD is used, the infant must have a seat of his or her own. Thus, additional costs are incurred to the parents for the seat of their infant. For children aged more than 2 years it is necessary already today to book and pay for a seat of their own (child ticket). On the average, these costs account for approx. 50 percent of the regular flight fare.

Another cost factor is the acquisition of a suitable child restraint device. Since it has been mandatory for a long time to transport children in a child restraint device in the car, it can be assumed that a child restraint device is available in the child's family. In a favourable case, this CRD can also be used on an aircraft passenger seat. In an unfavourable case, a suitable CRD must be rented or bought. If the various possible uses of a CRD (private cars, rented cars, aircraft) are included in the cost analysis, the expenditure for the acquisition can be assessed a small.

<u>Costs for the airline</u>

The so-called set-up of the qualitative cost analysis shows that costs are incurred to an airline for the fit check / qualification (to guarantee the operational processes), for the adaptation of the booking systems and for the training of the cabin crew. Related to the individual flight, such costs are non-recurring. The overall financial expenditure is to be assessed as insignificant

<u>Provision of the CRD by the airline:</u>

<u>Costs for the passenger:</u>

At present, it is possible to transport an infant aged up to 2 years on the lap of an adult at approx. 10 percent of the regular flight fare (infant ticket). If a CRD is used, the infant must have a seat of his or her own. Thus, additional costs are incurred to the parents for the seat of their infant. For children aged more than 2 years it is necessary already today to book and pay for a seat of their own (child ticket). On the average, these costs account for approx. 50 percent of the regular flight fare.

<u>Costs for the airline:</u>

If the airline provides the CRD, the purchase of a sufficient number of CRD as well as the set-up of an infrastructure for the storage and maintenance of the CRD must be taken into account for the non-recurring costs, besides the costs for a fit check / qualification, adaptation of the booking systems and training. Recurring costs are additionally incurred for the maintenance/repair (personnel costs) and the logistic distribution of the CRD. The set-up of a suitable infrastructure and the development of suitable logistic processes constitute a high cost potential. This becomes particularly clear when it is realised that an airline has to ensure the availability of fully functional CRD at several places. This means that it must be possible at several destinations to clean, maintain or store CRD. Furthermore, a sufficient number of CRD must be available at several destinations at all times. This requires logistic processes for the continuous coordination of the distribution and return of CRD.

It can be assumed that this involves a considerable expenditure for the airline. Furthermore, an increased fuel consumption is to be expected if CRD and/or built-in systems are permanently kept on board due to their additional weight.

Built-in systems have the advantage that they do not require an extra infrastructure. Additional development and approval costs are, however, incurred for their integration in the aircraft passenger seat.

Conclusion

The qualitative cost analysis shows that the use of CRD involves additional costs.

From economic aspects, the provision of the CRD by the passenger is to be considered as the favourite model. This is especially true if the passenger already has a CRD available which is suitable both for aircraft and passenger cars. If a new CRD is needed, the costs for purchase or rent can be assessed as low for the passenger, taking account of its various possible uses (private car, rental car, aircraft). The major matter of expense for the passenger is the seat which has to be additionally paid for infants. The expenses for fit checks, qualifications, software changes and training incurred to the airline under this peripheral condition can be assessed as low. Investments into the infrastructure and logistics are not necessary.

4 Regulatory Impact Assessment (Phase III)

The RIA is an evaluation of the pros and cons of an envisaged specification, taking into account various possible options to reach the expected social or safety goal, while quantifying as much as feasible their impact on all categories of affected sectors.

4.1 RIA Items

4.1.1 Purpose and intended effect

This study analyses the impact of such amendments by means of the “Regulatory Impact Assessment”, aiming at laying out the options and at examining their effects on safety, costs, logistics and social aspects. This is to gain an overview of the sectors concerned and to determine the most efficient solution.

Presently, the loop belt is an accepted restraint system for infants in aircraft in Europe.

The studies, test reports and accident analyses examined in phase I, however, come to the conclusion that the lap-held transport of infants restrained with or without a loop belt does not provide a safe restraint for the infant in the following scenarios: aborted take-off, runway overrun, turbulence and other accidents.

It is a crucial and generally accepted finding that infants’ and children’s safety being equivalent to adult’s safety is only possible by means of an extra seat and a appropriate CRD.

NTSB statement: “…Choosing to continue to exempt children under 2 from an adequate restraint requirement is then no different from granting a similar exemption for any other segment of the passenger population. Although ludicrous, exempting children under 2 is not functionally different from exempting passengers over 80 from a restraint requirement….”

Child restraint devices alone which are appropriate for children as examined in phase II, however, do not provide a sufficient solution for the safe transport of infants and children in aircraft. An equivalent safety for children and adults can only be achieved in combination with a procedure taking account of the outline conditions (both in technical and operational terms) of a CRD in the cabin layout and during evacuation.

4.1.2 Options

The following three options are analysed within this RIA:

4.1.2.1 Option 1: Do nothing

The regulations CS 25.785 (a), EU OPS 1.730 (a)(1) – (a)(3) are maintained without amendment.
The operator is thus committed to provide a seat and safety belts for each passenger older than two years as well as accepted CRD's for each infant younger than two years.

Double occupancy of seats is possible and is regulated by EU OPS 1.320 (b)(2) according to which the operator has to issue provisions in order to ensure that multi-seat occupancy is only possible on specific aircraft passenger seats and only by one adult and one infant. The infant needs to be restrained appropriately by a supplementary loop belt or another restraint system. The design and layout of the CRD required in EU OPS 1.320 and EU OPS 1.730 are only specified insofar as they need to be accepted by the "authority". The EU OPS do not give any further information about "accepted CRD".

4.1.2.2 Option 2: Add-on systems

This option provides the following:

- All passengers, including infants, need to have a seat of their own.
- Infants and Children aged up to 7 years shall only be transported on their own seat in an add-on CRD which is appropriate for their age group. Add-on systems are CRDs which are attached to an aircraft passenger seat.
- It must be ensured by a practicable procedure that the add-on CRDs fit on the respective aircraft passenger seats, can be attached safely and their functionality (safe restraint of the child) is ensured (e.g. by a "fit check"/qualification).

This option requires an amendment of CS 25/EU-OPS and ETSO C100b for add-on CRD for use in aircraft passenger seats.

The following provisions need to be amended:

a) CS 25.785(a)

Persons of all age groups are entitled to a seat of their own.

b) EU OPS 1.320(b)(2)

Persons of all age groups are entitled to a seat of their own.

Infants and children up to the age of 7 years need to be restrained in an accepted CRD.

c) EU OPS 1.730(a)(1)

Persons of all age groups are entitled to a seat of their own.

d) EU OPS 1.730(a)(3)

Infants and children up to the age of 7 years need to be restrained in a seat of their own with an accepted CRD. The operator must provide the possibility to use accepted CRDs in aircraft and must ensure their safe installation (e.g. by a "fit check"/qualification).

Accepted CRD should be ECE R 44, FMVSS 213 including Chapter 8, ETSO-C100b, TSO-C100b or an equivalent specific CRD standard.

Both the operators and the passengers accompanying the child can be responsible for providing the CRD.

This option likewise provides for the drawing-up of an annex to EU OPS 1.730 similar to the annex provided for in ACJ 1.730. This is to guarantee the smooth use of CRDs in the aircraft passenger cabin additionally by using a supplementary procedure. It is to asses approved child restraint devices (motor vehicle approval or aircraft approval) regarding their operational practicality in the cabin layout. This procedure requires CRD compliance with the safety standards (biomechanics and functionality in a crash) and takes account of the criteria of operational practicality (correlation of the geometric dimensions and attachment on the aircraft passenger seat). The procedure likewise has to take account of evacuation aspects. The possible seats for use of the respective CRD are defined for each cabin layout which enables a safe transport of the infant / child.

e) ETSO C100b

ETSO C100b reflects the TSO C100b. This standard needs to be adapted to the European conditions. This especially applies to the test seat, dummies and the related biomechanical pass-fail criteria (see ECE R44).

Variants: Two variants of this scenario are feasible, on the one hand the provision of the CRDs by the airline and on the other hand the provision of the CRD by the passenger. These variants are analysed with regard to the different impacts.

Variant 1: The airline provides the CRDs

This variant analyses the amendment of **OPTION 2** only in combination with the provision of the CRDs by the airline. Thus, the operator is solely responsible for the purchase, logistics, installation and maintenance.

Examples:

- The airline provides “aviation systems” in accordance with ETSO C100.
- The airline provides automotive systems in accordance with FMVSS 213 / CMVSS 213 / ECE-R44 03.

Variant 2: The passenger provides a CRD

In this variant, it is the passenger’s task to provide a CRD and to ensure the proper condition of the CRD. The operator has to inform the passenger as to which CRD types can be installed on the booked aircraft passenger seat (based on "fit check"/qualification) and is responsible for this area (geometric dimensions, attachment, seat pitch).

Example:

- The passenger provides a CRD system. For cost reasons and the possibility to use the CRD in the private car, only FMVSS-213 / CMVSS-213 / ECE-R44 03 systems are to be assumed as useful.

4.1.2.3 Option 3: Built-in systems

This option provides the following:

- All passengers, including infants, need to have a seat of their own.
- Children aged up to 7 years shall only be transported in a built-in CRD which is appropriate for their age group. Built-in systems are child seats integrated in the aircraft passenger seat.

This option requires an amendment of CS 25/EU-OPS and ETSO-C127a for the use of built-in systems in aircraft.

The following provisions need to be amended:

a) CS 25.785(a)

Persons of all age groups are entitled to a seat of their own.

b) EU OPS 1.320(b)(2)

Persons of all age groups are entitled to a seat of their own.

Infants and children up to the age of 7 years need to be restrained in an accepted CRD.

c) EU OPS 1.730(a)(1)

Persons of all age groups are entitled to a seat of their own.

d) EU OPS 1.730(a)(3)

Infants and children up to the age of 7 years need to be restrained in aircraft with built-in CRDs. The operator is responsible for the provision and safe use of built-in CRDs.

This option likewise provides for the drawing-up of an annex to EU OPS 1.730 similar to the annex provided in ACJ 1.730. This is to guarantee the smooth use of CRDs in the aircraft passenger cabin additionally by using a supplementary procedure. It is to assess the operational practicality of the CRD in the cabin layout. This procedure requires that the CRDs comply with the safety standards (biomechanics and functionality in case of a crash). The procedure likewise has to take account of evacuation aspects. The possible seats for use of the respective CRDs are defined for each cabin layout which enables a safe transport of the infant / child.

e) ETSO C127a

This ETSO should include a Minimum Performance Standard for the integration of built-in CRDs in an aircraft passenger seat which is oriented at the provisions ETSO C100, ECE-R44, FMVSS-213 and CMVSS-213.

ETSO-C127a should be supplemented as follows:

- Restraint criteria in accordance with the child's development (biomechanics)
- Static and dynamic test standards
- Buckle release test

4.1.3 Sectors concerned

The following sectors are directly concerned by the options:

- Passengers with infants and children
- Airlines
- CRD manufacturers
- EASA and national authorities

4.1.4 Surveys

The results of two surveys were used for the implementation of the RIA.

Passenger questionnaire

Passengers with infants and children were interviewed within a research project of the German BMVBS ("Examination for the Enhancement of the Cabin Safety of Infants"). This aircraft passenger survey was carried out at the airports of Düsseldorf, Cologne/Bonn and Frankfurt from July to September 1997. 365 adults were interviewed who were travelling with children aged up to 14 years. Due to cheaper ticket fares, more and more families with children use airplanes for their journeys. At the same time, people have an increased safety awareness. Thus, the results are valid until today. It has to be assumed that the parents' willingness to accept costs which are necessary for the safety of their children has even increased.

Airline questionnaire

The second survey was carried out in the course of this study. This survey addressed the airlines and focussed on including their findings, experiences and opinions regarding the topic “Transport of Children in Aircraft" in this study. Also the European airline associations were contacted within this survey and were asked for their support. A meeting was held at EASA with the representatives of the airline associations of IACA, AEA, ERAA and IATA. The associations introduced their comments with a revised questionnaire which was then sent to the respective association members (IACA, AEA, ERAA, IATA, ELFAA, EBAA and BDF: more than 120 members).

A total of 14 completed and evaluable questionnaires were returned by the airlines within the timeframe of this action. The AEA and BDF associations sent us the replies of their members in summary form.

4.1.5 Impacts

The following impacts influence the implementation of the options in the specified sectors.

- Safety
- Economic impacts
- Operation
- Social impacts
- Foreign comparable regulatory requirements
- Environmental impacts

Also equity and fairness issues were identified

4.1.5.1 Safety

JAA CSSG CRS WG Pre RIA for CRD: "…Although the need for an improved level of infant restraint in aircraft is not well supported by statistical data, especially in the case of commercial aircraft, and although few adults are killed in commercial accidents yearly, adults are required to be provided with a considerably higher level of turbulence and crash protection than that provided to infants. ..."

In the event of any impact-related emergency situation (such as emergency landing, aborted take-off, turbulence etc.,), the safety performance of a child restraint device must meet minimum performance criteria comparable to those of adults (taking account of the principle of equal protection irrespective of the age). With this assumption the actual occurrence rate of such emergency situations is not that relevant and does not need to be taken into account when establishing a safety scenario as long as their occurrence is realistic. Simply one day such a situation happens and in this given moment the child restraint device must "deliver" safety. A set of other "crashworthiness" requirements have also a low incident rate but are already part of airworthiness codes (e.g. ditching).

4.1.5.1.1 Option 1: Do nothing

Option 1 is unacceptable in terms of safety. Normally, infants (aged up to 2 years) are lap-held and are “restrained” with the loop belt. The loop belt rests by 100 per cent within the infant’s abdominal region. This may therefore lead to internal injuries even at relatively low accelerations such as e.g. in turbulence due to the restraint forces induced into the abdominal region of the infant. In the case of stronger accelerations (e.g. emergency landing conditions), severe up to fatal injuries are to be expected. From a biomechanical and medical point of view, it is known and accepted worldwide that forces must not be induced into the abdominal region of the human body. Research projects which were carried out independently of each other have shown that infants have a far lower safety level than adults. There is no study worldwide which specifies the loop belt as a safety device.

From an age of two years onwards, children are transported on their own seat and thus have their own survival space. They are not sitting within the adult’s excursion path any more. A safe transport, however, is not provided due to the lack of a restraint system which would be appropriate for children. The adult’s lap belt is not practicable for a safe restraint of smaller children (cf. phase II). It rests by 2/3 within the infant’s abdominal region. Under load, the belt slips into the infant's abdominal region causing internal injuries. Furthermore, it is not always possible to pull the adult’s belt tight enough, i.e. the child is not “tightly” fastened.

Provisions and approval standards covering the seat and belt system as well as brace positions exist for the restraint of adults. Compared to adults, there are currently no practical standards available with regard to restraint devices for infants and small children.

The “Certification Specifications for Large Aeroplanes CS 25” specify in principle the requirements with regard to passive safety for passengers. Pursuant to CS 25.785 (a), a seat must be provided for each occupant from the age of 2. This means that no own seat (survival space) is specified for infants (0 to 2 years). CS 25.785 (b) requires protection for emergency situations for each occupant in order to protect him or her from serious injuries. Furthermore, they require proof of compliance with static and dynamic tests (pursuant to CS 25.561 and CS 25.562) for aircraft passenger seats. The design of the seats and belt systems is based on a 77 kg occupant (50 percentile male). Aircraft passenger seats are normally approved pursuant to ETSO-C127a (Aircraft Seats and Berths); ETSO refers to SAE AS 8049b (Performance Standard for Seats in Civil Rotorcraft, Transport Aircraft and General Aviation Aircraft) defining static structural tests, fire tests and also dynamic tests. Maximum biomechanical loads for passengers are indicated for dynamic tests which must not be exceeded. These tests and tolerance limits, however, only relate to adult passengers and not to infants/children.

TSO C22g is especially implemented for the belt system, referring to SAE AS 8043. Also the SAE standards relate to the layout of the belt systems (e.g. width of the belt strap) only with regard to adults ("small adult female....large adult male").

The specific needs of infants / children are presently not taken into account for the approval of aircraft passenger seats and restraint systems in aircraft.

It is in principle possible to attach restraint systems appropriate for children additionally on the aircraft passenger seat or to integrate these into the adult aircraft passenger seat (see phase II). A standard for an adequate restraint of infants / children is not existing. Nor exist any provisions as to which technical standards a CRD needs to comply with in order to be admitted in aircraft (constructive provisions, test conditions, biomechanical tolerance limits for the occupant of a CRD, ...)

Children have another disadvantage compared to adults in emergency landing conditions, i e. the "brace position". Adult passengers can assume an adequate "brace position" on their seat. On forward-facing seats, they bend forward with their upper body and lay their head and hands against the backrest of the seat in front in order to minimise the effective loads. Due to their body length, small children are not able to assume the brace position of an adult. Therefore, the restraint is exclusively given by the adult lap belt, two thirds of which rest within the child's abdominal region. A brace position for a lap-held infant does not exist. Another hazard is the seating of the infant within the adult's excursion path.

This comparison of the present situation in the cabin with regard to adults and children makes it clear that children are put at a disadvantage compared to adults.

4.1.5.1.2 Option 2: Add-on systems

As an individual seat is required, the requirement for an individual survival space is fulfilled. For this option it is irrelevant whether or not the add-on CRD is provided by the airline or brought by the passenger. In both cases, a procedure ensures that the add-on CRD fits into the respective aircraft passenger seat, that it can be attached safely and that its functionality is ensured.

Standards are defined for the use of CRDs regarding their positioning in the cabin layout i.e. the CRD must not be positioned e.g. directly on the longitudinal or cross aisles or at direct accesses to the exits. Therefore, the children restrained in their CRDs as well as the persons attending them do not affect the other passengers during evacuation.

The following aspects are covered:

- The available adult aircraft passenger seat is "adapted" to the infant / child by a practical add-on-CRD.
- The restraint of the infant / child by the CRD taking account of the child’s development (biomechanics)
- The function of the CRD in case of a crash taking account of the specific installation
- Evacuation aspects

- Compatibility of the geometric dimensions of the aircraft passenger seat and the child seat
- Practicable attachment and release of the CRD from the aircraft passenger seat

Option 2 thus provides an equivalent safety of infants and children compared to adults' safety both in turbulence and in emergency landing conditions. It ensures a safe restraint which is appropriate for the child's age group (see phase II).

4.1.5.1.3 Option 3: Built-in systems

Built-in CRDs offer the advantage that they do not pose any compatibility problems due to their construction and approval in combination with the aircraft passenger seat, thus ensuring a firm and safe attachment of the CRD to the aircraft passenger seat.

Standards are also defined for built-in CRDs regarding their positioning in the cabin layout. i.e. the built-in CRDs are not positioned e.g. directly on the longitudinal or cross aisles or at direct accesses to the exits. Therefore, the children restrained in their CRDs as well as the persons attending them do not affect the other passengers during evacuation.

The following aspects are covered:

- The available adult aircraft passenger seat is "adapted" to the infant / child by a practical built-in CRD.
- The restraint of the infant / child by the CRD taking account of the child's development (biomechanics)
- The function of the CRD in case of a crash taking account of the specific installation
- Evacuation aspects

Option 3 thus provides equivalent safety for infants and children compared to adults' safety both in turbulence and in emergency landing conditions. It ensures a safe restraint which is appropriate for the child's age group (see phase II).

4.1.5.2 Economic

General

The following economic impacts are based on the data of the above mentioned airline questionnaire (chapter 4.1.3).

This questionnaire was carried out in the course of this study. A total of 14 completed and evaluable questionnaires were returned by the airlines. The data's of these questionnaires were complemented by more general inputs received from associations such as AEA and BDF to validate the following assumptions and improve the following economic models.

The different cost types are given for the sectors concerned for the cost accounting. The costs will be distinguished in recurring- and non-recurring-costs. Furthermore, a revenue calculation is carried out which takes account of the dynamic effects such as loss of passengers due to ticket fare increase and displacement of full-fare passengers by infants.

Option 1 is the benchmark for the cost-related analysis.

Cost types

- **Purchase**

  Costs incurred by the airline or passengers for the purchase of appropriate CRDs (automotive CRD, TSO CRD, built-in CRD). The selling price of the respective systems includes the costs for approval and development

- **Fit check**

  Costs incurred by the airline for a CRD fit check or qualification of the cabin layouts for CRDs (e.g. annex to EU OPS 1.730 similar to the annex in ACJ 1.730).

- **Adaptation of the booking systems**

  Costs incurred by the airline for changing the booking and operation software.

- **Training**

  Costs incurred by the airline for additional instructions or training of the cabin crew in handling child restraint devices.

- **Infrastructure**

  Costs incurred by the airline e.g. for storage and maintenance facilities.

- **Maintenance**

  Costs incurred by the airline for the maintenance, repair, cleaning and replacement of child restraint devices

- **Logistics**

  Logistic costs incurred by the airline for the provision of CRDs e.g. at the airport, in the cabin or at the "stop-over" destinations.

Dynamic revenue calculation

The dynamic revenue calculation takes account of the following dynamic effects:

- **Additional revenues due to ticket fare increase**

  Increase of ticket fares for infants and children (2 to 7 years) leads to additional revenues

- **Loss of passengers due to ticket fare increase**

  Increase of ticket fares for infants and children leads to losses in this category of passengers. In addition there will be a loss of attending parents for each infant and each child (2 to 7 years).

- **Displacement due to excess demand**

  Mandatory CRDs lead to a displacement of passengers by infants. Thus, the airlines suffer losses because an infant occupies a seat that could otherwise be sold to an adult at 100 per cent of the ticket fare.

- **Decrease of displacement**

  Loss of passengers leads to unoccupied seats. Due to excess demand these seats are partially resaleable to the above mentioned displaced passengers. 50 per cent (assumption) of the still displaced passengers will leave the airline.

Dynamic ticket fare calculation

The dynamic ticket fare calculation shows which means exist to achieve cost recovery. Since only infants and children (aged 2 to 7 years) benefit from the enhanced safety level, the costs are apportioned to them. The ticket prices for infants and children (aged 2 to 7 years) were equally increased in order to achieve an even cost burden for the families.

4.1.5.2.1 Airlines

Besides the costs incurred by the airlines for the different options revenues are generated by the sale of tickets. These costs and revenues are calculated as an example for one year for the individual options.

The costs incurred for possible spare CRDs and follow-up qualifications of new CRDs are taken into account. The exemplary calculations are carried out on the basis of the averaged data derived from the airline questionaire. The following fictitious airline was defined for this analysis:

- The airlines fleet consists of 35 aircraft (questionnaire)
- 7 airplanes share one cabin layout = 5 different cabin layouts within the airlines fleet (questionnaire)
- Layout changes every 3 years (questionnaire)
- Purchasing costs / CRD lifespan (assumption)

  - Automotive CRD: 20 CRDs per aircraft. CRD lifespan of 3 years, each year purchase of 2 exchange or replacement CRDs per aircraft
  - TSO CRD: 20 CRDs per aircraft. CRD lifespan of 4 years, each year purchase of 1 exchange or replacement CRD per aircraft
  - Built-in CRD: 25 CRDs per aircraft. CRD lifespan of 7 years, no exchange or replacement CRD necessary

  Less add-on CRDs than built-in CRDs are needed per aircraft since add-on CRDs can be exchanged between the aircraft as needed.

- Costs for fit check / qualification for automotive CRDs for a three-year period (change of layout). One fit check / qualification per year for 1 new CRD model (assumption)
- Aircraft load factor of 80 per cent (assumption)
- The airline transports 5,000,000 pax per year (questionnaire)

  Infants (0-2 years): 1.3% → 65,000 Infants per year (questionnaire)

  Children (2-7 years): 2.62% → 131,000 Children per year (questionnaire)

- Loss of Passengers due to ticket fare increase

  Linear ratio of ticket fare increase to loss of passengers 2:1 (passenger questionnaire).

  For example: The ticket fare increase amounts to 10 per cent → loss of passengers equals 5 per cent

- Displacement

  An annual 20 per cent of all flights have an excess demand.

  In the worst case, 20 per cent of the 65,000 infants occupy a seat that would otherwise be sold to an adult at 100 per cent of the ticket fare.

- Dynamic Ticket Fare Calculation

  Infant and child tickets are equally increased

- Adult ticket fare for European domestic flight € 250 (assumption)

Costs to the airline for the introduction of CRDs

	Option 2.1		Option 2.2	Option 3
	AUTOMOTIVE CRDs	TSO CRDs:	AUTOMOTIVE CRDs:	Built- In CRDs
Cost type	**[€]**	**[€]**	**[€]**	**[€]**
Purchasing	€ 50,000	€ 400,000	€ 0	€ 500,000
Fit check	€ 20,000	€ 15,000	€ 25,000	€ 0
Training	€ 15,000	€ 15,000	€ 15,000	€ 15,000
Adaptation of the booking system	€ 160,000	€ 160,000	€ 160,000	€ 160,000
Infrastructure	€ 106,000	€ 106,000	€ 0	€ 0
Maintenance	€ 86,000	€ 86,000	€ 0	€ 187,000
Logistics	€ 142,000	€ 142,000	€ 0	€ 0
Costs:	**€ 597,000**	**€ 924,000**	**€ 200,000**	**€ 862,000**

Option 1: Do nothing

Presently, the use of a loop belt or a CRD accepted by the authority is mandatory in aircraft. Due to its design, the use of the loop belt is the most favourable way of restraining a child in the aircraft both regarding the purchase and the other cost types. As an alternative to the loop belt, an airline can allow the passengers to bring their own automotive child seat. Presently, approx. 80 per cent of the interviewed airlines permit the use of automotive CRDs requiring, however, that the CRD is provided by the passengers.

In Europe the seat costs are presently as follows:

Infant ticket: double occupancy with a loop belt at Ø10 per cent of adult fare or € 20 fixed price

Child ticket: Ø 66 per cent of adult

4.1.5.2.1.1 Option 2: Add-on systems

Option 2 Variant 1: The airline provides the CRDs

The additional costs and revenues generated by this option are calculated for the above mentioned fictitious airline in the following, differentiating between automotive CRDs and TSO CRDs.

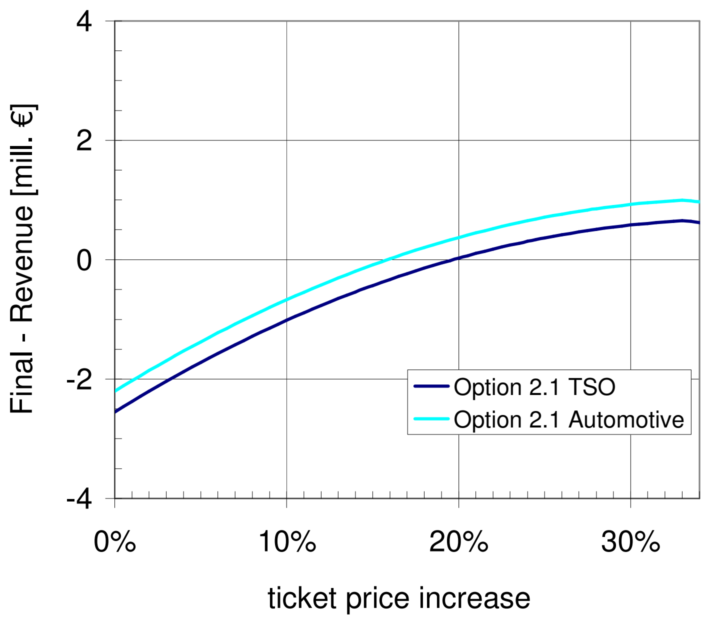
- Infant ticket: Increase of 33 % of the adult fare (questionnaire)
- Child ticket: Increase of 11% of the adult fare (questionnaire)

Comparison of Costs and Revenues:

	Automotive CRD	TSO-CRD
Costs for CRD Implementation	-579.000	-924.000
Dynamic Revenues	1.214.100	1.214.100
Final Revenue	**635.100**	**290.100**

Dynamic Ticket Fare Calculation:

The following diagram shows the revenues in correlation to an **equal increase** of ticket fares for infants and children.



Break even

Automotive CRD: Break-even point at a ticket fare increase of approx.16 per cent

TSO CRD: Break-even point on a ticket fare increase of approx.20 per cent

Summary:

The purchase of a sufficient number of CRDs is necessary in addition to the costs incurred for fit check, adaptation of the booking system und training. The set-up of an infrastructure for storage and maintenance of the CRDs has to be taken into account. Additional costs are incurred for the maintenance/repair (personnel costs) and the logistic distribution of the CRDs. The set-up of a practicable infrastructure and the development of practicable logistic processes represent a high cost potential. This becomes particularly clear when it is realised that an airline has to ensure the availability of fully functional CRDs at several places. This means that it must be possible to clean, maintain or store CRDs also at several destinations. Furthermore, a sufficient number of CRDs must be available at several destinations at all times. This requires logistic processes for the continuous distribution and return of CRDs.

The incurred costs have to be compared with the revenues by the indicated price increases for infant and child tickets.

The above diagram shows that the break-even point is reached at an equal increase of the ticket fares for infants and children by 16 per cent for automotive CRD and 20 per cent for TSO CRD.

Option 2 Variant 2: The passenger provides a CRD

The additional costs and revenues generated by this option are calculated for the above mentioned fictitious airline in the following assuming that only automotive CRDs are provided by the parents.

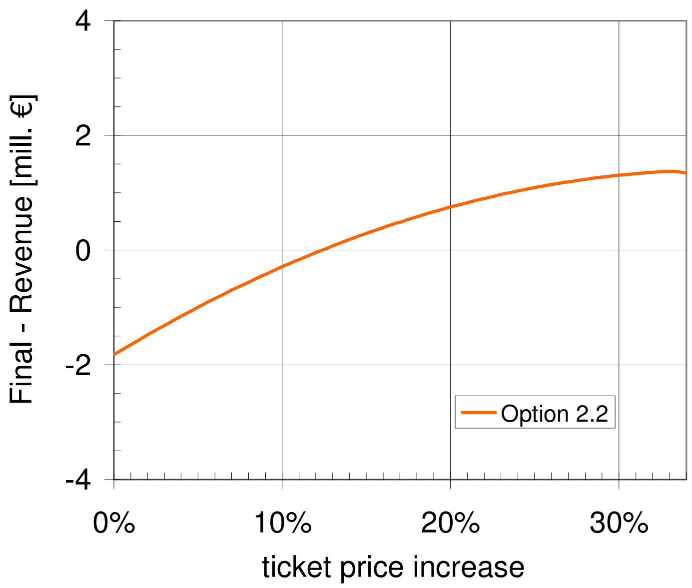
- Infant ticket: Increase of 25 % of the adult fare (questionnaire)
- Child ticket: Increase of 1% of the adult fare (questionnaire)

Comparison of Costs and Revenues:

	Automotive CRD
Costs for CRD Implementation	-200.000
Dynamic Revenues	188.350
Final Revenue	**-11.650**

Dynamic Ticket Fare Calculation:

The following diagram shows the revenues in correlation to an **equal increase** of ticket fares for infants and children.



Break even

Automotive CRD: Break-even point at a ticket fare increase of approx.12 %

Summary:

An airline incurs costs for the fit check, adaptation of the booking system and for the training of the cabin crew.

The fit check is part of the tasks of the airline also in this variant, in order to ensure a smooth operation. The fit check enables the airline to identify the type of child seats and possible seat positions in their cabins. Thus, the airline can advise its passengers and inform them about the possible child seat models.
In this variant, there is no logistic expenditure for the airline.

The incurred costs have to be compared with the revenues by the indicated price increases for infant and child tickets.

The above diagram shows that the break-even point is reached at an equal increase of the ticket fares for infants and children by 12 per cent for automotive CRD.

4.1.5.2.1.2 Option 3: Built-in systems

The additional costs and revenues generated by this option are calculated for the above mentioned fictitious airline in the following:

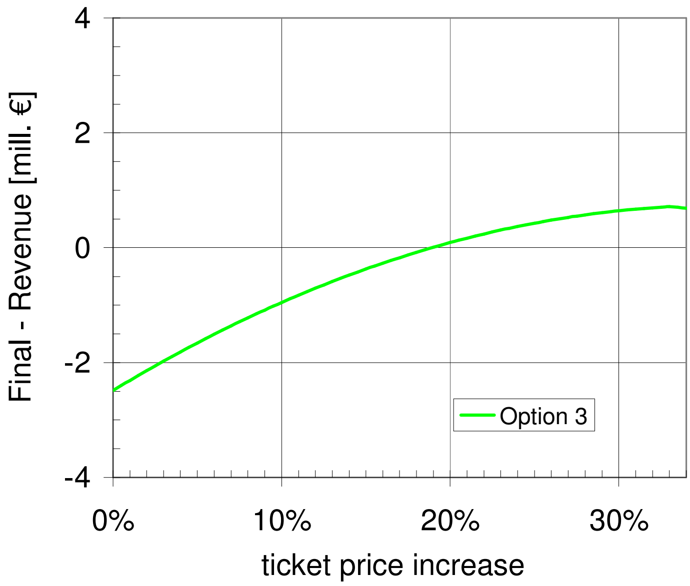
- Infant ticket: Increase of 18 % of the adult fare (questionnaire)
- Child ticket: Increase of –2 % of the adult fare (questionnaire)

Cost Calculation:

	Built- in CRD
Costs for CRD Implementation	-862.000
Revenues	-462.900
Final Revenue	**-1.324.900**

Dynamic Ticket Fare Calculation:

The following diagram shows the revenues in correlation to an **equal increase** of ticket fares for infants and children.



Break even point

Built- in CRD: Break-even point at a ticket fare increase of approx. 19 per cent

Summary

The airline incurs costs for the purchase, training, adaptation of the booking system and maintenance. The purchasing costs for built-in systems can only be estimated roughly. This calculation is based on an additional price of € 4,000 / CRD to the regular passenger seat price. The maintenance costs were indicated much higher by the airlines compared to the other options.

Design studies have shown that built-in systems can be laid out as backward- or forward-facing CRD in a seat. As they are integrated directly in the aircraft passenger seat, there is no additional expenditure for the fit check, logistics and infrastructure.

The above diagram shows that the break-even point is reached at an equal increase of the ticket fares for infants and children by 19 per cent for built-in CRD.

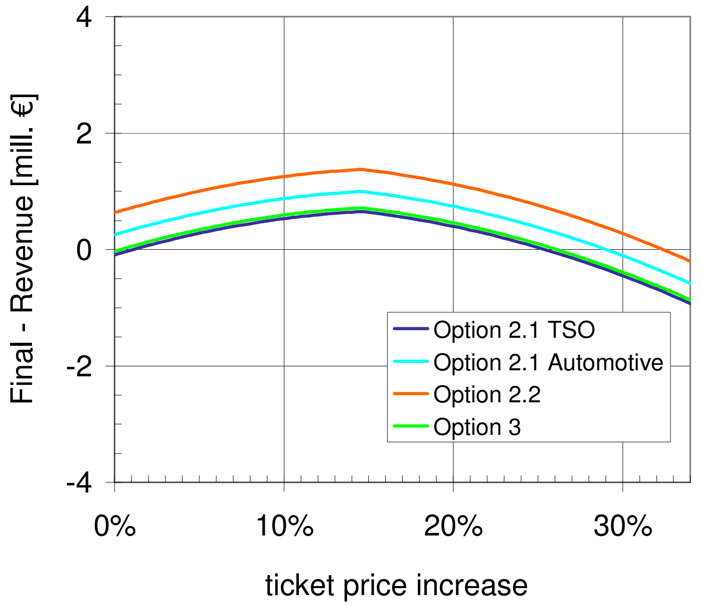
4.1.5.2.1.3 Alternative scenario

The above considerations apportioned the costs incurred by an equal increase of the ticket fares to infants and children (aged 2 to 7 years). However, there are also other possible considerations. Since infants now obtain a seat of their own like children, it is e.g. feasible to increase the ticket fare of infants to the ticket fare of children.

- Increase of infant tickets from 10 per cent to 66 per cent of the adult fare (+56 per cent for infants).
- Uniform ticket fare for infants and children (aged 2 to 7 years).

Dynamic Ticket Fare Calculation:

The following diagram shows the revenues in correlation to an **equal increase** of ticket fares for infants and children. At the graphs starting point (0 per cent of ticket fare increase) the infant Ticket fare has already been increased from 10 per cent to 66 per cent of the adult fare. During the further course of the graph there is an equal increase of the ticket fares for infants and children.



Break even

The increase of the ticket fares for infants from 10 per cent to 66 per cent of the adult fare triggers a "boost of revenues". Taking account of all dynamic cost factors, there are almost no further price increases necessary in order to cover the costs.

4.1.5.2.2 Passengers

4.1.5.2.2.1 Option 1: Do nothing

In Europe, the seat costs for an infant in double occupancy with a loop belt amount to Ø10 per cent of an adult's ticket or a fixed price of approx. € 20.00 is charged. For children, seat prices of Ø66 per cent of an adult's ticket are charged.

4.1.5.2.2.2 Option 2: Add-on systems

Variant 1: The airline provides the CRDs

The passengers do not need to obtain an appropriate CRD since the airline provides CRDs. However, an extra seat is required for the infant. The airline questionnaire states the following ticket fares for option 2 variant 1:

- Infant ticket: Increase of 33 % of the adult fare (questionnaire)
- Child ticket: Increase of 11 % of the adult fare (questionnaire)

The dynamic ticket fare calculation for the airline, however, shows that an increase of the infant and child ticket fares by approx. 16 per cent (automotive CRDs) or approx. 20 per cent (TSO CRD) would be sufficient for option 2 variant 1 to cover the costs.

Variant 2: The passenger provides a CRD

The vast majority of children (80 per cent) come with their own CRD to the airport as the passenger survey states. It is therefore assumed that passengers will only provide automotive CRDs. Due to the potentially high price of pure TSO CRDs and the fact that these are only practicable in aircraft, it is not likely that the parent provide a TSO CRD. If no individual CRD is available, it has to be purchased (approx. € 175) or rented (approx. € 60 - 70). Furthermore, an extra seat for the infant is required. The airline survey specifies the following ticket fares for option 2 variant 2:

- Infant ticket: Increase of 25 % of the adult fare (questionnaire)
- Child ticket: Increase of 1 % of the adult fare (questionnaire)

The dynamic ticket fare calculation for the airline, however, indicates that an increase of the infant fares by approx. 12 per cent (automotive CRDs) would be sufficient for option 2 variant 2 to cover the costs.

4.1.5.2.2.3 Option 3: Built-in systems

The passengers do not need to obtain an appropriate CRD. However, an extra seat for the infant is required. The airline survey specifies the following ticket fares for option 3:

- Infant ticket: Increase of 18 % of the adult fare (questionnaire)
- Child ticket: Decrease of 2 % of the adult fare (questionnaire)

The dynamic ticket fare calculation for the airline, however, indicates that an increase of the infant and child ticket fares by approx. 19 per cent would be sufficient for option 3 to cover the costs.

4.1.5.2.3 CRD manufacturers

4.1.5.2.3.1 Option 1: Do nothing

As long as the loop belt + double occupancy are permitted and the transport of children aged 2 to 7 years in CRDs is not regulated by law, there is no market for CRD manufacturers.

4.1.5.2.3.2 Option 2: Add-on systems

A change of EU-OPS 1.730 would generate a market segment for CRD manufacturers. Presently, some 5,000 aircraft are commercially used within the European Union which transport 706 million passengers on 9.5 million flights per year. In statistic terms, the share of infants and children (2-7 years) accounts for approx. 3.92 per cent. So there is a Europe-wide need for the transport of 27.7 million children each year. The market for the loop belt production will be shrinking.

Variant 1: The airline provides the CRDs

In option 2, variant 1 there is a need of Ø 20 CRDs per aircraft. This indicates a market volume of approx. 100,000 units with a lifespan of 3 years each.

Variant 2: The passenger provides a CRD

There is a Europe-wide need for the transport of 27.7 million children in aircrafts each year.

4.1.5.2.3.3 Option 3: Built-in systems

In option 3 there is a need of Ø 25 built-in CRDs per aircraft. Less add-on CRDs than built-in CRDs are needed per aircraft since add-on CRDs can be exchanged between the aircraft as needed. This corresponds to a market volume of approx. 125,000 units with a lifespan of 7 years each. The market for the loop belt production will be shrinking.

4.1.5.2.4 EASA and national authorities

The EASA and national authorities are concerned with the development of specifications and certification criterions for option 2 and 3.

4.1.5.3 Operation

The Impact Operation analyses the entire operational process. This means that both the safe attachment of the CRD on the aircraft passenger seat (Phase II: Operational Practicality) and the logistic and operational problems (feeders, change of airline etc) are analysed.

4.1.5.3.1 Airlines

4.1.5.3.1.1 Option 1: Do nothing

From an operational point of view, the loop belt is a practicable attachment method for infants. Its use is common practise and well-known by the airlines. Furthermore, it has a low weight, is easy to stow and to handle.

Besides the loop belt, EU OPS also enables the use of restraint systems which are accepted by the respective national authorities. There is no obligation to carry out a fit check so that the compatibility with the aircraft passenger seat cannot be guaranteed.

Children aged over 2 years are restrained with the adult's belt on a seat. In operational terms, this is equal to the fastening of an adult.

4.1.5.3.1.2 Option 2: Add-on systems

The operational practicality of add-on CRDs depends on the fact that a CRD also fits into the provided aircraft passenger seat. This means that fastening and unfastening is possible. The procedure required here and described in phase II ensures the compatibility of the CRD with the aircraft passenger seat. A fitting CRD supports operational practicality and avoids discussions of passengers with the crew which may lead to delays and the missing of slots.

Variant 1: The airline provides the CRDs

If the airline provides the CRDs this offers the advantage that appropriate CRDs are available. The cabin crew can be trained in the respective CRDs and do not have to cope with a large number of different CRD models. This would also be a practicable solution in global travel since every airline provides its own CRD.

The disadvantage for the airlines is the necessity to set up a respective infrastructure and to develop practicable logistic processes.

Variant 2: The passenger provides a CRD

If the parents bring appropriate CRDs there is no need to set up an infrastructure and to develop logistic processes.

Disadvantages are a potential broken CRD or compatibility problems that may arise when the airline is changed (e.g. on feeders). This means that the formerly practicable CRD may possibly no longer fit onto the new aircraft passenger seat.

4.1.5.3.1.3 Option 3: Built-in systems

Built-in CRDs do not pose any of the above-stated compatibility problems due to their construction. Once built in on the aircraft, they are folded up when needed and are ready for use. Cabin crew can be trained in the respectively available built-in CRDs in order to ensure smooth boarding. Another advantage is that the responsibility for the operation and maintenance lies completely with the airline, ensuring a standardised safety and quality level. Furthermore, it is not necessary to develop any logistic processes.

4.1.5.4 Social

Any positive or negative social impacts shall be identified, e.g. on employment, working hours, working conditions, movement of personnel and health.

4.1.5.4.1 Airlines

4.1.5.4.1.1 Option 1: Do nothing

It is presently not ensured that a CRD brought by the passengers is compatible with the aircraft passenger seat. In addition, the required use of a loop belt may be refused by passengers who are informed about the hazards related to it. This involves a potential for conflict between the passengers and the crew and thus increased stress.

4.1.5.4.1.2 Option 2: Add-on systems

The cabin crew is responsible for the check of the correct installation of the CRD. In both variants of this option, a procedure ensures that the add-on CRD fits into the respective aircraft passenger seat, that it can be attached safely and that its functionality is ensured.

Variant 1: The airline provides the CRDs

Additional work load is incurred for the maintenance, check and cabin crew staff. This additional work load can lead to a deterioration of the working conditions (increased stress for the cabin crew etc.). In return, there is a potential to create new services and thus new jobs. A positive effect is that clear and unambiguous procedures regarding the safe transport of children lead to a decrease of stress among the cabin crew.

Variant 2: The passenger provides a CRD

Minor additional work load is incurred for the cabin crew staff. This additional work load can lead to a deterioration of the working conditions (increased stress for the cabin crew etc.). In return, there is a potential to create new services and thus new jobs. A positive effect is that clear and unambiguous procedures regarding the safe transport of children lead to a decrease of stress among the cabin crew.

4.1.5.4.1.3 Option 3: Built-in systems

Additional work load is incurred for the maintenance, check and cabin crew staff. This additional work load can lead to a deterioration of the working conditions (increased stress for the cabin crew etc.). In return, there is a potential to create new services and thus new jobs. A positive effect is that clear and unambiguous procedures regarding the safe transport of children lead to a decrease of stress among the cabin crew.

4.1.5.4.2 Passengers

General

The impacts of increased flight fares on the travel behaviour of families with children are shown in the following on the basis of the data retrieved in the survey "Questionnaire for Study on Child Restraint" (this survey interviewed 365 passengers).

Effects of a 50% seat price for children under 2 years

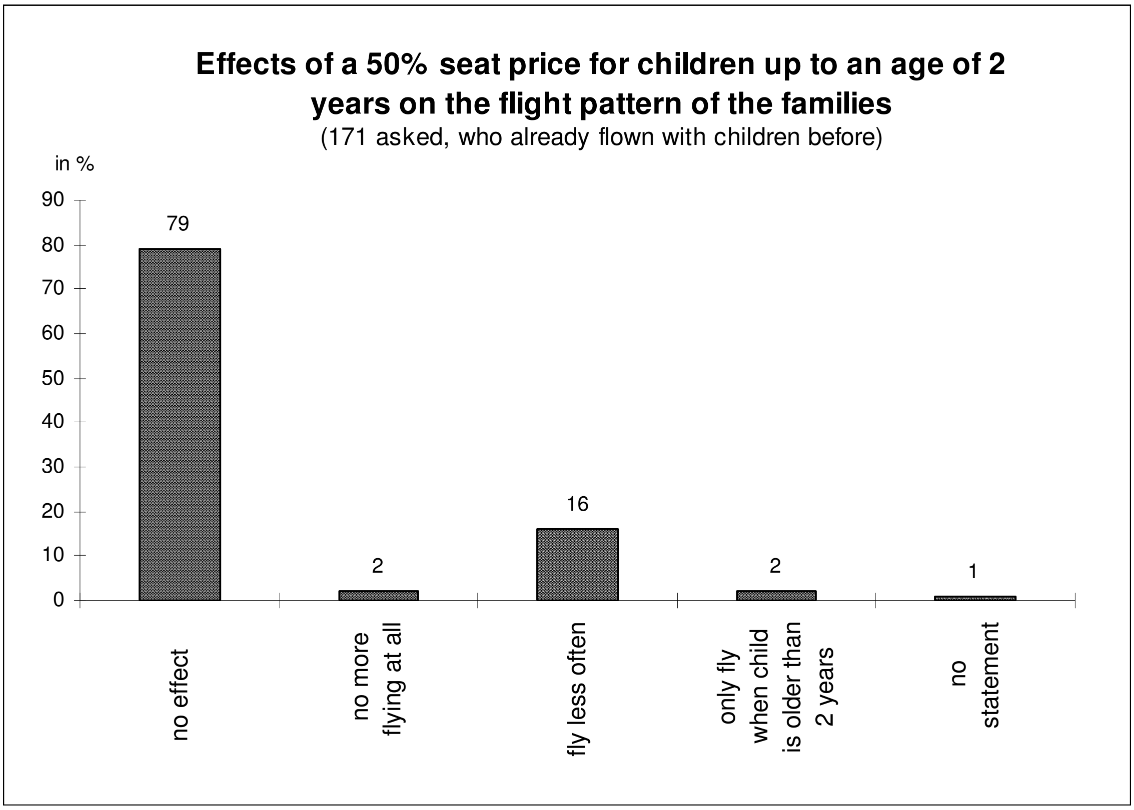


Figure 4-1: Effects of a 50% seat price for children under 2 years

When asked about the effect, extra payment may have an effect on the flight frequency with children, the following result turned out. The question assumed a seat fare of 50 per cent of the normal fare for children under 2 years. It must be taken into account that the ticket fares for infants accounted for approx. 10 percent of adult tickets. 79 percent of the 171 interviewed persons who had already flown with children before indicated that extra payment would have no effect on the flight frequency. 16 per cent indicated that they would fly less frequently. This survey was conducted in 1997. Due to lower ticket prices since then, more and more families with children use airplanes for their journeys. At the same time, people have an increased safety awareness. Based on this information, it can be assumed that these results are valid to date. It has to be assumed that the parents' willingness to accept costs necessary for the safety of their children has even increased.

4.1.5.4.2.1 Option 1: Do nothing

The financial burden for passengers with children is as follows: In Europe, the seat costs for an infant in double occupancy with a loop belt amount to Ø10 per cent of an adult's ticket or a fixed price of approx. € 20.00 is charged. For children, seat fares of Ø66 per cent of an adult's ticket are charged.

4.1.5.4.2.2 Option 2: Add-on systems

Children aged up to seven years are transported in an appropriate CRD (add-on). In contrast to option 1 "do nothing", this ensures an equivalent safety level for infants/ children and leads to an equal treatment of infants and children as well as adults thus complying with the EU Charter outlined in the following:

<u>Charter of Fundamental Rights of the European Union (proclaimed on 12 December 2007): Chapter III "EQUALITY":</u>

Article 21: Non-discrimination

"Any discrimination based on any ground such as…, age…shall be prohibited."

Article 24: The rights of the child

"Children shall have the right to such protection and care as is necessary for their well-being…"

"In all actions relating to children, whether taken by public authorities or private institutions, the child's best interests must be a primary consideration."

One finding regarding the economic impact is the fact that the airlines are expecting a price increase for the tickets of children aged up to 7 years if option 2 is implemented.

<u>Variant 1: The airline provides the CRDs</u>

To cover the costs incurred by the airline, it is sufficient, pursuant to the dynamic ticket fare calculation carried out, to raise the ticket fares for infants and children for automotive CRDs by 16 per cent and for TSO CRDs by 20 per cent of the adult fare.

This means for:

Automotive CRDs:

- Infant ticket: Increase from 10 per cent to 26 per cent of the adult fare
- Child ticket: Increase from 66 per cent to 82 per cent of the adult fare

TSO-CRDs:

- Infant ticket: Increase from 10 per cent to 30 per cent of the adult fare
- Child ticket: Increase from 66 per cent to 86 per cent of the adult fare

A decrease in passengers travelling with children by 8 to 10 per cent is estimated due to the expected price increase.

Variant 2: The passenger provides a CRD

The passengers need to obtain an appropriate CRD. If no appropriate CRD is available, a CRD has to be purchased (approx. € 175) or rented (approx. € 60). To cover the costs incurred by the airline, it is sufficient, pursuant to the dynamic ticket fare calculation carried out, to raise the ticket fares for infants and children by 12 per cent of the adult fare.

This means for:

Automotive CRD:
- Infant ticket: Increase from 10 per cent to 22 per cent of the adult fare
- Child ticket: Increase from 66 per cent to 78 per cent of the adult fare

A decrease in passengers travelling with children by 6 per cent is estimated due to the expected price increase**.**

4.1.5.4.2.3 Option 3: Built-in systems

Children aged up to seven years are transported in an appropriate CRD (built-in). In contrast to option 1 "do nothing", this ensures an equivalent safety level for infants/ children and leads to an equal treatment of infants and children compared to adults thus complying with the Charter of Fundamental Rights of the European Union Chapter III Article 21+24 (see option 2).

One finding of the economic impact is the fact that the airlines are expecting a price increase for the tickets for children aged up to 7 years if option 3 is implemented.

Passengers do not have to obtain an appropriate CRD, but require an extra seat for the infant. To cover the costs incurred by the airline, it is sufficient, pursuant to the dynamic ticket fare calculation carried out, to raise the ticket fares for infants and children by 19 per cent of the adult fare.

This means for:

Built-in CRD:
- Infant ticket: Increase from 10 per cent to 39 per cent of the adult fare
- Child ticket: Increase from 66 per cent to 85 per cent of the adult fare

A decrease in passengers travelling with children by 9 per cent is estimated due to the expected price increase**.**

4.1.5.5 Foreign comparable regulatory requirements

4.1.5.5.1 Option1: Do nothing

Loop belt

In international aviation, double seat occupancy by an adult and an infant (< 2 years) is common practise.

In Europe, Australia and Asia, the infant is additionally restrained by a loop belt in double seat occupancy.

The loop belt is prohibited in the USA and Canada. In double seat occupancy, only lap-holding is permitted.

CRD

Europe and Australia also permit CRDs to restrain infants. No specific regulations regarding the kind and design of the CRD are made within the sphere of influence of the EU-OPS. However, they have to be accepted by the "authority for use in aircraft".

CRDs for infants and children restrained on a seat of their own are permitted in the USA, Australia and Canada. The CRDs either have to be approved in accordance with FMVSS 213 plus § 8 inversion test, CMVSS 213, 14CFR 21.305 (d) or TSO C100b or have to be manufactured in accordance with a standard of the United Nations and be approved by an authority. Aerospace companies are allowed to offer and use seats and/or child restraint devices which are approved in accordance with a "Type Certificate or Supplemental Type Certificate".

In all countries, an extra seat for all passengers is mandatory for children from 2 years onwards. There is no obligation to transport children from two years onwards in a safe restraint system which is appropriate for children. As a rule, children are restrained with the adult lap belt.

4.1.5.5.2 Option 2: Add-on systems

Option 2 provides that all passengers have an aircraft passenger seat of their own, and children aged 0 to 7 years have to be additionally restrained with an add-on CRD. Loop belts do not have to be provided or reserved by the airlines any more.

Presently there are no adequate international regulatory requirements or efforts to introduce the respective regulations. EU airlines operating internationally may be facing competitive disadvantages upon the implementation of option 2. This will be the case if the ticket fares are increased due to the CRD requirement and if non-European airlines can offer cheaper fares. On the other hand, the adaptation of children's safety is a positive marketing instrument and can become a unique selling proposition for the European airlines.

4.1.5.5.3 Option 3: Built-in systems

Option 3 provides that all passengers have an aircraft passenger seat of their own, and children aged 0 to 7 years have to be restrained with a built-in CRD. Loop belts do not have to be provided or reserved by the airlines any more.

Presently there are no adequate international regulatory requirements or efforts to introduce the respective regulations. EU airlines operating internationally may be facing competitive disadvantages upon the implementation of option 3. This will be the case if the ticket fares are increased due to the CRD requirement and if non-European airlines can offer cheaper fares. On the other hand, the adaptation of children's safety is a positive marketing instrument and can become a unique selling proposition for the European airlines.

4.1.5.6 Environmental

From an ecological point of view, the additional weight of an unused CRD (e.g. a built-in CRD) is so-called “dead weight”. The CRDs are transported without a direct benefit when they are not occupied. On the other hand, a much bigger share of the weight in the cabin is transported and also supplied with energy for service and convenience reasons. The ecological aspect of unused CRDs is therefore assessed as negligible.

4.1.6 Equity and fairness issues identified

The assessment of equity and fairness in the implementation of the above-mentioned options is detailed in the following summary.

4.2 Summary

This summary compares options 2 and 3 with option 1 with the positive and negative impacts in order to assess the impacts for the sectors concerned taking account of the equity and fairness aspect.

4.2.1 Option 2: Add-on systems

- All passengers, including infants, obtain a seat of their own.
- Children aged up to 7 years are transported on their own seat in a safe add-on CRD which is appropriate for their age group.
- It must be ensured by a practicable procedure that the add-on CRDs fit on the respective aircraft passenger seats, can be attached safely and their functionality is ensured (by a fit check/ qualification).
- Variant 1: The airline provides the CRDs
  Variant 2: The passenger provides a CRD

Variant 1: The airline provides the CRDs

Impact	Sector	Remarks
Safety	Passengers	Equivalent safety of infants and children compared to adults.
Economic	Passengers	For cost coverage an increase of 16 to 20 per cent of the ticket prices is estimated based on the dynamic ticket fare calculation.
Social	Passengers	A decrease in passengers travelling with children by 8 to 10 per cent is estimated due to the expected price increase for cost coverage. Compliance with the EU Charter: Equality of infants, children and adults
Economic	Airlines	Due to the dynamic cost recovery calculation the costs can be compensated or even overcompensated by a moderate increase of the ticket fares for infants and children.
Operation	Airlines	Additional expenditure especially in infrastructure logistics. This option guarantees installability. No delay due to non-fitting CRDs.
Social	Airlines	Additional work load for the existing personnel. There is a potential to create new services and thus new jobs.
Foreign comparable regulatory requirements	Airlines	The European airlines have a competitive disadvantage compared to the other airlines without a uniform international regulation (ICAO), depending on the level of the ticket fare increase. On the other hand, the adaptation of children's safety is a positive marketing instrument and can become a unique selling proposition for the European airlines.
Economic	EASA and national authorities	The EASA and national authorities are concerned with the development of specifications and certification criterions.
Economic	CRD-Manufacturer	The market for the loop belt production will be shrinking. New market segment for CRDs

Variant 2: The passenger provides a CRD

Impact	Sector	Remarks
Safety	Passengers	Equivalent safety of infants and children compared to adults.
Economic	Passengers	For cost coverage an increase of 12 per cent of the ticket prices is estimated based on the dynamic ticket fare calculation.
Social	Passengers	A decrease in passengers travelling with children by 6 per cent is estimated due to the expected price increase for cost coverage. Compliance with the EU Charter: Equality of infants, children and adults
Operation	Passengers	The passenger provides an appropriate CRD (automotive)
Economic	Airlines	Due to the dynamic cost recovery calculation the costs can be compensated or even overcompensated by a moderate increase of the ticket fares for infants and children.
Operation	Airlines	This option guarantees installability by a procedure. No delay due to non-fitting CRDs. When the airline is changed (e.g. feeder), compatibility problems may arise.
Social	Airlines	Minor additional work load for the existing personnel. There is a potential to create new services and thus new jobs.
Foreign comparable regulatory requirements	Airlines	The European airlines have a competitive disadvantage compared to the other airlines without a uniform international regulation (ICAO), depending on the level of the ticket fare increase. On the other hand, the adaptation of children's safety is a positive marketing instrument and can become a unique selling proposition for the European airlines.
Economic	EASA and national authorities	The EASA and national authorities are concerned with the development of specifications and certification criterions.
Economic	CRD-Manufacturer	The market for the loop belt production will be shrinking. New market segment for CRDs

Equity and fairness

Variants 1 and 2 of option 2 include slightly different costs for the airline or for the passengers. In general, however, the following findings apply for both variants:

Pursuant to the cost coverage calculation, the additional financial burden for passengers with children is tolerable. A decrease in passengers travelling with children by 6 to 10 per cent is estimated due to the expected price increase, depending on the variant and the CRD system. This churn rate, however, is dependent on the parents' state of information regarding a safe child restraint in aircraft. The children are treated fairly with the option. They are transported in a safe add-on CRD which is appropriate for their age group and obtain equivalent safety compared to adult passengers.

Internationally operating EU airlines may possibly face competitive disadvantages. This will be the case if the ticket fares are increased more than in the cost coverage calculation and thus non-European airlines are able to offer cheaper fares. Opposed to this is the adaptation of children’s safety as a positive marketing instrument which can be used as unique selling proposition by the European airlines.

In summary, it has been identified that the additional costs are accepted by the passengers and the airline can even extend its range of services. According to the findings of the determined impacts, neither the passenger sector nor the airline sector is put at a disadvantage.

4.2.2 Option 3: Built-in systems

- All passengers, including infants, obtain a seat of their own.
- Children aged up to 7 years are transported in a safe built-in CRD which is appropriate for their age group.
- It will be ensured by a practicable regulation that the functionality is provided.

Impact	Sector	Remarks
Safety	Passengers	Equivalent safety of infants and children compared to adults.
Economic	Passengers	For cost coverage an increase of 19 per cent of the ticket prices is estimated based on the dynamic ticket fare calculation.
Social	Passengers	A decrease in passengers travelling with children by 9 per cent is estimated due to the expected price increase for cost coverage. Compliance with the EU Charter: Equality of infants, children and adults
Economic	Airlines	Due to the dynamic cost recovery calculation the costs can be compensated or even overcompensated by a moderate increase of the ticket fares for infants and children.
Operation	Airlines	Very good practicality, smooth boarding, standardised safety and quality are ensured. No delay by non-fitting CRDs
Social	Airlines	Additional work load for the existing personnel. There is a potential to create new services and thus new jobs
Foreign comparable regulatory requirements	Airlines	The European airlines have a competitive disadvantage compared to the other airlines without a uniform international regulation (ICAO), depending on the level of the ticket fare increase. On the other hand, the adaptation of children's safety is a positive marketing instrument and can become a unique selling proposition for the European airlines.
Economic	EASA and national authorities	The EASA and national authorities are concerned with the development of specifications and certification criterions.
Economic	CRD-Manufacturer	The market for the loop belt production will be shrinking. New market segment for CRDs

Equity and fairness

Pursuant to the cost coverage calculation, the additional financial burden for passengers with children is tolerable. A decrease in passengers travelling with children by approx. 9 per cent is estimated due to the expected price increase. This churn rate, however, is dependent on the parents' state of information regarding a safe child restraint in aircraft. The children are treated fairly with the option. They are transported in a safe built-in CRD which is appropriate for their age group and obtain equivalent safety compared to adult passengers.

Internationally operating EU airlines may possibly face competitive disadvantages. This will be the case if the ticket fares are increased more than in the cost coverage calculation and thus non-European airlines are able to offer cheaper fares. Opposed to this is the adaptation of children’s safety as a positive marketing instrument which can be used as unique selling proposition by the European airlines.

In summary, it has been identified that the additional costs are accepted by the passengers and the airline can even extend its range of services. According to the findings of the determined impacts, neither the passenger sector nor the airline sector is put at a disadvantage.

4.3 Final Assessment

Preferred Option recommended

The following options were analysed within this RIA:

Option 1: Do nothing

Option 2: Add-on systems

- Variant 1: The airline provides the CRDs
- Variant 2: The passenger provides a CRD

Option 3: Built-in systems

These were analysed with regard to their impact on safety, their economic and social impacts, impacts of operational practicality and foreign comparable regulatory requirements, specifying their impacts on the sectors concerned (passengers, airlines and CRD manufacturers). Each of the stated options has its advantages and disadvantages for the sectors concerned. Pursuant to the evaluation of the impacts on the individual options, both option 2 and option 3 have proven practicable.

These two options fulfil the performance standards defined in phases I and II regarding the restraint of children in aircraft:

- all passengers, including infants, are entitled to a seat of their own.
- Children aged up to 7 years shall be transported on their seat in a CRD which is appropriate for their age group.
- The functionality of the CRD must be ensured by a practicable regulation.

It was found that the additional costs incurred by options 2 und 3 are accepted by the passengers and the airlines can even extend their range of services.

Irrespective of that, the costs for the implementation of options 2 or 3 only account for approx. 0,1 to 0,2 per cent of the operational costs of an airline which shows that the potential costs or benefits in relation to the total cost structure of an airline are relatively small.

Neither the passenger sector nor the airline sector is put at a disadvantage by the implementation of these options. Yet it is achieved that the performance standards of the EU Charter regarding the equality of infants and children compared to adults are now complied with as well.

Options 2 and 3 differ for the airlines predominantly in the economic and operational impacts.

Thus, option 2 variant 2 provides a financial advantage regarding the economic impact compared to option 2 variant 1 or option 3. Depending on the size, fleet or business model of the airline, however, option 2 variant 1 or option 3 provide an advantage regarding the impact on the operational practicality (e.g. feeders, change of airline). As both options and variants provide an advantage, depending on the different outline conditions of the airline, both option 2 and option 3 should be implemented as possible alternatives. It is also possible to implement both variants of options 2 and 3 simultaneously. Thus, it is possible for the respective airline to define the appropriate model themselves and to optimise the economic and the operational benefit. Furthermore, a new market is opened up for the CRD manufacturers and service providers for the development of tailor-made implementation concepts.

For this reason, the study comes to the result that option 1 should be replaced by options 2 and 3.

To adapt the passive safety of children in aircraft to adults' safety level, it is necessary to amend the present regulations and/or to formulate new regulations.

We recommend the following further steps:

1. Regulatory steps

The named options require an amendment of the following provisions:

a) CS 25.785(a)

Persons of all age groups are entitled to a seat of their own.

b) EU OPS 1.320(b)(2)

Persons of all age groups are entitled to a seat of their own.

Infants and children up to the age of 7 years need to be restrained in an accepted CRD.

c) EU OPS 1.730(a)(1)

Persons of all age groups are entitled to a seat of their own.

d) EU OPS 1.730(a)(3)

Infants and children up to the age of 7 years need to be restrained in a seat of their own with an accepted add-on or built-in CRD.

Add-on CRD: Accepted CRD should be ECE R 44, FMVSS 213 including Chapter 8, ETSO-C100b, TSO-C100b or an equivalent specific CRD standard. The operator must provide the possibility to use accepted CRDs in aircraft and must ensure their safe installation (e.g. by a "fit check"/qualification). Both the operators and the passengers accompanying the child can be responsible for providing the CRD.

Built-in CRD: The operator is responsible for the provision and safe use of built-in CRDs (e.g. certified by a supplemented ETSO C127a).

These options likewise provide for the drawing-up of an annex to EU OPS 1.730 similar to the annex provided for in ACJ 1.730. This is to guarantee the smooth use of CRDs in the aircraft passenger cabin additionally by using a supplementary procedure. It is to asses approved child restraint devices (motor vehicle approval or aircraft approval) regarding their operational practicality in the cabin layout. This procedure requires CRD compliance with the safety standards (biomechanics and functionality in a crash) and takes account of the criteria of operational practicality (add-on CRD: correlation of the geometric dimensions and attachment on the aircraft passenger seat). The procedure likewise has to take account of evacuation aspects. The possible seats for use of the respective CRD are defined for each cabin layout which enables a safe transport of the infant / child.

e) ETSO C100b

ETSO C100b reflects the TSO C100b. This standard needs to be adapted to the European conditions. This especially applies to the test seat, dummies and the related biomechanical pass-fail criteria (see ECE R44).

f) ETSO C127a

This ETSO should include a Minimum Performance Standard for the integration of built-in CRDs in an aircraft passenger seat which is oriented at the provisions ETSO C100, ECE-R44, FMVSS-213 and CMVSS-213.

<u>ETSO-C127a should be supplemented as follows:</u>

- Restraint criteria in accordance with the child's development (biomechanics)
- Static and dynamic test standards
- Buckle release test

<u>2. Research / Study</u>

The study has shown which principle requirements have to be placed on CRDs in order to guarantee a safe transport of children (restraint principles, biomechanical tolerance limits etc.). These requirements for add-on and built-in CRDs can be set by laws and regulations.

We would suggest further research into the following areas:

- There are presently no clear approval requirements for built-in systems. Therefore, these should be developed within a research project.

- Research projects should be initiated in order to analyse the types of attachment (e.g. Isofix, lap belt with lateral push-button lock (motor vehicles)) of CRD on aircraft passenger seats, and also in order to show potentials for improvement.

- The parents' willingness to accept a respective increase in the ticket prices depends, amongst other factors, on the state of information regarding a safe child restraint in aircraft as well as their financial viability. It would therefore be interesting to analyse this interplay on a Europe-wide basis in further detail in a study.

3. ICAO

We recommend a worldwide harmonisation regarding the following core statements:

- All passengers, including infants, obtain a seat of their own. (no double occupancy)
- Children aged up to 7 years are transported in a safe CRD which is appropriate for their age group.
- It will be ensured by a practicable regulation that the functionality is provided.

Equal conditions of competition between airlines worldwide will be ensured when having a global requirement for the use of CRD in aircraft. ICAO is the only organisation to enable a respective worldwide implementation.

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