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Child Restraint in Australian Commercial Aircraft

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Abstract

Commercial airlines in Australia do not require infants under the age of 24 months to occupy their own seats during flight, but all passengers must be restrained during taxi, take-off, landing and turbulence. Adults are required to wear the standard aircraft seat lap belt. For infants and young children, the situation is less clear. Child restraint systems (CRS) potentially offer the safest solution. However, the suitability and effectiveness of available Australian automotive CRS have not been investigated.

Twenty models of CRS, certified to AS/NZS 1754:2004, were fitted to a typical commercial aircraft seat according to the manufacturer's instructions. Fourteen of the CRS models had difficulty fitting within the available space or could not be adequately installed due to interference with the aircraft seat lap belt latch. Additionally, one required a top tether strap (not normally available in commercial aircraft) to be used in the installation. An FAA style turbulence test demonstrated that all the remaining Australian automotive CRS adequately retained the infant dummy when exposed to 1G of vertical acceleration. Eleven models were subjected to modified FAA dynamic sled tests in an aircraft seat. The CRS exhibited significant forward motion, rotation and rebound motion as a result of design incompatibilities between the aircraft seat and lap belt system and the lack of a top tether.

In tests where the child dummies were restrained only by the aircraft seat lap belt, excessive forward motion of the dummy head and torso occurred. This motion is likely to result in impact with the forward seat back.

Four infant carriers (slings), which were selected as representative of those available in the market, were also tested. An inversion test demonstrated that the carriers were able to retain the infant provided the

carrier was securely fastened. Dynamic testing, using a 9G sled pulse, demonstrated that these carriers were not able to restrain infants under crash situations. Furthermore, the forward motion of the adult dummy restrained only by a lap belt trapped the infant in the space between the front row seat back, the head, torso and knees of the adult.

Included in the infant sling test series was the supplementary loop belt (belly belt). Although retained during dynamic testing, the infant dummy underwent significant forward excursion resulting in severe impact of the dummy's head with the forward seat back. In addition, the adult dummy folded over the infant trapping and crushing it in the process.

The report makes a series of suggestions about child restraint systems and procedures for use in Australian aircraft.

CONTENTS

EXECUTIVE SUMMARY

Background

Commercial air travel remains the safest mode of transport available in OECD countries. Commercial airlines in Australia do not require infants under the age of 24 months to occupy their own seats during flight. However, the children carried in the arms of adult passengers must be restrained during taxi, take-off, landing and turbulence.

The aims of this project were to review the developments in safe transport of children in aircraft and to conduct a test program based on current Australian child restraint systems (CRS). This initial program was later extended to include the assessment of infant carrier systems (commonly referred to as baby slings) for use as infant restraints in aircraft.

A US Civil Aerospace Medical Institute (CAMI) study found that lap-held restraint systems allowed excessive forward body excursion of the test dummies, resulting in severe head impact with the seat back directly in front. The tests showed how a lap-held infant could be crushed between the forward seat back and the accompanying adult during impact (Gowdy & De Weese 1994). Following the CAMI study, the US Federal Aviation Administration (FAA) banned the use of booster seats and all lap-held restraint devices in aircraft during take-off, landing and taxi. This has resulted in lap-held children travelling wholly unrestrained in aircraft.

The travelling public is likely to expect that the level of safety offered to child passengers in commercial aircraft is equivalent to that of adult passengers restrained by lap belts. The use of an appropriate child restraint system can offer the highest level of safety for young children travelling in aircraft, both in turbulence and in crash situations. However, the compatibility of current Australian automotive CRS with aircraft seating has not been investigated and their performance in aircraft emergency situations is unknown.

There are very few preventable child deaths in aircraft crashes. Newman, Johnston and Grossman (2003) found that the use of CRS would prevent 0.4 child air-crash deaths per year. They concluded that making infant air-seats compulsory would raise air travel costs which could result in a net *increase* in deaths and injuries as families opt for automobile travel – a higher-risk mode of transport per kilometre of travel.

Child restraint testing

A selection of automotive CRS available in Australia was chosen for testing in this study to cover the range of common child restraint types. The DME Corporation PlaneSeat, certified for use in both motor vehicles and aircraft in the United States, was also examined. The testing was completed in three stages:

1. **Fit test**

   The CRS were fitted to an economy class aircraft seat row to check for compatibility. Twenty Australian standard CRS were fitted to the aircraft seat according to the manufacturer's instructions. Fourteen of the CRS models had problems in this test. Either they did not fit within the 31-inch seat pitch or they were difficult to fit due to interference with the latching mechanism of the aircraft seat lap belt. One restraint was designed for use only with a top tether strap requiring an anchorage system not available in commercial aircraft.

2. **Turbulence (inversion) test**

The CRS were subjected to the FAA seat inversion test for turbulence. This test caused no difficulty for the Australian CRS, which have 6-point harnesses for the child. Booster seats were not tested in this series.

3. **Dynamic sled test**

The Australian automotive CRS were subjected to the requirements of the dynamic FAA aircraft seat test, without the top tether normally required in motor vehicle installation. The CRS were installed on a single aircraft seat row by the lap belt and subjected to a 16G longitudinal test with a velocity change of more than 45 km/h. Forty-two sled tests were conducted involving 11 models of Australian CRS together with tests where dummies were restrained only by the aircraft seat lap belt. The average sled deceleration for the tests was 18.9G and the mean entry velocity was 47.6 km/h.

The dummies were retained in the CRS in all sled tests. However, all the CRS exhibited significant forward motion, rotation, and rebound motion. This less controlled movement, in comparison with typical automotive testing of CRS, was due to the following:

- the upper tether could not be installed;
- the more vertical geometry of the aircraft seat lap belt;
- the poor compatibility of the aircraft seat lap belt design and the CRS belt paths;
- the poor interaction of the CRS with the aircraft seat base cushion and frame;
- a rebound phase that was poorly controlled due to the more extensive forward motion of the CRS.

In tests where the child dummies were restrained only by the aircraft seat lap belt, excessive forward motion of the dummy head and torso occurred due to the lack of upper body restraint and the folding over of the aircraft seat back. This motion is likely to result in impact with the forward seat back.

Infant carrier testing

Four commercially available infant carriers were chosen as representative and were tested to evaluate their performance with respect to retention of the child, forward excursion, and crushing by the adult. Two samples of the standard 'supplementary loop belts' (or belly belts) were included for comparative testing. The testing was conducted in two stages:

1. **Turbulence (inversion) test**

The infant carriers were subjected to an inversion test to simulate turbulent conditions. An infant dummy was placed in the carrier and fitted to an adult dummy restrained by a lap belt in an aircraft seat. The tests demonstrated that infants could be adequately restrained when exposed to 1G of vertical acceleration provided the carrier was securely fastened.

2. **Sled test**

A lap-belt restrained adult dummy in an aircraft seat, with an infant dummy in a carrier, was subjected to a 9G dynamic sled test. The severity of the pulse was based on the results of a static load test. The commercially available infant carriers tested were not able to restrain infants under crash situations.

The infant carriers could be redesigned to ensure that the infant was restrained in dynamic loads equivalent to the test pulse. If this was done, then an infant carrier would form an alternative to the supplementary loop belt.

Suggested actions

The following suggestions are made based on the findings of this study and the principle that infants and young children are entitled to the same level of protection, both in flight and during emergency landing situations, that is afforded to adults.

1. The use of CRS by infants and young children on flights in Australia is to be encouraged. The CRS used could be either designed specifically for use in aircraft, or, Australian automotive CRS approved for use in aircraft as per suggestion number 3.
2. Testing should be conducted of the system of an upper tether strap for Australian automotive CRS with a non-breakover aircraft seat back, as currently used by Qantas.
3. An approval system should be established to ensure that any Australian automotive CRS to be used in aircraft fits in the aircraft seat and is compatible with the aircraft lap belt. The approval could be in the form of an extra test added to the existing motor vehicle requirements similar to the FAA approval system.
4. Improvements in the crash performance of Australian automotive CRS in aircraft could be achieved by making changes to the seating systems in the aircraft to minimise forward excursion of the CRS in the seat. In order of priority, these suggested improvements are:
   a. Supply a properly mounted upper tether, either as used by Qantas should testing show that this is effective or, by supplying attachment points in the aircraft for CRS use. This could be achieved by restricting CRS use to the seats forward of a bulkhead and by requiring a modified bulkhead design with appropriate attachment points built in for the tether.
   b. Change lap belt geometry (angled at 45 to 60 degrees instead of vertical) for use with a CRS to reduce the initial forward excursion of the base. However, such seat belt geometry may not be appropriate for other users of the belt.
   c. Make changes to the seat base cushion to ensure its retention under CRS dynamic loads.
5. Improvements in the crash protection offered in aircraft to an infant seated on the lap of an adult could be achieved if some seats were fitted with lap sash or harness type seat belts for use by parents holding infants. These seats, possibly adjacent to a bulkhead could be forward- or rearward-facing. Controlling the upper torso motion of the adult has the potential to reduce crash loading to an infant seated on the lap of an adult.
6. If suggestion 5 was implemented, then an approval system for infant carriers (slings) for use in aircraft should be put in place. A sling system could be designed and developed as a replacement for the belly belt. This type of infant carrier could offer improved retention and comfort in turbulent conditions; in conjunction with appropriate seating fitted with a lap/sash or harness for the parent, it could offer improved safety for the infant in a crash.
7. The changes resulting from the incorporation of ISO rigid anchorage systems (ISO-fix or latch systems), which are becoming mandatory worldwide, need to be studied and accommodated for use in aircraft.

ABBREVIATIONS

AC	Advisory Circular
AIS	Abbreviated Injury Scale
AS/NZS	Joint Australian and New Zealand Standard
ATD	Anthropomorphic Test Device/Dummy
CAA	Civil Aviation Authority (UK)
CAAP	Civil Aviation Advisory Publication (Australia)
CAMI	Civil Aerospace Medical Institute (US)
CAO	Civil Aviation Order (Australia)
CASA	Civil Aviation Safety Authority (Australia)
CAR	Civil Aviation Regulations (Australia) (Canada)
CRS	Child Restraint System(s)
ECE	Economic Commission for Europe
FAA	Federal Aviation Administration (US)
FAR	Federal Aviation Regulations (US) (part of the Code of Federal Regulations)
FMVSS	Federal Motor Vehicle Safety Standard (US)
fps	Frames per second
G	Gravitational constant
HIC	Head Injury Criterion
IARV	Injury Assessment Reference Value
ISO	International Organization for Standardization
NHTSA	National Highway Traffic Safety Administration (US)
OECD	Organisation for Economic Co-operation and Development
QUEST	Quality Evaluation and Standards Testing Centre, Britax Childcare
TNO	Netherlands Organisation for Applied Scientific Research

1 INTRODUCTION

1.1 Scope and aims

Commercial airlines in Australia do not require infants under the age of 24 months[1] to occupy their own seats during flight. However the children carried in the arms of an adult passenger must be restrained during taxi, take-off, landing and turbulence. At present the only means available to restrain children in this position is with a "supplementary loop belt" (or belly belt) attached to the adult seat belt (CASA 2002). Studies have shown that such devices could cause serious and potentially fatal abdominal and head injuries to young children in survivable crashes (CAA 1992; Gowdy & DeWeese 1994). This project has arisen from current concerns regarding child safety on commercial aircraft in Australia (Gibson 2003; Waddington 2004).

It is generally accepted that the use of a child restraint system (CRS) offers the highest level of safety for infants travelling in aircraft in both turbulence and crash situations. The travelling public has an expectation that the level of safety offered to child passengers in commercial aircraft is equivalent to that of adult passengers restrained by a lap belt. However, the compatibility of current Australian automotive CRS for use in aircraft has not been sufficiently investigated; for example, available CRS may not all fit in standard commercial economy-class aircraft seats. Further, the performance of these devices in aircraft emergency situations is unknown. Australia has one of the most demanding automotive CRS requirements in the world. It requires the use of a top-tether in addition to the existing seat belt to limit the head excursion of the child (AS/NZS 1754). There is no suitable arrangement in current aircraft cabins and passenger seats for the use of this top tether. Any installation that involves a change in the aircraft seat system must be approved as a modification to the aircraft under the Australian *Civil Aviation Regulations* (CAR 1988). One Australian airline has adopted a method of fastening a top tether over the seat back. The effectiveness of this practice with breakover seats has not been fully examined.

The aim of this project was to examine the current dilemma faced by CASA, the airlines and parents of child travellers in Australia. The approach used was to review the developments in safe transport of children in aircraft, and to design and conduct a test program of Australian Standard (AS/NZS 1754) certified automotive CRS. The testing was intended to determine the CRS dimensional suitability and crashworthiness capabilities when used in commercial aircraft.

Early in the project, a suggestion was made by the industry that alternatives to the supplementary loop belt also be investigated. Subsequently, a test program was added to the project to assess infant carrier systems (commonly referred to as 'baby slings') as possible replacements for the supplementary loop belt.

This report consists of the following sections:

- Section 1 – Introduction
  A brief background about the restraint of children in aircraft and developments in both regulation and products in other countries is presented.

[1] Current regulations in Australia define an infant as a child being less than 3 years of age. Internationally, an infant is defined as being less than 2 years of age. Australian airline policies use 2 years for compatibility with the international convention.

- Section 2 – Evaluation of Australian CRS in aircraft
  An overview of the test methodology used in the project, which included both fit and sled testing. The results and problems encountered in the test program are discussed. Comparisons are drawn with other available aircraft CRS, such as the FAA approved DME seat and retention with the aircraft lap belt.
- Section 3 – Evaluation of infant carrier (slings) in aircraft
  An overview of the test methodology used in the project, which included sled and turbulence testing. The results and problems encountered in the test program are discussed.
- Sections 4-6 – Suggested actions, Glossary and References
- Appendix A – CRS profiles
  Descriptions of each of the tested CRS, the test results achieved, the problems encountered in using the specific CRS in an aircraft, and photographs. A description of the DME Corporation PlaneSeat CRS, specifically designed for aircraft use, is included.
- Appendix B – Infant carrier profiles
  Descriptions of each of the tested infant carriers with a summary of the test results, the problems encountered, and photographs.

A companion DVD is available, which contains video footage of the child restraint system testing. The DVD is presented in 5 parts as follows:

Part 1: Aircraft CRS testing
Safe-n-Sound Unity Baby Carrier
Babylove Primo Baby Carrier
Safe-n-Sound Royale convertible child restraint
Safe-n-Sound Galaxy convertible child restraint
Babylove F1-304 Sovereign convertible child restraint
IGC Aunger convertible child restraint
Safe-n-Sound Discovery child restraint
Safe-n-Sound Maxi Rider convertible booster
Safe-n-Sound Maxi Rider 2005 convertible booster
Safe-n-Sound Olympian booster Seat
Safe-n-Sound Nova booster cushion

Part 2: Aircraft lap belt testing
TNO P3/4 9 kg, 9-month-old dummy
TNO P3 15 kg, 3-year-old dummy
TNO P6 22 kg, 6-year-old dummy
TNO P6 22 kg, 6-year-old dummy with child harness and Qantas top tether

Part 3: DME Corporation PlaneSeat testing
DME CRS-2000 PlaneSeat

Part 4: Infant carrier (sling) testing
Amsafe loop belt
Snugli Comfort Vent Soft Carrier
Infantino GoGo Rider
Theodore Bean Infant & Toddler Carrier
BabyBjörn Original Baby Carrier

Part 5: Standard automotive CRS testing (AS/NZ 1754)
Safe-n-Sound Royale convertible child restraint

1.2 Background review

1.2.1 Commercial aircraft incidents, child injuries and cost concerns

The Kegworth disaster is a prime example of a potentially survivable aircraft crash. On 8 January 1989, a Boeing 737-400 on approach to East Midlands Airport, Kegworth, Leicestershire, crashed across the nearby motorway. Of the 126 occupants, 47 died and 74 were seriously injured. One infant on board was lap-held and restrained by a 'supplementary loop belt'. The child was severely injured and his mother later died in hospital from injuries, which were more severe than those sustained by occupants of neighbouring seats (Carter 1992).

In 1989, United Airlines Flight 232 crashed outside Sioux City, Iowa after one of the engines exploded. A 22-month old infant died after his mother was instructed by the flight attendant to place him on the floor of the cabin (Newman T B 2003). Another 11-month-old infant was lost by its parents during the crash. The child was rescued from the burning wreckage after being heard crying.

In a 1996 address to the U.S. Congress Subcommittee on Aviation, Jim Lightfoot offered the following cases (CTI 1996):

> *"… the Avianca Crash in New York followed upon Sioux City with seven children injured, one of whom died. Then, in 1994, a baby girl was thrown from her mother's lap in the USAir crash in Charlotte, North Carolina, and that child died… In both instances the National Transportation Safety Board determined a child safety seat would have saved the children's lives."*
>
> *"One American Airlines flight from Miami to San Francisco encountered turbulence so severe that there were 26 people injured. Among those were two toddlers that were literally thrown from their parents' laps."*
>
> *"Perhaps the saddest turbulence accident was a flight that experienced severe turbulence on approach into San Juan. The only injury was a skull fracture to a 7-week-old lap child, again torn from his mother's arms."*

Fife, Rosner and McKibben (1981) studied aircraft accident reports for crashes occurring between 1976 and 1979. Crashes that had survivors and fatalities, and which had infant passengers on board, were considered in the analysis. The relative risk of mortality between unrestrained infant passengers and restrained adult passengers was determined based on US data and that obtained from 39 other nations. Crude estimates yielded a relative risk of 7.1 based on US data, and 7.4 from worldwide data. When the possible effects of seat location and crash severity were considered, the relative risk was estimated as 5.9 based on US data, and 9.6 from worldwide data. The observed risk to infant passengers was attributed to the absence of a mechanical restraint system.

Chandler (1999) reported that in twenty-three aircraft accidents since 1970, the following injuries to lap-held infants would probably have been prevented by a CRS:

- 1972, one infant sustained minor injuries in turbulence
- 1984, one infant sustained serious injuries in a crash
- 1985, one infant sustained minor injuries in turbulence
- 1986, one infant sustained minor injuries in turbulence
- 1986, one infant sustained minor injury in a crash
- 1989, one infant died of smoke inhalation after a crash

- 1990, one infant sustained serious injuries in turbulence
- 1994, one infant sustained fatal injuries in a crash.There has been concern that the proposed changes to FAA regulations, ruling that children younger than two years must travel in approved CRS, may force travellers to opt for car travel. Newman, Johnston and Grossman (2003) performed risk and economic analyses of the proposed regulations in order to estimate: the number of prevented child air-crash fatalities; the threshold proportion of families switching from air travel to car travel above which the risk of the policy exceeds its benefit; and, the cost per death prevented. In summary, the analyses indicated that:

- The use of child safety restraint systems for airplane travel would prevent about 0.4 child air-crash deaths per year in the United States.
- The increase in deaths resulting from increased car travel could exceed the number of deaths prevented by child safety restraints if more than 5-10% of families switch from air to car travel. This estimate is unlikely to exceed 15%, although it varies depending on assumptions on trip distance, driver characteristics, and the effectiveness of CRS.
- Assuming no increase in car travel, the cost per death prevented would be approximately $6.4 million for every dollar cost of the round trip air ticket for the child.
- The researchers concluded that a policy requiring the use of CRS during air travel for children younger than two years could result in a net *increase* in deaths and injuries due to automobile travel, unless infant air-seats are provided at a low cost to travelling families.

1.2.2 The international situation

United States

In 1994, the US Civil Aerospace Medical Institute (CAMI) published findings from a study involving dynamic impact tests in which a variety of CRS in airline passenger seats were subjected to 16G peak longitudinal deceleration loads (Gowdy & DeWeese 1994). The study found that lap-held restraints allowed excessive forward body excursion of the test dummies, resulting in severe head impact with the seat back directly in front. The tests showed how a lap-held infant could be crushed between the forward seat back and the accompanying adult during impact. Further, excessive abdominal pressure exerted by the belt was recorded on the child test dummy.

Following the CAMI study, the US Federal Aviation Administration (FAA) issued a final rule in 1996 (61 FR 28416) banning the use of booster seats, and all lap-held restraint devices in aircraft during take-off, landing and taxi. This has resulted in lap-held children travelling wholly unrestrained in aircraft. In November 2001, the American Academy of Pediatrics (AAP) issued recommendations that children occupy their own seats on planes with suitable CRS (AAP 2001).

Current US regulations (FAA 2004) state that:

> *"A seat (or berth for a nonambulant person) must be provided for each occupant who has reached his or her second birthday."* (Sec. 25.785 (a));
>
> *"… a person may: (i) Be held by an adult who is occupying an approved seat or berth, provided that the person being held has not reached his or her second birthday and*

does not occupy or use any restraining device;" (Sec. 91.107 (a)(3)(i); Sec. 121.311 (b)(1); Sec 135.128 (a)(1));

"Notwithstanding any other provision of this section, booster-type child restraint systems (as defined in Federal Motor Vehicle Safety Standard FMVSS 213 (49 CFR 571.213)), vest- and harness-type child restraint systems, and lap held child restraints are not approved for use in aircraft;" (Sec. 91.107 (a)(3)(i)(4); Sec. 121.311 (b)(2)(ii)(D); Sec 135.128 (a)(2)(ii)(D)).

In September 1999, the U.S. National Highway Traffic Safety Administration (NHTSA) issued a final rule concerning Child Restraint Systems and Child Restraint Anchorage Systems. The rule requires that vehicles be fitted with a dedicated three-point anchorage system for child restraints – an upper anchorage point and two lower anchorage points. The upper anchorage allows the attachment of the CRS top-tether. The lower anchorage system includes a 6 mm diameter rigid rod or bar (an ISO rigid bar anchorage system), which is attached to the vehicle at the seat bight and provides an anchorage for the rigid or flexible connectors of the CRS. While the rule does not expressly require that a top tether be used, the head excursion limits for testing have been modified so as to enforce that top tethers are used in order to comply with the restrictions. The current requirements of the Federal Motor Vehicle Safety Standard 213 'Child Restraint Systems' (FMVSS 213 in 49 CFR Part 571) include a frontal head excursion limit of 813 mm (32") from the seat bight when tested without a top tether, and 720 mm (28") limit when tested with a top tether installed. An additional knee excursion limit of 915 mm from the seat bight is imposed (NHTSA, 2003).

Child restraint remains one of the 'Most Wanted Safety Improvements' by the US National Transportation Safety Board (NTSB) (Recommendation A-95-51). With support from the American Academy of Pediatrics and the Association of Flight Attendants, the NTSB recommended *"… all occupants should be restrained during takeoff, landing, and turbulent conditions and that all infants and small children should be restrained in an approved child restraint system appropriate to their height and weight."* Despite this, the FAA has not issued regulations that mandate the use of child restraints citing concerns about diversion of child passengers to automobile travel.

In 2004, the FAA initiated a public education campaign, *Turbulence Happens*, encouraging parents and guardians to use approved child restraint systems on aircraft. The website and flyer states "*FAA strongly recommends that all children who fly, regardless of their size, use the appropriate restraint based on their size and weight.*" Approved CRS bear a label with red lettering, which states, "*This restraint is certified for use in motor vehicles and aircraft*". The FAA does not directly control the approval of CRS: certification follows FMVSS 213, which sets out the dynamic test requirements for CRS use in motor vehicles. For aircraft use, an additional 180-degree inversion test requirement must be met. As a general guide to parents, the FAA advises that a CRS of less than 16 inches (400 mm) width will fit in most aircraft seats.

The United Kingdom

The UK Civil Aviation Authority (CAA) conducted its own investigations into automotive CRS use in aircraft, the results of which are published in CAA paper 92020 (CAA 1992). Tests on anthropomorphic dummies showed that while forward-facing CRS offered similar degrees of protection to children in aircraft as in cars, rearward-facing CRS did not. The CAA currently mandates that various CRS are available to all children less than 2 years of age on board aircraft, the types of which depend on the age or size of the child (CAA 2003). Such devices include approved shoulder harnesses, car-type restraints, and loop belts.

The requirements set out in the CAA Air Navigation Order (CAA 2003) are as follows:

> *"All passengers of three years of age or more are properly secured in their seats by safety belts (with diagonal shoulder strap where required to be carried) or safety harness."* (Sec. 2) a) i));
>
> *"All passengers under the age of three years but not less than two years are properly secured in their seats by safety belts (with diagonal shoulder strap where required to be carried) or safety harness, or are properly secured in a car type safety seat …… and which safety seat is in turn properly secured to an aircraft passenger seat."* (Sec. 2) a) ii));
>
> *"All passengers under the age of two years but not less than six months are properly secured by means of a child restraint device …… which safety seat is in turn properly secured to an aircraft passenger seat."* (Sec. 2) a) iii));
>
> *"All passengers under the age of six months are properly secured by means of a supplementary loop restraint device which meets the requirements …… aforesaid."* (Sec. 2) a) iv)).

Canada

The current Canadian Aviation Regulations CAR Part VI Subpart 5 state that:

> *" … every passenger who is not an infant shall … (b) if responsible for an infant for which no child restraint system is provided, hold the infant securely in the passenger's arms;"* (Sec. 605.26 Use of Passenger Safety Belts and Restraint Systems);
>
> *"No operator of an aircraft shall permit the use of a child restraint system on board the aircraft unless … (e) the tether strap is used according to the manufacturer's instructions or, where subsection (2) applies, secured so as not to pose a hazard to the person using the child restraint system or to any other person … (2) Where a seat incorporates design features to reduce occupant loads, such as the crushing or separation of certain components, and the seat is in compliance with the applicable design standards, no person shall use the tether strap on the child restraint system to secure the system."* (Part VI Subpart 5 Sec. 605.28 Child Restraint System).

1.2.3 The Australian situation

The Civil Aviation Safety Authority (CASA) governs the practice in Australia. Subregulation 251(1) of the Civil Aviation Regulations 1988 requires that *"… seat belts shall be worn by all crew members and passengers: (a) during take-off and landing; (b) during an instrument approach; (c) when the aircraft is flying at a height of less than 1,000 feet above the terrain; and (d) at all times in turbulent conditions."*

Part 20, Section 20.16.3 of the Civil Aviation Orders states:

> *"An infant may be carried in the arms or on the lap of an adult passenger, in a bassinet or in an infant seat … providing the bassinet or infant seat is restrained so as to prevent it from moving under the maximum accelerations to be expected in flight and in an emergency alighting, and precautions are taken to ensure that, at the times seat belts are required to be worn, the infant will not be thrown from the bassinet or infant seat under these acceleration.";*
>
> *"When an infant is carried in the arms or on the lap of a passenger … the seat belt, when required to be worn, shall be fastened around the passengers carrying or nursing the infant, but not around the infant";*

"An infant seat, being a seat designed for the seating and restraint of infants, must not be used on an aircraft unless CASA or a recognised authority has approved the seat in writing as being of a type that is suitable for use by infants in an aircraft".

The Civil Aviation Advisory Publication, CAAP 235-2(1) was issued by CASA in December 2002 to provide advice and the preferred method for complying with CAR 1988. It states that:

"An infant carried in the arms of an adult passenger (lap held) must be restrained, but the adult seat belt must not be fastened around both adult and infant. During an emergency landing sequence, the restraining loads on the adult would be transferred from the lap belt through the infant causing serious or potentially fatal injuries";

"A device known as a "supplementary loop belt" provides an additional seat belt with stitched loops through which the adult seat belt is passed. The adult belt is fastened around the adult, and the additional belt is then separately fastened around the infant. This is the only known device which provides an acceptable restraint for a lap held infant during the times specified in CAO 20.16.3 subsection 3";

"The supplementary loop belt will provide some restraint to an infant during turbulence or mild longitudinal emergency loading such as a rejected take off. However, the supplementary loop belt does not provide an equivalent level of protection to a lap belt restraint for a separately seated adult during a severe but potentially survivable crash. The supplementary belt is even less effective for a new-born infant as their skeletal structure would be unable to cope with any significant load from the 5 cm wide webbing. For an equivalent level of protection, all infants should be seated in an individual infant restraint device in a separate passenger seat".

A brief study of Australian CRS in commercial aircraft seats was conducted in 1995 (Bonicci 1995). This limited test series included only three frontal dynamic tests with a Qantas approved forward-facing CRS without tether and a Britax forward-facing CRS with a top tether attachment. The study found that the use of the top tether did not significantly improve the dynamic performance of the CRS.

At the 18th Aviation Safety Forum (ASF)[2] held on 20 May 2004, the ASF presented a Position in Principle that '*…subject to some practical constraints listed below, infants are entitled to the same level of protection both in flight and during emergency landing situations that is afforded to adults…*". It was recommended (Recommendation 31) that CASA organise and hold an industry conference relating to infant restraint.

The Infant Restraint Conference was held by CASA on 23 November 2004 in Canberra. It was decided at that conference to await the outcome of this project before considering any changes to the local advisory material. Airline cabin crew attending the conference suggested that the use of infant carriers (slings) should be considered as possible infant restraint systems. Parents often carried their infants on board in these devices only to be told that they could not use them during take-off, landing and in turbulence. As a result of this suggestion, the original project plan was extended to include an evaluation of a sample of available infant carrier systems.

1.2.4 Recent developments

Internationally, infants can still be lap-held by parents or guardians throughout a flight. While the use of a supplementary loop belt or 'belly-belt' is mandatory in the UK, it is

[2] The Aviation Safety Forum (ASF) is an Australian consultative body of experienced aviation industry and consumer representatives, which acts as an advisory committee to the Civil Aviation Safety Authority (CASA).

prohibited in the US and Canada. In Australia, both Qantas and Virgin Blue Airlines require the use of loop belts for lap-held infants at all times when other passengers are required to wear seat belts.

In Australia and Canada, automotive child restraints can only be installed on aircraft if they can be fitted in a similar fashion to the motor vehicle installation. This requires that the seat be restrained by the lap belt and a top tether attachment, which is not possible on normal aircraft seats. In Australia, Qantas Airways supplies a tether strap manufactured by Britax for this purpose, which attaches to the rear leg of the seat. Virgin Blue currently does not allow the use of CRS on board their aircraft. The additional costs involved for travelling families has deterred further action. For domestic flights, lap-held infants travel free of charge while Qantas charges the full adult fare for children two years and older and for infants travelling in their own seats. On international flights, infants are charged 10% of the adult fare if lap-held and 75% if they occupy their own seats; children older than two years are also charged 75% of the adult fare if they occupy their own seat.

One solution is for the airline itself to provide child restraints that are specifically designed for aircraft use. Currently, only Virgin-Atlantic and Qatar Airways make such devices available. Since their CAA approval in 1992, Virgin-Atlantic has provided Infant CareChairs to children aged from 6 months to 3 years occupying seats on their flights. The CareChair was developed jointly by Virgin Airlines and Aviation Furnishings International (AFI), and is designed specifically for use in aircraft. The seat is made of aircraft approved materials, incorporates a five-point harness, weighs 13 lbs (5.9 kg), and folds for storage (Gooding 1999) (see Figure 1.1).

Figure 1.1. The AFI CareChair provided by Virgin-Atlantic is CAA approved since 1992 for use by infants from 6 months to 3 years of age (Gooding 1999)

Qatar Airways currently provides the DME Corporation CRS-2000 PlaneSeat, which is designed to accommodate infants (up to 20 lbs or 9 kg) and toddlers (up to 40 lbs or 18 kg) in rearward-facing or forward-facing configurations, respectively (see Figure 1.2). The seat folds to 6 inches (150 mm), weighs a nominal 10 lbs (4.5 kg) and is certified for use in aircraft and motor vehicles to FMVSS 213 (DME Corporation 1999). The seat costs between US $800 and $1200 each depending on quantity and upholstery (Ritter 2001).

Figure 1.2. DME Corporation CRS-2000 PlaneSeat in rearward-facing configuration (top left), forward-facing configuration (top right) (Ritter 2001), and folded for storage (bottom) (DME Corporation 1999)

Amsafe Aviation has developed another solution for children aged 1 to 4 years and weighing up to 44 lbs (20 kg). The Amsafe Child Aviation Restraint System 'CAReS' is a supplemental restraint system, which secures a child in its own seat. The harness slips over the seat back and attaches to the existing lap belt restraint. At present, the product is in the certification stage and Amsafe advises that it will not be made available for purchase by the general public, but will be made available for use in various airlines once approved (Amsafe 2004).

Figure 1.3. Amsafe's CAReS restraint (Amsafe 2004)

The Luftikid is an inflatable, forward-facing child restraint for children ranging in height from 710 to 1200 mm and in weight from 9 to 25 kg (see Figure 1.4). The German design weighs only 700 g and is 16G compliant. The device is currently approved by TÜV[3] for use only on certain qualified cabins in ATLAS JET International Airways, LTU, Condor Flugdienst GmbH, and Condor Berlin GmbH aircraft (TÜV 2004).

[3] The TÜV Rheinland Group is an international testing services company, which approves CRS for use in certain aircraft seats (TÜV 2004).

Figure 1.4. The Luftikid inflatable child restraint (Luftikid 2004)

The Sit ‘n’ Stroll 5-in-1 Travel System is a child restraint approved for use on motor vehicles and aircraft in the US. The restraint can be used in a rearward- or forward-facing configuration. In addition, it converts into a stroller (see Figure 1.5), which fits down the aisle of a standard aircraft cabin. The system measures 18 inches (460 mm) wide, weighs 16.5 lb (7.5 kg) and retails for about US $200 (Strolex Corporation 2005).

Figure 1.5. The Sit ‘n’ Stroll 5-in-1 Travel System by Strolex Corporation (2005)

While the FAA has banned all supplementary restraint devices with the exception of approved CRS during takeoff, taxi and landing, a variety of alternative devices have become available for purchase in the US for securing lap-held infants during flight.

The Tyke Tube Infant Air Safety Capsule is a capsule with a cushioned interior, which allows a lap-held infant to be restrained via an internal five-point restraint. The capsule itself is then strapped to the adult’s lap belt (see Figure 1.6). The product has passed FAA dynamic testing at 16.9G but has yet to be approved (Tyke Tube Industries 2000).

The Baby B’Air Safety Vest attaches to the adult’s lap belt and is designed for infants up to 2 years of age. The design is intended to address the problems of abdominal loading by the belly belt by distributing the load through the vest area, Figure 1.7. The product is not approved for use during taxi, takeoff and landing (Baby B’Air 1996).

Figure 1.6. The Tyke Tube Infant Air Safety Capsule (Tyke Tube Industries 2000)

Figure 1.7. Baby B'Air Safety Vest front view (left), rear view (centre) and in use (right) (Baby B'Air 1996)

Recent changes to FMVSS 213 require that new automotive CRS in the U.S. be fitted with two lower connectors for use in motor vehicles with ISO rigid anchorage systems, which have become mandatory on all vehicles sold in North America (NHTSA 1999). FAA concerns have been raised regarding rigid connectors and the potential damage to aircraft seat cushions and the intrusion into the leg space of passengers seated immediately behind the seat. Some vehicles being sold in Australia are now also fitted with this system.

To assist in addressing these changes, the FAA recently published a request for comments on allowing the use on board aircraft of dedicated CRS, which are approved by the Administration (FAA 2005). The aim is to allow the use of CRS that do not meet the specific requirements of automotive CRS standards.

2 EVALUATION OF AUSTRALIAN CRS IN AIRCRAFT

2.1 CRS test methodology

2.1.1 Introduction

The CRS samples for use in the testing were selected to cover the range of common child restraint types available in Australia. Many of the CRS tested were supplied by Britax Childcare and were of the Safe-n-Sound brand. Britax has the majority of the CRS market in Australia. A selection of other brands was included in the test series for comparison. These CRS included Babylove, IGC (Mother's Choice, GoSafe and Bertini), Fisher-Price and Infa. The classes of CRS types, together with the appropriate anthropomorphic test dummies (as required by AS/NZS 1754:2004), are presented in Table 2.1.

Table 2.1. Classification of Child Restraint Systems and approximate age/weight ranges

Type	Description	Age/Weight Range	ATD
A	Rearward-facing infant restraint with a harness	Birth to 6 months (up to 9 kg)	TNO P3/4 (9 kg)
A/B	Convertible child restraint (rearward- or forward-facing) with a harness	Birth to 4 years (up to 18 kg)	TNO P3/4 (9 kg) TNO P3 (15 kg)
B	Forward-facing child restraint with a harness	6 months to 4 years (8 to 18 kg)	TNO P3 (15 kg)
B/E	Convertible child restraint/booster seat with a harness	6 months to 7 years (8 to 26 kg)	TNO P6 (22 kg)
E	Child booster seat with high back and with or without a harness or child booster cushion without a back or harness	3 to 7 years (14 to 26 kg)	TNO P6 (22 kg)

Testing of the CRS was carried out at the Britax Quality Evaluation and Standards Testing (QUEST) Centre. The Quest Centre is accredited for testing to AS/NZS 1754, AS/NZS 3629 and AS/NZS 2088, and it has a dynamic test sled with an angled seat fixture for seat testing to the standard required by FAR 25.562 (FAA 1988). The Centre has a selection of child-sized TNO "P" series ATDs available for use, including the P3/4 (9 kg, 9-month-old), P3 (15 kg, 3-year-old) and P6 (22 kg, 6-year-old).

Britax Childcare provided the Safe-n-Sound test samples and carried out the testing at no charge in the interest of improving child safety.

The CRS samples were subjected to three tests: an aircraft seat fit test, the FAA inversion test, and a dynamic sled test. These tests are described below and test results are presented in Section 2.2.

2.1.2 Aircraft seat fit test

The CRS were physically fitted into the aircraft seat row in order to check whether they could be installed in an aircraft seat with a lap belt. Qantas Airways Ltd provided two rows of two economy class aircraft seats for the test procedure (see Figure 2.1). These B/E Aerospace seats are AS 8049 and FAR 25.853(c) approved, and have a width of 450 mm between the armrests. The seat-cushions were 480 mm wide by 460 mm deep and were held in place by hook and loop (Velcro®) strips. Qantas advised that the seat rows are installed at a pitch of 31 inches (790 mm) on board their aircraft.

Figure 2.1. The aircraft seat row supplied by Qantas

Each CRS was installed according to the manufacturer's instructions, but without attachment of the top tether strap. Any difficulties in the installation and removal were recorded.

2.1.3 Inversion test

Several sample CRS were subjected to the inversion test required for approval of CRS for aircraft use to FMVSS 213 (see Section 1.2.2). Only a limited number of CRS were tested, as it was expected that the test would cause no difficulty for the majority of Australian CRS, which have 6-point harnesses for the child. For this test, the CRS was secured by a safety belt to an aircraft seat simulator. The seat and CRS with a secured dummy of appropriate size was rotated forward through 180 degrees. The requirement is that when the CRS is rotated forward it must not fall out of the belt and the dummy must not fall out of the CRS.

2.1.4 Dynamic sled test

The capabilities of the Australian CRS without a top tether when in an aircraft crash environment were tested by means of a dynamic sled test[4], based on the requirements of the FAA aircraft seat test. The test requirements are set out in FAR Sec. 25.562 *Emergency Landing Dynamic Conditions* (FAA 1988) and are summarized in Table 2.2. Additional guidelines were published by the FAA in the corresponding Advisory Circular issued in January 1996 (AC 25.562-1A *Dynamic Evaluation of Seat Restraint Systems & Occupant Protection on Transport Category Airplanes*).

Table 2.2. FAA Dynamic Seat Test Requirements for compliance with FAR 25.562

Dynamic Test Requirements	**FAA Test 1 Criteria**	**FAA Test 2 Criteria**
Test orientation	Vertical, aircraft longitudinal axis 30° to the horizontal	Aircraft longitudinal axis horizontal, 10° yaw right or left
Min. Δ velocity, m/s (km/h)	10.67 (38.4)	13.41 (48.3)
Max. rise time, s	0.08	0.09
Min. peak acceleration, G	14	16
Floor deformation	none	10° pitch, 10° roll
ATD head response criteria	HIC<1000*	HIC<1000*
ATD chest response criteria	Where installed, straps must remain on shoulder. Individual strap loads <1,750 pounds or <2,000 pounds combined*.	Where installed, straps must remain on shoulder. Individual strap loads <1,750 pounds or <2,000 pounds combined*.
ATD pelvis response criteria	Lap belt must remain on pelvis. Lumbar compressive loads <1500 pounds*.	Lap belt must remain on pelvis. Lumbar compressive loads <1500 pounds*.
ATD leg response criteria	Femur axial compressive loads <2,250 pounds each*.	Femur axial compressive loads <2,250 pounds each*.

* These injury protection criteria are for the responses of a 170 lb (75 kg) adult male ATD.

The FAA requires two dynamic tests to evaluate an aircraft seat, its restraint system, the related interior systems, and the responses of an anthropomorphic test dummy (ATD).

[4] Dynamic sled tests are designed to simulate the inertial effects of real-world vehicle crashes. Sled tests are conducted to assess vehicle components such as seat assemblies and restraint systems, without having to carry out full-scale crash tests. In the various types of sled testing, the sleds are subject to a defined acceleration/deceleration time pulse in order to achieve a defined horizontal velocity change.

In the CRS sled testing, a decelerating sled was used in which the rail-mounted sled platform is propelled by means of elastic bands (bungee cords). The required sled deceleration pulse was then achieved by means of re-usable polyurethane tube devices placed in parallel inside steel pipes, which are rigidly attached to a fixed barrier. Deceleration occurs when a set of steel shafts on the sled, which are fitted with olive-shaped ends, are rammed inside the polyurethane tubes, absorbing the impact energy. The sled pulse is controlled by combining the length and rigidity of the polyurethane tubes, the sled entry velocity and the shape of the olives.

The seats are required to demonstrate protection of the occupant from serious injury to the head, chest, lower spine and femurs.

FAA Test 1 is a single row seat test, which determines the level of protection afforded by the seat in an impact where the force acts primarily in the direction along the axis of the spinal column of the passenger combined with a forward component. FAA Test 2 is a single row seat test, which determines the level of protection afforded by the seat in an impact force primarily in the direction of the longitudinal axis of the aircraft, combined with a yaw component.

Most important for preventing injury in a crash situation to a fully restrained child in a CRS is ensuring that the child's head does not make contact with any of the surrounding structures. In the case of the aircraft seat, this implies that the head excursion must be kept within the aircraft seat envelope and not impact with the forward seat back. For this project, the sled test was designed to produce the maximum head excursion of the child dummy in an aircraft crash.

The most severe FAA test is the 16G longitudinal test (FAA Test 2). For the CRS dynamic testing in this project, a worst-case scenario was used in which this FAA test was used but without the 10 degrees of yaw in order to yield the maximum frontal head excursion possible.

In comparison, the current Australian CRS standard (AS/NZS 1754:2004) requires that the CRS, with a top tether, be subjected to a velocity change of 49 km/h and with a deceleration of between 24G and 34G to be achieved within 30 ms. These test conditions are more severe than the FAA testing of aircraft seats.

In this study, the dynamic test was based on a single row of aircraft seats. The aircraft seats are fragile and were damaged by the multiple testing required, especially the back reclining mechanism. A single row of seats was used for the dynamic tests to minimise maintenance between tests and ensure that there was a back up available if the row failed, so ensuring that the test series would not be delayed. This procedure also had a secondary advantage in that it allowed the fit testing of the CRS to be conducted in parallel with the dynamic tests.

The CRS samples to be tested were fitted to the aircraft seat according to the manufacturer's instructions, but using only the aircraft seat lap belt which was adjusted by means of a 60 to 80 N pull to the free-end of the webbing. The child dummies were chosen and fitted in the CRS restraints according to the Australian test standard AS/NZS 3629.1:2004. The CRS harnesses were adjusted with the use of a spacer between the back of the specific dummy and the child restraint, as specified in AS/NZS 3629.1:2004. The 25 mm spacer was then removed to give a repeatable amount of slack in the harness for the testing.

The CRS were then tested to the FAA pulse in this configuration. For comparison purposes, some tests were made using a supplementary Safe-n-Sound top tether strap, as used by Qantas.

Lateral high-speed digital video (at 500 fps) was taken of each sled test to observe the dummy responses and allow the head excursion in the test to be measured. Measurements of dummy head and chest acceleration, sled deceleration and lap belt loads were also recorded during the tests when the appropriate instrumentation was fitted.

2.1.5 Assessment of injury

The test requirements of the current Australian CRS standard, AS/NZS 1754:2004 'Child restraint systems for use in motor vehicles', are that the resultant head deceleration of the test dummy shall not exceed 150G when the CRS is subjected to a velocity change of not less than 49 km/h and a deceleration of between 24G and 34G achieved within 30 ms. The standard specifies head excursion limits for rearward-facing infant restraints or convertibles (Type A or A/B) in which the test dummy's head must remain within the area bounded by the lines AC and CD in Figure 2.2. Here CD represents the horizontal plane at a distance of 800 mm above the seat bight (or seat reference point A). AC is the plane running through the vehicle seat back, from the seat bight to the intersection at CD. Note the AB and BE boundaries correspond to transversely installed CRS, which were not examined in this study. There is no forward excursion limit imposed in AS/NZS 1754:2004.

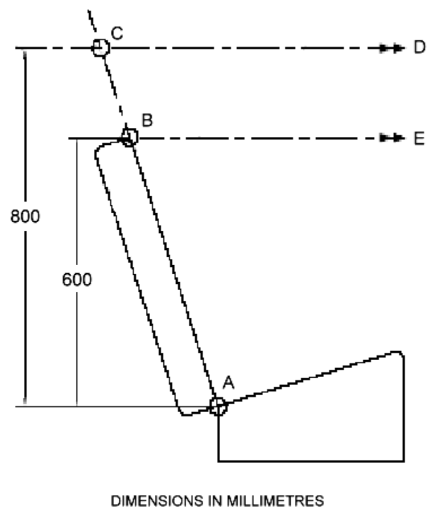

Figure 2.2. Dummy head excursion requirements from AS/NZS 1754:2004

The Injury Assessment Reference Values (IARVs) developed by Mertz et al. (2003) were also used as a guide for interpreting whether a given dummy response was likely to be injurious. The Mertz et al. IARVs were chosen as they are the most commonly applied injury criteria used in the automotive industry. These reference values have been scaled from the adult values for use with different sized child dummies used for the tests and these values are presented in Table 2.3. The peak resultant acceleration of the head CG (centre of gravity) was scaled by Mertz et al. from 180G for the mid-sized male, which represents a less than 5% risk of skull fracture. Thoracic spinal accelerations at T4 (the 4^{th} thoracic vertebra) are scaled up from a 60G limit for mid-sized males. For children, a larger load can be applied before rib fracture occurs, but often at AIS[5]≥4 heart failure may occur prior to rib fracture.

[5] AIS – Abbreviated Injury Scale. See Glossary for definition.

Table 2.3. IARVs scaled for different sized child dummies, after Mertz et al. (2003)

	ATD Size			
Injury Assessment Criteria	**6-month-old**	**12-month-old**	**3-year-old**	**6-year-old**
HIC_{15} *	377	389	568	723
Peak head CG acceleration (G)	156	154	175	189
Peak chest acceleration (T4) (G)	88	87	92	93

* HIC_{15} refers to a HIC calculation limited to 15 ms time intervals.

The Head Injury Criterion (HIC) used for the FAA aircraft seat certification was not used in this project, as it is based on the acceleration of the head resulting from a head impact. The HIC IARVs are given in Table 2.3 for comparison purposes.

HIC is defined as:

$$HIC = \max\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)$$

where: $a(t)$ = resultant acceleration of the head's centre of gravity during the $t_2 - t_1$ time interval (in G)
$t_2 - t_1$ = time interval during the acceleration pulse in which $a(t)$ attains a maximum value (in ms)

HIC is based on the Wayne State University Concussion Tolerance Curve (see Figure 2.3) proposed by Lissner et al. (1960). This curve plots the effective acceleration of the head, which is an average anterior-posterior acceleration of the skull measured at the occipital bone, in impacts of the forehead with a rigid planar surface, against effective duration of the pulse (SAE 1980). The latter part of the curve with the asymptotic value of 42G is based on volunteer whole body data, which did not involve direct blows to the head. Patrick et al. (1965) recommended that this asymptotic value be raised to 80G. This revised level has been used as the basis of the US Federal Motor Vehicle Safety Standards (FMVSS).

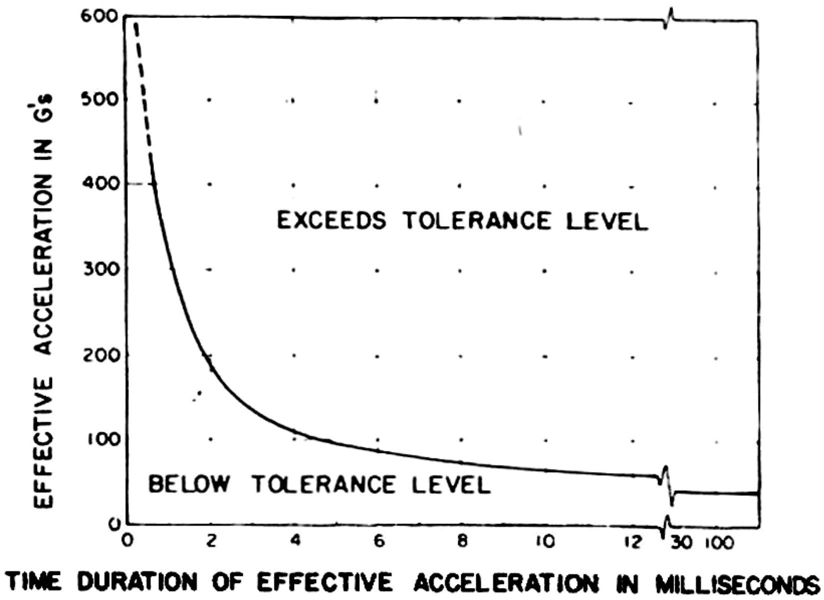

Figure 2.3. The Wayne State University Concussion Tolerance Curve, from SAE (1980)

For this test series the main injury predictor used to rate the CRS was the maximum dummy head excursion during the sled test. In most tests, the dummy had additional instrumentation fitted with triaxial head and chest accelerometers to measure head and chest acceleration as well as the seat lap belt load.

2.2 CRS test results

2.2.1 Fit testing

A total of 20 Australian approved CRS and the DME PlaneSeat were fit tested. The CRS samples were fitted to the aircraft seat according to the manufacturer's instructions. The conditions under which the fit tests were conducted did not fully reflect the complexity of installation within an aircraft cabin where additional restrictions would most likely occur due to one-sided access, limited headroom and/or differing seat pitches. It became obvious that many of the CRS had not been designed for compatibility with the constraints of the aircraft seats. The results of the fit tests are summarised in Table 2.4.

Fourteen of the CRS models had problems in this test. The problem areas encountered were mainly concerned with the CRS being too large to fit within the confines of the aircraft seat, or being incompatible with the latch mechanism of the aircraft lap belt. These problems are described in the following sections.

Infant restraint base mount is incompatible with aircraft lap belt

The infant restraints (Type A) tested come with a detachable base mount that allows the carrier module to be easily detached and re-attached to a motor vehicle seat. The base is installed in the seat via the lap belt or lap-sash belt, which is threaded through slots in the base and secured via the side-mounted latch mechanism. The carrier module can then be snapped into place via the engagement vanes or similar mechanisms within the base. However, when installing the base in an aircraft seat, the centrally mounted latch of the aircraft lap belt interferes with the attachment mechanism. This interference prevents the carrier module from being engaged (see Figure 2.4). To effectively install these CRS in an aircraft seat would require a modification that relocates the latch, for example by adding an extension to or shortening the tongue side of the belt.

Figure 2.4. Incompatibility of infant restraint base mounts with the aircraft seat lap belt

Table 2.4. Summary of CRS fit test results (✓- yes, ✗ - no, ~ - marginal/with difficulty, n/a - not applicable)

CRS Model	a) Fits within armrests	b) Fits within 31” seat pitch§	c) Lap belt can be fastened	d) Lap belt can be adjusted	e) Lap belt can be released	f) Harness can be adjusted	Comments/Observations
Type A: Rear facing baby carrier							
Safe-n-Sound Baby Safety Capsule	✓	~	✓	✓	✓	✓	b) D = 660 mm
Safe-n-Sound Unity Baby Carrier	~	✓	~	~	~	✓	a) Slight overhang on the armrests (20 mm) c) d) e) Cannot be installed with the base due to lap belt latch position – interferes with carrier engagement vanes. Requires shortening of the tongue side belt by 60-65 mm. Without the base, the lap belt comes over the infant with the latch within easy reach.
Babylove Primo 6 in 1 Baby Capsule	✓	✓	~	~	~	✓	c) d) e) Cannot be installed with the base due to lap belt latch position – interferes with carrier engagement vanes. Without the base, the lap belt latch locates between the infant’s legs in an awkward position.
Type A/B: Convertible child restraint: rear facing for babies, forward facing for toddlers							
Safe-n-Sound Royale Retractor	✓	~	~	~	~	✓	b) D = 660 mm in A mode c) d) e) Little access in B mode Note: Lap belt latch locates between the infant’s legs in an awkward position in A mode.
Safe-n-Sound Galaxy Ultra	✓	✗	~	~	~	✓	b) D = 680 mm in A mode c) d) e) Little access in B mode Note: Lap belt latch locates between the infant’s legs in an awkward position in A mode.
BabyLove F1-304 Sovereign	✓	✗	~	~	~	✓	b) D = 760 mm in A mode c) Lap belt tongue just reaches the slot d) Uses maximum length of belt. The belt must be twisted before engagement to allow adjustment due to the direction of pull. e) There is little access to release the lap belt latch. The buckle must be flipped in order to release the latch in both modes.
IGC GoSafe Convertible 2000	✓	~	~	~	~	✓	b) D = 660 mm in A mode c) d) e) Difficult to access lap belt latch in rear facing mode.
IGC Aunger	✓	✓	~	~	~	✓	c) d) e) Difficult in B mode due to little access. The buckle must be flipped in order to release the latch in A mode.
IGC Bertini Classique	✓	✗	✗	✗	✗	✓	b) D = 700 mm in A mode c) d) e) No access in A mode
Fisher-Price Convertible	✓	~	✓	✓	✓	✓	b) D = 670 mm
Infa Securé Turn-a-Tot	✓	✓	~	~	~	✓	d) e) Difficult to access the lap belt latch once fastened in B mode. In A mode, it is difficult to fasten and adjust the lap belt due to the location of the latch. For proper adjustment, the latch must be located at the centre, under the CRS.
DME CRS-2000 Plane Seat	✓	✓	✓	✓	✓	✓	
Type B: Forward facing seat for toddlers							
Safe-n-Sound Discovery Plus	✓	✓	✓	✓	✓	✓	
Safe-n-Sound Series 3	✓	✓	✓	✓	✓	✓	Note: This CRS is designed for use with a top tether. The lap belt is positioned across the front of the seat, which means that any forward rotation will dislodge the seat. This cannot be used in aircraft.
Type B/E: Convertible booster seat							
Safe-n-Sound MaxiRider	✓	✓	✓	✓	~	✓	d) Aircraft lap belt buckle must be turned in order to release the latch. Note: In both the upright and reclined modes, the aircraft lap belt buckle ends up behind the child, in the lumbar region, with only thin padding covering it. This would be too uncomfortable for a child.
Type E: Child booster seat							
Safe-n-Sound Apollo	✓	✓	✓	✓	✓	✓	
Safe-n-Sound Olympian	✓	✓	✓	✓	✓	✓	
BabyLove Graduate	✗	✓	✓	✓	✓	✓	
IGC GoSafe Advance	✓	✓	✓	✓	✓	✓	Note: The geometry of the CRS is such that when fastened the lap belt has little adjustment and may be too tight for some children.
IGC GoSafe SportsBaby	✗	✓	✓	✗	✓	✓	Note: The geometry of the CRS is such that when fastened the lap belt has little adjustment and may be too tight for some children.
Safe-n-Sound Nova (booster cushion)	✓	✓	✓	✓	✓	n/a	

§ D = Maximum depth of CRS when installed on the aircraft seat, measured from the seat bight. At a seat pitch of 31 inches (790 mm), the fit will vary according to the vertical position of the point of maximum depth of the CRS and the angle of the seat back. D = 660 mm is used here as the cut-off value.

Location of lap belt latch in rear facing restraints without base mount

Often when infant restraints (Type A) without their base mounts, and convertible child restraints (Type A/B) in rearward-facing mode, are installed in aircraft seats, the lap belt latch is often poorly positioned. In some designs, the belt is passed through slots located at the leg area of the carrier. This arrangement locates the lap belt latch under or between the legs of the infant, under thin padding, which may be uncomfortable. Other designs require the lap belt to be passed through slots that position the belt over the top of the carrier. The lap belt latch is then located directly above and within reach of the infant (see Figure 2.5).

Figure 2.5. Location of the aircraft lap belt latch for rearward-facing restraints without a base mount: a) under the infant (left) or b) over the infant (right)

CRS is oversized for aircraft seat pitch

The standard aircraft seat pitch is 30 to 31 inches (760 to 790 mm) for economy-class seating. Rearward-facing infant restraints (Type A) and convertible child restraints (Type A/B) in rearward-facing mode are often too long to fit (see Figure 2.6). Those CRS, which fit within the seat pitch, usually interfere with the layback of the forward seat.

Figure 2.6. Superimposed images to show the fit of convertible child restraints in reclined rearward-facing mode within a 31-inch aircraft seat pitch

Little or no access to fasten, adjust or release lap belt latch

Child restraint systems are designed for installation on car seats using the standard lap or lap-sash seat belts. The slots are designed for a belt to be passed through to the other side, where it can be engaged with a buckle mounted on the seat. In many cases, the centrally mounted aircraft lap belt latch was difficult to access through the slot, to engage, adjust or release. A major problem arises from the latch needing to be pulled outwards to release (see Figure 2.7). Often there is no clearance in which to release the latch, or care must be taken to fasten the belt so as to allow subsequent release.

Figure 2.7. Access problems in engagement, adjustment and release of aircraft lap belt latch

CRS is oversized for aircraft seat width

Many of the polystyrene child booster (Type E) seats are too wide to fit between the aircraft seat armrests. The aircraft seats used in this project measured 450 mm between the armrests, with 480 mm wide cushions. Economy-class aircraft seats are commonly 400 to 460 mm wide (16 to 18 inches), which is even narrower than the test seats used. Further, this style of restraint can also be too bulky for the standard aircraft seat lap belt. Some of the simpler styles without seat belt locators (notches in the sides to guide seat belt placement) require the lap belt to be adjusted to its full length. This may cause the lap belt to be too tight for some children (see Figure 2.8).

Figure 2.8. Oversized child booster seats

2.2.2 Inversion tests

The Safe-n-Sound Royale, Safe-n-Sound Galaxy and BabyLove F1-304 Sovereign were subjected to the FAA inversion test for turbulence. The CRS samples were secured in the aircraft seat simulator according to the manufacturer's instructions for installation within vehicles but without the top tether attachment. The tests were performed using a TNO 3-year-old dummy secured in the 6-point harnesses in forward-facing mode (see Figure 2.9).

In all tests the CRS remained secured in the aircraft seat under 180 degrees of forward rotation and the child dummy was retained.

Figure 2.9. A TNO 3-year-old dummy in a Safe-n-Sound Royale CRS mounted in the aircraft style seat of the inversion test rig, undergoing the 180 degrees forward rotation

2.2.3 Dynamic sled tests

A total of 34 sled tests of 11 models of Australian CRS were completed. At least one sample of each child restraint type was sled tested to investigate its dynamic performance. Eight Safe-n-Sound CRS models were tested along with 3 models from other manufacturers: Babylove Primo 6-in-1, Babylove F1-304 Sovereign Convertible and IGC Aunger Convertible. Also included were five tests where the child dummies (TNO P3/4, P3 and P6) were restrained only by the standard aircraft lap seat belt. The results are summarised in Table 2.5, discussed in Section 2.3.5, and details are provided in Appendix A: CRS profiles and in the companion DVD. Also included in this DVD are tests of the FAA approved DME aircraft CRS.

The average sled deceleration for the tests was 18.9G and the mean entry velocity was 47.6 km/h. The sled deceleration pulse remained consistent throughout the test series. To check on test repeatability, three pulses for a repeated test configuration are compared in Figure 2.10. The sled pulses are compared over the range of the various CRS types in Figure 2.11.

Table 2.5. Summary of CRS dynamic sled tests

Model	Configuration	ATD	Test no.	Test Sample	Sled decel. (g)	Entry velocity (km/h)
Type A: Rear facing baby carrier						
Safe-n-Sound Unity Baby Carrier	No base	TNO P3/4 (9kg)	8165	1	20.0	48.18
Babylove Primo 6-in-1 Baby Capsule	No base	TNO P3/4 (9kg)	8292	1	18.0	47.73
			8298	1	19.0	47.80
Type A/B: Convertible child restraint: rear facing for babies, forward facing for toddlers						
Safe-n-Sound Royale Retractor Convertible	Simple rear recline	TNO P3/4 (9kg)	8161	1	20.0	47.49
			8162	1	18.5	47.63
			8163	1	19.0	47.64
			8164	2	19.0	47.70
	Frontal recline	TNO P3/4 (9kg)	8158	1	20.0	47.56
			8159	1	19.0	47.45
			8160	1	19.0	46.95
	Frontal recline	TNO P3 (15kg)	8166	2	18.0	47.63
			8167	3	19.0	47.15
			8169	1	19.0	47.15
	Frontal recline, with top tether	TNO P3 (15kg)	8168	3	19.0	48.19
Safe-n-Sound Galaxy Ultra Convertible	Simple rear recline	TNO P3/4 (9kg)	8291	1	19.0	47.73
	Frontal recline	TNO P3 (15kg)	8247	1	18.0	47.72
	Frontal recline, with top tether	TNO P3 (15kg)	8248	1	19.0	47.56
Babylove F1-304 Sovereign Convertible	Frontal recline	TNO P3/4 (9kg)	8290	1	19.0	47.48
	Simple rear recline	TNO P3/4 (9kg)	8289	1	19.0	47.73
	Frontal recline	TNO P3 (15kg)	8251	1	19.0	47.61
IGC Aunger Convertible	Simple rear recline with baby insert	TNO P3/4 (9kg)	8287	2	19.0	47.68
	Frontal recline	TNO P3/4 (9kg)	8288	2	19.0	47.73
	Frontal recline, main belt path	TNO P3 (15kg)	8252	1	18.0	47.02
	Frontal recline, alternative belt path	TNO P3 (15kg)	8250	1	18.0	47.54
Type B: Forward facing seat for toddlers						
Safe-n-Sound Discovery Plus		TNO P3 (15kg)	8249	1	18.5	47.47
Type B/E: Convertible booster seat						
Safe-n-Sound Maxi Rider	Forward facing, reclined with harness	TNO P3 (15kg)	8253	1	19.0	47.51
	Forward facing, with harness and top tether	TNO P3 (15kg)	8294	1	19.0	48.10
	With lap belt only	TNO P6 (22kg)	8255	1	18.0	47.65
Safe-n-Sound Maxi Rider 2005	Forward facing, with harness	TNO P3 (15kg)	8296	1	18.0	47.19
	Forward facing, with harness and top tether	TNO P3 (15kg)	8295	1	19.0	47.67
	With lap belt only	TNO P6 (22kg)	8299	1	18.0	48.01
	With lap belt and top tether	TNO P6 (22kg)	8297	1	19.0	47.25
Type E: Booster seat with high back						
Safe-n-Sound Olympian	With lap belt only	TNO P6 (22kg)	8258	1	19.5	47.82
Type E: Booster cushion with no back						
Safe-n-Sound Nova	With lap belt only	TNO P6 (22kg)	8259	1	18.0	47.82
Standard Aircraft Seat Lap Belt						
Aircraft lap belt	Normal	TNO P3/4 (9kg)	8293	-	20.0	48.28
	Normal	TNO P3 (15kg)	8254	-	19.0	47.58
	Normal	TNO P6 (22kg)	8256	-	19.0	48.17
	Normal	TNO P6 (22kg)	8257	-	19.0	48.31
	With harness and top tether	TNO P6 (22kg)	8300	-	19.0	47.02

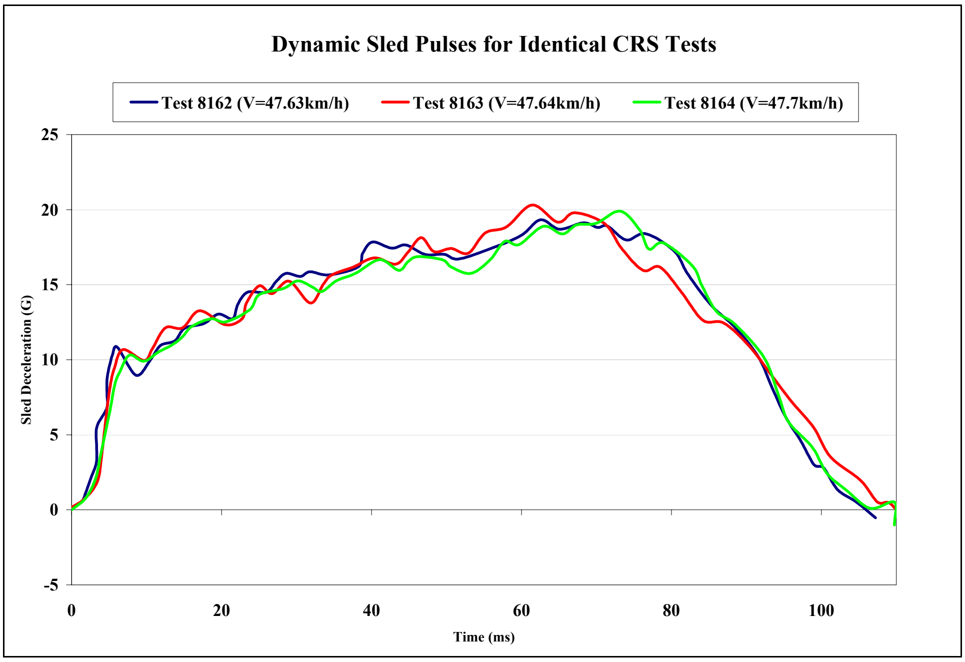

Figure 2.10. Comparison of sled deceleration pulses for repeated tests

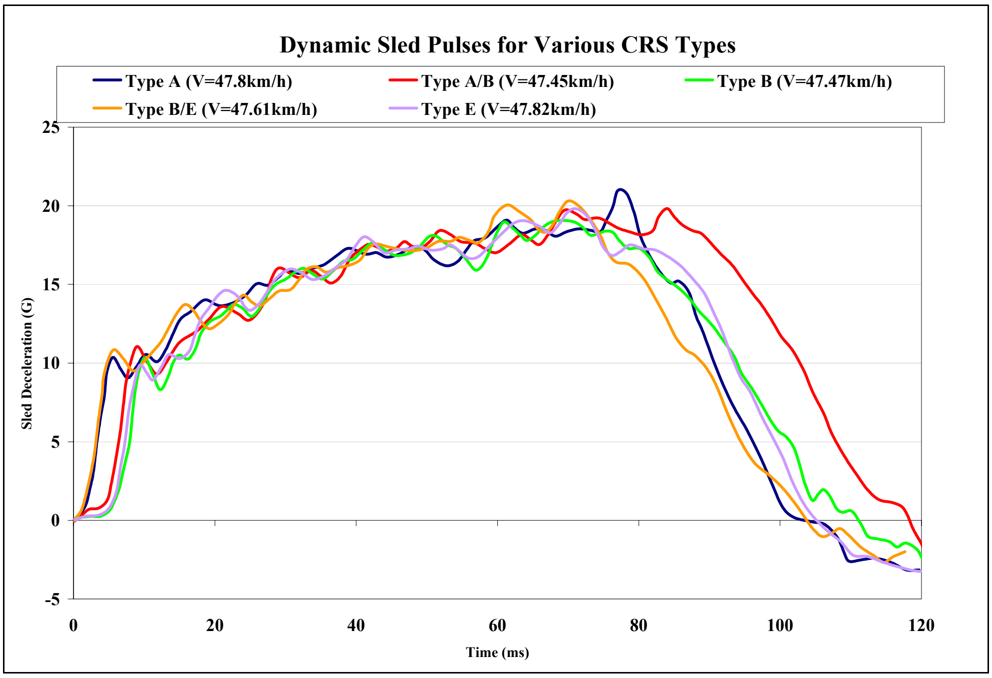

Figure 2.11. Comparison of sled deceleration pulses over the range of CRS types

Measured dummy responses

The measured dummy responses and lap belt loads measured during the sled tests are summarised in Table 2.6.

The resultant head and chest acceleration peak values, which exceed 150G for the head and 85G for the chest, are shown in bold type. A double value is recorded when a significant head and/or thorax impact occurred, typically as a result of the dummy head impacting the knees or edge of the seat base. The lap belt loads recorded are a function of the severity of the impact and the mass of the dummy and the CRS.

Dummy head excursions

The aircraft seat was tested with a lap belt-restrained TNO P10 (74 kg) adult dummy for comparison with the child dummy responses in the aircraft seat. This also allowed measurement of the dynamic motion of the seat back with an adult occupant. The images of the forward seat back with the adult dummy were superimposed onto the images of the CRS tests of a Type A/B convertible in forward-facing configuration at similar times in the sled pulse (see Figure 2.12). Note that there is a parallax error due to the position of the high-speed camera during the testing.

Table 2.6. Summary of dummy responses and lap belt loads for the CRS tests

Model	ATD	Test no.	Head acc. (peak) (g)	Chest acc. (peak) (g)	Lap belt load (kN)
Type A: Rear facing baby carrier					
Safe-n-Sound Unity Baby Carrier	TNO P3/4 (9kg)	8165	No instrumentation		-
Babylove Primo 6-in-1 Baby Capsule	TNO P3/4 (9kg)	8292	-	-	4.3
		8298	No instrumentation		-
Type A/B: Convertible child restraint: rear facing for babies, forward facing for toddlers					
Safe-n-Sound Royale Retractor Convertible	TNO P3/4 (9kg)	8161	59	48	-
		8162	58	49	-
		8163	59	48	-
		8164	No instrumentation		3.5
	TNO P3/4 (9kg)	8158	148	43	4.5
		8159	Data lost		4.3
		8160	**151**	44	4.1
	TNO P3 (15kg)	8166	37, **210**	38, 58	4.9
		8167	44, **173**	47, 71	4.7
		8169	46, **174**	69, **142**	4.9
	TNO P3 (15kg)	8168	36, 147	49, **99**	5.2
Safe-n-Sound Galaxy Ultra Convertible	TNO P3/4 (9kg)	8291	-	-	3.4
	TNO P3 (15kg)	8247	106	48	4.7
	TNO P3 (15kg)	8248	130	**126**	5.9
Babylove F1-304 Sovereign Convertible	TNO P3/4 (9kg)	8290	-	-	3.5
	TNO P3/4 (9kg)	8289	-	-	3.4
	TNO P3 (15kg)	8251	90	**99**	3.7
IGC Aunger Convertible	TNO P3/4 (9kg)	8287	43	48	3.7
	TNO P3/4 (9kg)	8288	-	46	3.8
	TNO P3 (15kg)	8252	60	**103**	4.7
	TNO P3 (15kg)	8250	**156**	**200+**	4
Type B: Forward facing seat for toddlers					
Safe-n-Sound Discovery Plus	TNO P3 (15kg)	8249	**200+**	**200+**	5.5
Type B/E: Convertible booster seat					
Safe-n-Sound Maxi Rider	TNO P3 (15kg)	8253	91	**123**	1.7
	TNO P3 (15kg)	8294	89	70	2.2
	TNO P6 (22kg)	8255	No instrumentation		4.5
Safe-n-Sound Maxi Rider 2005	TNO P3 (15kg)	8296	65	-	5.6
	TNO P3 (15kg)	8295	83	**108**	5.6
	TNO P6 (22kg)	8299	-	**109**	4.7
	TNO P6 (22kg)	8297	-	-	4.9
Type E: Booster seat with high back					
Safe-n-Sound Olympian	TNO P6 (22kg)	8258	No instrumentation		3.7
Type E: Booster cushion with no back					
Safe-n-Sound Nova	TNO P6 (22kg)	8259	No instrumentation		3.4
Standard Aircraft Seat Lap Belt					
Aircraft lap belt	TNO P3/4 (9kg)	8293	121	-	-
	TNO P3 (15kg)	8254	104	67	2.5
	TNO P6 (22kg)	8256	No instrumentation		3.6
	TNO P6 (22kg)	8257	No instrumentation		3.7
	TNO P6 (22kg)	8300	**200+**	-	5.7

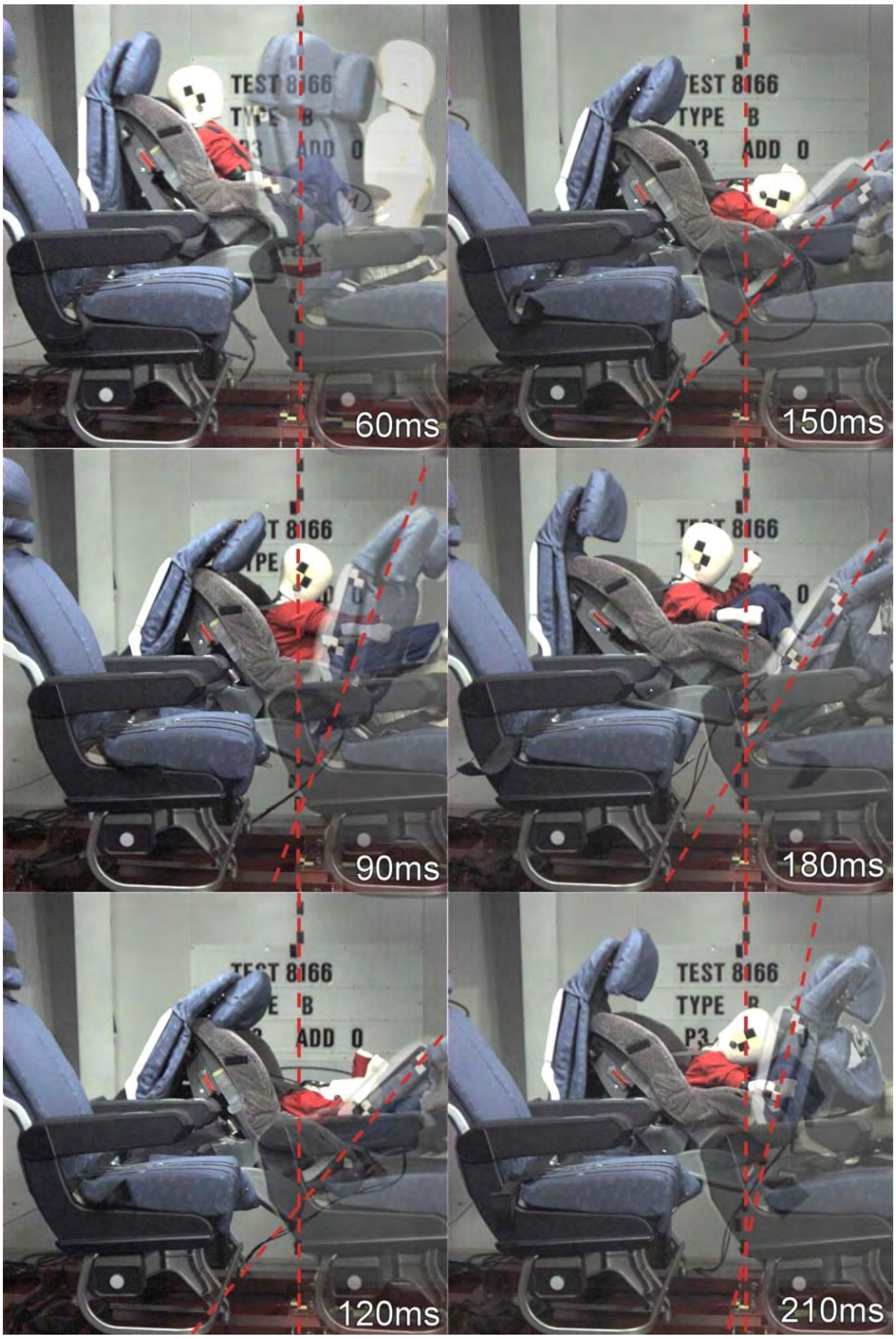

Figure 2.12. The motion of a forward-facing Type A/B convertible during a sled test with the motion of a seat with the adult dummy as occupant superimposed at 31-inch seat pitch

Contact between the head and the forward seat back is likely to occur at points along the head trajectory in the region of maximum head excursion, depending on the phasing of the forward seat back motion.

Similarly in Figure 2.13, the motion of a seat back with an adult dummy occupant has been superimposed onto images of a Type A/B convertible in rearward-facing mode during a sled test.

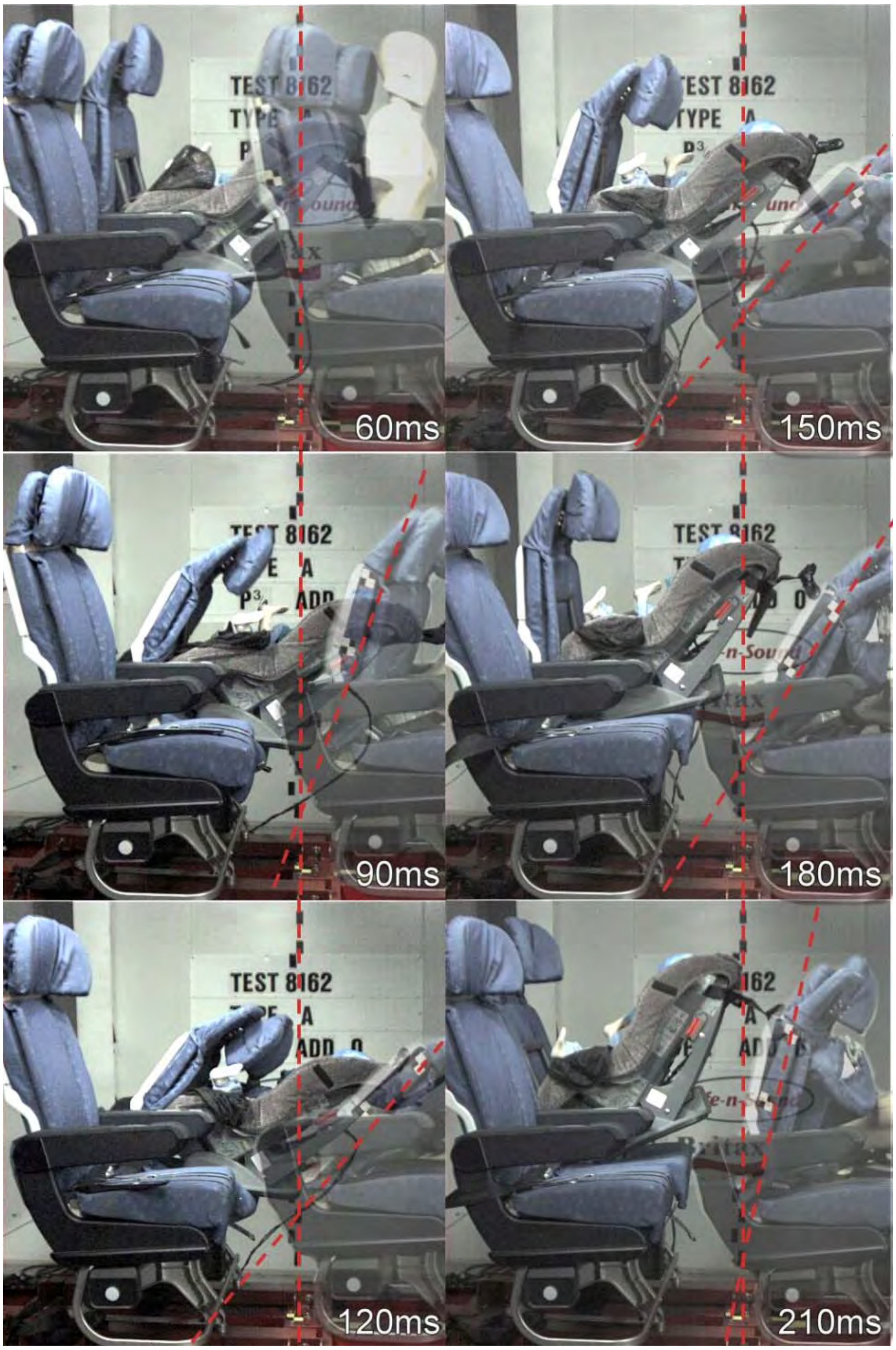

Figure 2.13. The motion of a rearward-facing Type A/B convertible during a sled test with the motion of a seat with the adult dummy as occupant superimposed at 31-inch seat pitch

The times indicated are the periods since the start of the sled pulse. The broken red lines indicate the approximate positions of the forward seat back at these times, taking into account the parallax error due to the camera position. The vertical lines represent the approximate position of the forward seat back if it were locked in position at 31-inch pitch. This line coincides with the broken black line on the wall in the background, which can be used as a reference when viewing the sled test videos to indicate the position of the forward seat back.

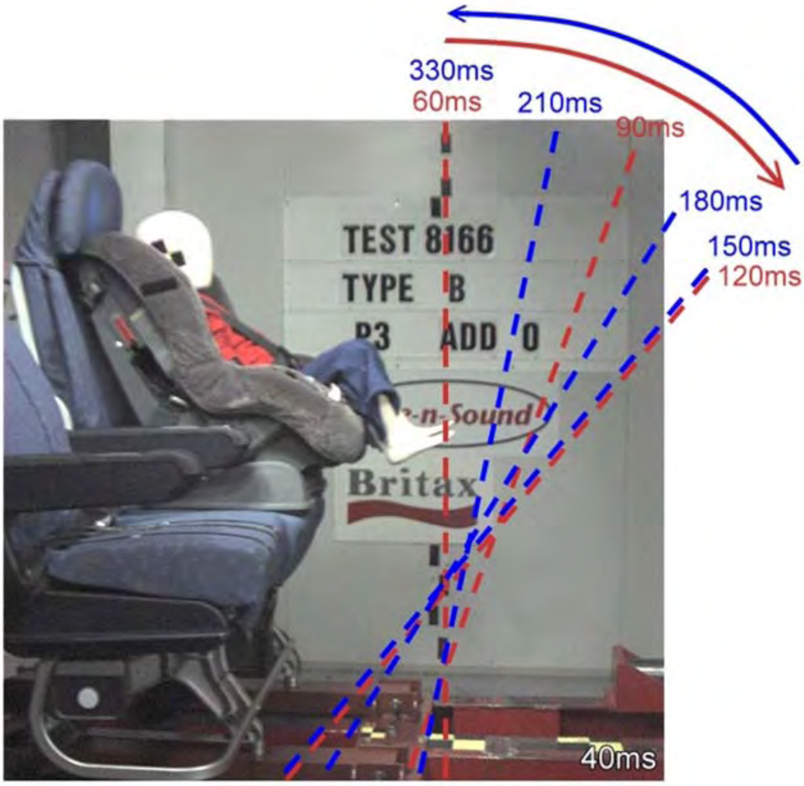

Figure 2.14. Initial position (at time = 40 ms) of a forward-facing Type A/B convertible during a sled test, with the motion of the seat back at 31-inch pitch with the adult dummy as occupant illustrated; the broken red lines show the forward deflection of the seat back with time and the broken blue lines indicate the rebound motion of the forward seat back

From the above superimpositions, the motion of the forward seat back at 31-inch pitch and with an adult dummy occupant can be predicted, as illustrated in Figure 2.14. The broken red lines show the forward deflection of the seat back with time. The broken blue lines show the rebound motion of the forward seat back. With the adult dummy occupant, the forward seat back begins to rotate at approximately 50ms after the beginning of the sled pulse. The seat back rotates forward approximately 40° before it returns to the upright position at around 330 ms.

Dummy head and leg excursions and contacts were obtained from the lateral high-speed video of each sled test – data in Table 2.7 and Table 2.8 The image superimposition technique was used to determine possible contacts with the forward seat back. This method takes into account the behaviour of the forward breakover seat back. For fixed seat backs, it can be assumed that a dummy head excursion of 620 mm from the seat bight will result in head impact with the forward seat, and so the forward-facing tests would have resulted in severe head or facial impact. The single-row test set up is a worst-case situation in that the CRS could not make use of the seat in front to limit its forward motion in the tests. In all the rear-facing CRS tests, the CRS itself would have hit the forward seat back. In most of the forward-facing CRS tests there is the possibility of head impact with the forward seat back. All of the various dummies restrained only by the aircraft seat lap belt would have made head contact with the forward seat back, except the TNO P¾ (9-month-old, 9 kg).

Table 2.7. Summary of the dummy and CRS forward excursions for the Type A and A/B child restraints

Model	Test no.	Head exc. from seat bite (mm) @ time after olive contact	Leg exc. from seat bite (mm)	CRS exc. from seat bite (mm)	Observations	Contacts
Type A: Rear facing baby carrier						
Safe-n-Sound Unity Baby Carrier	8165	940 (remains within capsule) @ 96ms	-	910		Restraint likely to contact forward seat back. Heavy facial contact with aircraft seat backrest on rebound.
Babylove Primo 6-in-1 Baby Capsule	8292	Video lost			The CRS rebound bar bent at the point of exit from the seat.	
	8298	760 (remains within capsule) @ 86ms	-	840	Rebound bar bent at point of exit from the CRS.	Facial contact with aircraft seat backrest on forward rotation.
Type A/B: Convertible child restraint: rear facing for babies, forward facing for toddlers						
Safe-n-Sound Royale Retractor Convertible	8161	920 (remains within capsule) @ 96ms	-	1010	The aircraft seat back swings forward and approaches the infant's torso and legs. Head contact on rebound is not visible due to the interference of the empty seat.	Possible torso/leg contact with aircraft seat back during forward rotation. Restraint likely to contact forward seat back.
	8162	910 (remains within capsule) @ 98ms	-	1010	No visible head contact. Head appears to brush the seatback.	Restraint likely to contact forward seat back.
	8163	910 (remains within capsule)	-	1010	Rebound bar was damaged due to multiple sled runs.	Restraint likely to contact forward seat back. Facial contact with aircraft seat backrest on rebound.
	8164	910 (remains within capsule) @ 92ms	-	970	No head contact (approx. 60 - 70 mm from seatback)	Restraint likely to contact forward seat back.
	8158	Video lost			High deceleration bump (20g) at the end of sled pulse.	
	8159	750 @ 112ms	890	890		Restraint and leg contact with the forward seat back is likely.
	8160	750 @ 112ms	875	860		Restraint and leg contact with the forward seat back is likely.
	8166	900 @ 120ms	1150	850	The CRS rotated into the fully reclined position. There was no visible failure of the recline locating elements.	Restraint and leg contact with the forward seat back is likely. Head contact is possible.
	8167	Video lost				
	8169	890 @ 130ms	1200	785	The CRS rotated into the fully reclined position. There were cracks in the rear part of the base due to multiple test runs.	Restraint and leg contact with the forward seat back is likely. Head contact is likely.
	8168	880 @ 124ms	1200	890	The CRS rotated into the fully reclined position. The yellow plastic retention latch that locks the recline position dislodged.	Restraint and leg contact with the forward seat back is likely. Head contact is possible.
Safe-n-Sound Galaxy Ultra Convertible	8291	-	-	930		Restraint contact with the forward seat back is likely.
	8247	740 @ 126ms	740 (knee), 1000 (feet)	700		Leg contact with the forward seat back is likely.
	8248	740 @ 108ms	765 (knee), 1050 (feet)	700		Leg contact with the forward seat back is likely.
Babylove F1-304 Sovereign Convertible	8290	860 @ 118ms	660 (knee), 860 (feet)	720		Restraint and leg contact with the forward seat back is likely. Head contact is possible.
	8289	-	-	570 (base), 1050 (back)		Restraint contact with the forward seat back is likely.
	8251	1020 @ 132ms	860 (knee), 1090 (feet)	790		Restraint and leg contact with the forward seat back is likely. Head contact is likely.
IGC Aunger Convertible	8287	900 @ 100ms	-	900		Restraint contact with the forward seat back is likely.
	8288	870 @ 118ms	520 (knee), 720 (feet)	500 (base), 780 (back)	Excessive forward rotation of the restraint.	Head contact with the forward seat back is possible.
	8252	1010 @ 132ms	740 (knee), 1010 (feet)	560 (base), 880 (back)	Excessive forward rotation of the restraint. The aircraft lap belt cut through the belt path rib.	Head and leg contact with the forward seat back is likely.
	8250	800	855	780		Restraint and leg contact with the forward seat back is likely.

Table 2.8. Summary of CRS and dummy forward excursions for Type B, B/E and E child restraints, and the standard aircraft seat lap belt

Model	Test no.	Head exc. from seat bite (mm) @ time after olive contact	Leg exc. from seat bite (mm)	CRS exc. from seat bite (mm)	Observations	Contacts
Type B: Forward facing seat for toddlers						
Safe-n-Sound Discovery Plus	8249	780 @118ms	820	785	Excessive forward rotation of dummy head and torso. Head impacts with the knees.	Restraint and leg contact with the forward seat back is likely.
Type B/E: Convertible booster seat						
Safe-n-Sound Maxi Rider	8253	865 @ 128ms	690 (knee), 930 (feet)	650		Leg contact with the forward seat back is likely. Head contact is possible.
	8294	880 @ 126ms	660 (knee), 945 (feet)	640 (base), 720 (back)		Restraint and leg contact with the forward seat back is likely. Head contact is possible.
	8255	910 @ 118ms	600	600 (base), 930 (back)	Excessive forward rotation of dummy head and torso. Face impacts with own seat cushion.	Head and leg contact with the forward seat back is likely.
Safe-n-Sound Maxi Rider 2005	8296	830 @ 118ms	740 (knee), 1000 (feet)	650		Restraint and leg contact with the forward seat back is likely. Head contact with the forward seat back is possible.
	8295	845 @ 114ms	750 (knee), 1020 (feet)	650		Restraint and leg contact with the forward seat back is likely. Head contact is possible.
	8299	1080 @ 126ms	670 (knee), 995 (feet)	600 (base), 840 (back)	Excessive forward rotation of dummy head and torso. Face impacts with own seat cushion.	Head and leg contact with the forward seat back is likely.
	8297	1060 @ 126ms	680 (knee), 1010 (feet)	590 (base), 830 (back)	Excessive forward rotation of dummy head and torso. Face impacts with own seat cushion.	Head and leg contact with the forward seat back is likely.
Type E: Booster seat with high back						
Safe-n-Sound Olympian	8258	940 @ 118ms	560 (knee), 870 (feet)	550 (base), 775 (back)	Excessive forward rotation of dummy head and torso. Face impacts with own seat cushion.	Head and leg contact with the forward seat back is likely.
Type E: Booster cushion with no back						
Safe-n-Sound Nova	8259	865 @ 112ms	540 (knee), 920 (feet)	500	Excessive forward rotation of dummy head and torso. Face impacts with own seat cushion.	Head and leg contact with the forward seat back is likely.
Standard Aircraft Seat Lap Belt						
Aircraft lap belt	8293	600	460 (feet)	-		
	8254	685 @ 108ms	460 (knee), 690 (feet)	-	Aircraft seat headrest broke off.	Head contact with the forward seat back is possible.
	8256	Video lost				
	8257	740 @ 100ms	455 (knee), 775 (feet)	-		Leg contact with the forward seat back is likely. Head contact is possible.
	8300	745 @ 112ms	675 (knee), 1010 (feet)	-		Leg contact with the forward seat back is likely. Head contact is possible.

CRS Dynamic Performance

The dynamic performances of the tested CRS are discussed in this section by CRS type.

CRS Type A: Rearward-facing infant restraints

The two infant restraint models of this type that were tested were the Safe-n-Sound Unity and the Babylove Primo baby carriers. These are similar in design and are intended for installation in a rearward-facing configuration. The systems both have a base mount that can be installed on the seat separately. The bassinet or carrier module can then be easily detached and re-attached from the base. The carriers are also intended for use without the base mount installed.

For neither of these two models could the base mounts be installed in the aircraft seats using the standard lap belt. This was due to the lap belt latch interfering with the attachment mechanism, preventing the carrier module from properly engaging with the base (see Figure 2.4). The restraints were tested without the base mounts installed.

The dynamic tests showed excessive motion of these restraints. The carrier moves initially in a forward direction until it is likely to hit the forward seat back. This impact may not be severe if the carrier is initially touching or very close to the forward seat back. The back of the aircraft seat on which it is mounted flexes forward and comes close to the face and legs of the dummy (see Figure 2.15). On rebound, the carrier rotates about the lap belt. This can result in the carrier hitting the aircraft seat back and causing an impact to the face.

Figure 2.15. Rearward-facing infant restraints in sled tests showing (left) excessive forward flexion of the aircraft seat back, and (right) excessive rotation of the restraint about the lap belt upon rebound

CRS Type A/B: Convertible child restraints

Four models of convertible child restraints were tested in various configurations using the TNO P3/4 (9 kg) and P3 (15 kg) dummies. The models included the Safe-n-Sound Royale, Safe-n-Sound Galaxy, IGC Aunger and Babylove F1-304 Sovereign.

In rearward-facing mode, these restraints behave much like the Type A rearward-facing infant restraints. There is excessive forward motion of the restraint, with the aircraft seat back rotating forwards towards the occupant. The rebound bar of the CRS buckles under this forward loading. On rebound, the restraint itself rotates about the lap belt back towards the aircraft seat back. Whether impact occurs depends on the deceleration level, the flexibility of the aircraft seat back, the inertia of the dummy head, and the levels of adjustment of the child harness and the lap belt.

In forward-facing mode, these restraints behave much like the type B forward-facing child restraints. There is excessive forward motion of the seat and child occupant dummy. At full excursion of the dummy, the arms and legs are likely to hit the forward seat back. The head rotates forward and possibly impacts the knees. On rebound, there is a second possible impact to the back of the dummy head on the aircraft seat back or the restraint itself.

CRS Type B: Forward-facing child restraints

The Safe-n-Sound Discovery restraint was tested in reclined mode. The restraint is designed for installation in a car seat with the standard seat belt and a top tether attachment. Aircraft seats do not provide an upper anchorage point for top tether attachments. Accordingly, for installation in the test aircraft seat, the restraint was secured only by the aircraft lap belt.

On dynamic loading the seat moves forward. While the seat itself may not impact the forward seat, the child occupant dummy is thrown forward against the harness. The arms and legs of the dummy are likely to hit the forward seat back. The head rotates forward and possibly impacts the child's knees. On rebound, there is a second possible impact of the back of the head with the aircraft seat back or the restraint itself (see Figure 2.16).

Figure 2.16. Motion of the TNO P3 (15 kg) dummy in the Safe-n-Sound Discovery type B CRS

CRS Type B/E: Convertible child booster seats

Two Safe-n-Sound Type B/E restraints were tested in the series: the currently available Maxi Rider model and the new Maxi Rider model for 2005. These forward-facing restraints are harnessed for toddlers weighing up to 18 kg (B mode), or can be used as booster seats for children from 14 to 26 kg (E mode). When used as a Type E CRS, the vehicle seat belt system is used to restrain the occupant. The TNO P3 (15 kg) and P6 (22 kg) dummies were used for these tests.

In the testing, the Maxi Rider tended to fold over about the seat bight (see Figure 2.17).

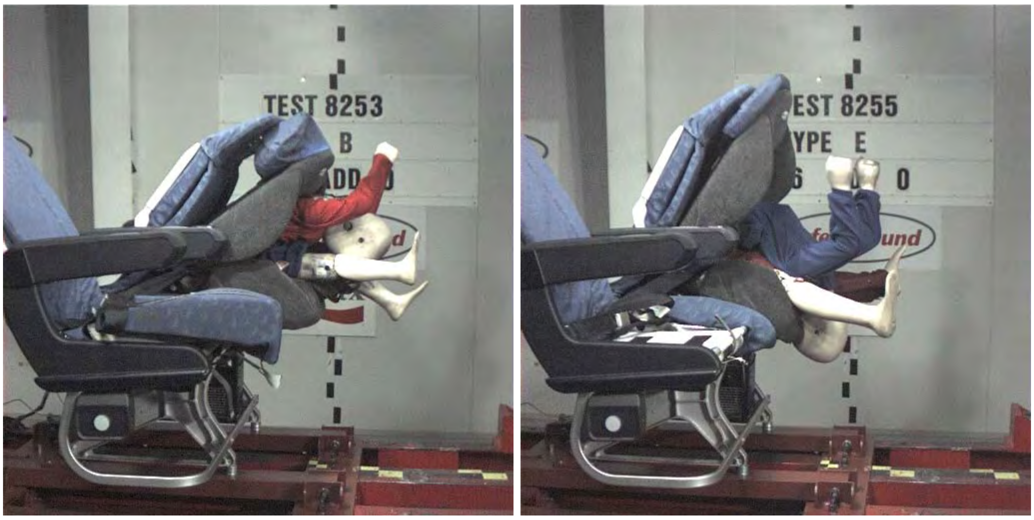

Figure 2.17. Safe-n-Sound Maxi Rider as a child restraint with harness (left), and a booster seat with aircraft lap belt only (right)

The dummy was thrown forward with the arms and legs likely to impact the forward seat back. With the harness, the head of the dummy still rotates forwards towards the knees or in between the legs. With the lap belt only, the head of the larger dummy rotates forwards and impacts with the seat cushion between its legs. This excessive head rotation suggests that impact with the forward seat back is likely in both configurations.

The new 2005 Maxi Rider is stiffer in design than the previous model. While the restraints did not fold over about the seat bight, the results are similar to those of the earlier Maxi Rider. Head rotation is severe and likely to result in impact with the forward seat back (see Figure 2.18).

Figure 2.18. 2005 Model Safe-n-Sound Maxi Rider as a child restraint with harness and Qantas top tether (left), and a booster seat with aircraft lap belt and Qantas top tether (right)

CRS Type E: Child booster seats

Two child booster seats were tested in the series. The Safe-n-Sound Olympian is a high-backed booster seat, while the Safe-n-Sound Nova has no back. Both are designed as boosters for children weighing 14 to 26 kg.

The seats behaved much like the convertible booster seats in Type E mode. Both seats allowed excessive forward body and head rotation resulting in the child's head impacting the seat cushion between its legs (see Figure 2.19).

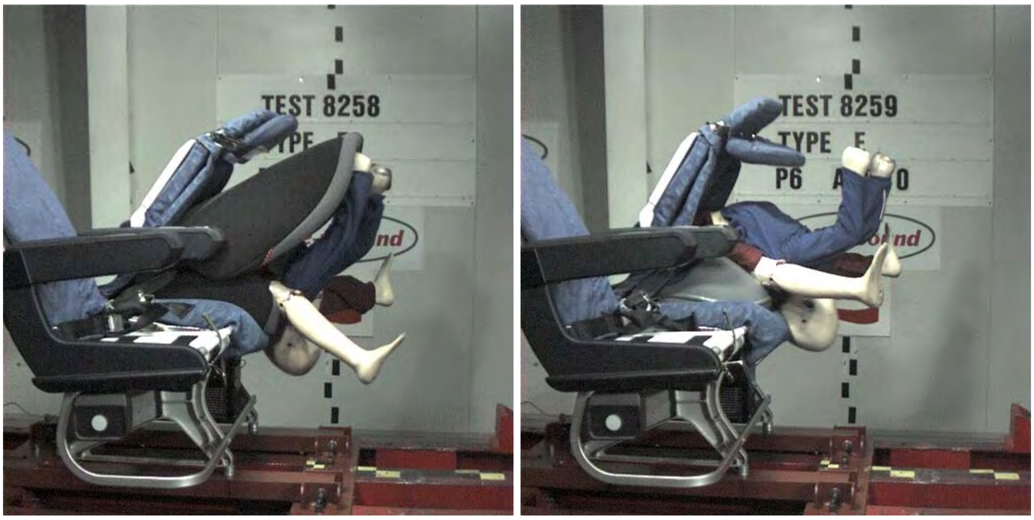

Figure 2.19. Child booster seats (left) with high back, and (right) with no back, used with the aircraft lap belt only

Aircraft lap belt performance

Some tests were performed with the dummy restrained only by the aircraft lap belt, to demonstrate the dummy behaviour without a child restraint. In all tests, the aircraft seat back folds over about the seat bight, causing excessive forward rotation of the torso and head of the child occupant. It is likely that the head and limbs of the larger dummies will impact the forward seat back. Figure 2.20 and Figure 2.21 show the maximum excursion of the 9-month-old (P3/4), 3-year-old (P3) and 6-year-old (P6) dummies. The images have been superimposed with images of the forward seat with an adult occupant at the same instance and set at 31-inch pitch, to observe the possible impacts.

Figure 2.20. TNO P3/4 (9 kg) dummy (left) and TNO P3 (15 kg) dummy (right) in aircraft lap belt only

The 6-year-old dummy was tested with a full child harness and Qantas top tether (see Figure 2.21). This configuration did not successfully limit the torso excursion due to the behaviour of the aircraft seat back.

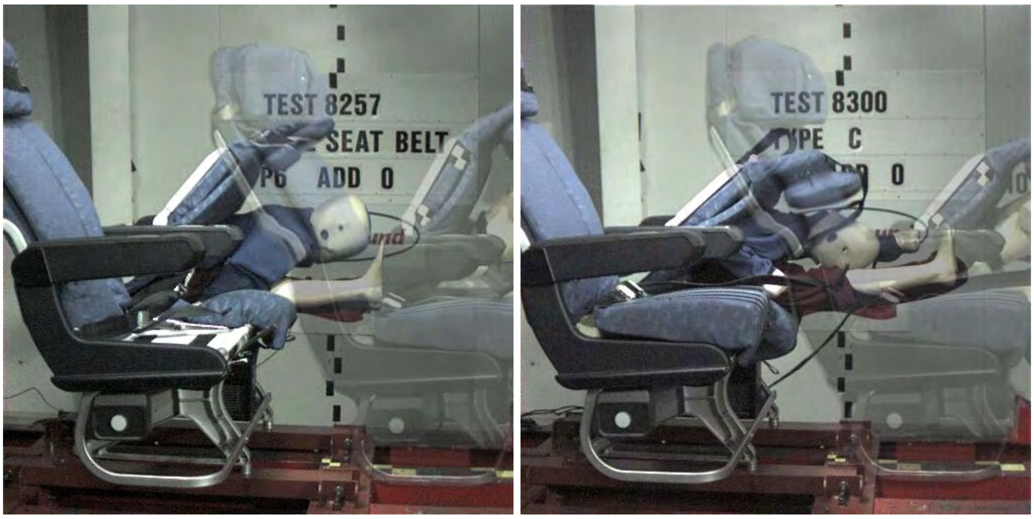

Figure 2.21. TNO P6 (22 kg) dummy in aircraft lap belt only (left) and in the lap belt with harness and Qantas top tether (right)

2.3 Discussion – CRS use in aircraft

The use of automotive CRS on aircraft is far safer for infants and children than if they are simply lap held (with or without restraint) or restrained using the standard aircraft lap belt. However, there exists many incompatibility issues between Australian CRS and the aircraft seat system that need to be addressed. It should be noted that CRS complying with the US FMVSS 213 and the European ECE R44 regulations would not perform any better in aircraft seats than the Australian approved CRS.

Fit testing of Australian CRS in the test aircraft seats found that of the 20 models tested, 14 had problems with fitting into the 31-inch seat pitch and/or with interference from the aircraft seat lap belt. Eight child restraints were incompatible with the aircraft seating system for the following reasons:

- Two Type A baby carriers (Safe-n-Sound Unity, Babylove Primo 6 in 1) could not be used in an aircraft seat with the removable base, because the lap belt latch interfered with the base.
- Three Type A/B convertibles (Safe-n-Sound Galaxy Ultra, Babylove Sovereign and IGC Bertini Classic) could not be used in the 31-inch aircraft seat pitch because they were too large.
- One Type B forward-facing CRS (Safe-n-Sound Series 3) was designed for use with a tether strap which cannot be attached in an aircraft.
- Two Type E booster seats (Babylove Graduate and IGC GoSafe SportsBaby) were too wide to fit between the armrests and interfered with the lap belt adjustment.

The CRS samples were subjected to the FAA inversion test for turbulence. This test caused no difficulty for the Australian CRS, which have 6-point harnesses for the child.

A total of 42 sled tests were conducted and 11 models of Australian CRS were tested. In these tests, motion of the CRS was not as well controlled as when tested for use in motor vehicles to the Australian Standard AS/NZS 1754:2004, despite the lower severity test pulse. For comparison, a test to AS/NZS 1754:2004 of the Safe-n-Sound Royale type A/B convertible is included in Part 5 of the companion DVD. The dummy was retained in the CRS in all sled tests. However, all CRS exhibited significant forward motion, rotation and rebound motion. This less well controlled motion, in comparison with typical automotive testing, was due to the following:

- The AS/NZS 1754:2004 test has the upper tether in place with the appropriate anchorage mechanism a configuration not available in aircraft.
- The geometry of the aircraft seat lap belt is more vertical than the systems typically used in motor vehicle rear seats; this allowed the CRS to move forward further in the initial stages of the test.
- The low level of compatibility between the aircraft seat lap belt and the CRS made applying adequate tension to the belt difficult.
- The interaction of the CRS with the seat base cushion and frame was poor; the narrow seat base allowed excessive rotation and the aircraft seat base cushion became detached allowing forward motion of the CRS.
- The rebound phase of the test was poorly controlled due to the more extensive forward motion of the CRS.

The DME Corporation PlaneSeat CRS, which operates without an upper tether, performed well compared with the Australian automotive CRS. While some caution is required when making this comparison, due to the differing test procedures and severities, it does indicate that the performance of automotive CRS without an upper tether could be improved.

The lack of the upper tether is the most significant cause of the excessive forward motion of the CRS in the aircraft seats. This has a direct effect on the amount of head excursion of the dummy that occurs. Qantas currently uses an upper tether arrangement which is not effective when used with a breakover seat. It was therefore not possible to test this arrangement during this test series as the aircraft test seat used was designed to break over. The testing with a fixed seat back would make a useful extension of the testing described here.

The Type E booster seats and booster cushions are for children in the weight range of 14 to 26 kg (14 kg is the weight of an average 2½-year-old). These seats are marked as not suitable for use with only a lap belt in a vehicle. Therefore, they are not suitable and should not be used in aircraft where there are only lap belts.

Tests of dummies restrained only by the lap belt (both child and adult), indicated the different level of protection offered, when compared with road vehicle occupants wearing lap sash belts.

The testing was conducted with the measured amount of slack in both the lap belt and the CRS harness required when tested to the Australian Standard AS/NZS 1754:2004. This slack requirement is meant to be equivalent to the way the CRS are typically used; however, this level of slack contributed to the forward motion observed.

The fact that so many of the Australian automotive CRS models are not suitable for use in aircraft creates a difficult problem for the airlines. If Australian automotive CRS are to be used in commercial aircraft then these problems will need to be addressed. For example, adding a set of further requirements for CRS use in aircraft in Australia and having an extended approval scheme could address the incompatibility problems. The airlines would need to train staff to deal with the installation problems. The availability of belt extensions would overcome some of the interference problems between the lap belt and the CRS.

Finally, some means of incorporating an upper tether strap for the CRS would greatly improve the seat responses. The tether strap arrangement currently used by Qantas needs some additional public testing to confirm that it is effective. An alternative would be to include CRS tether anchorages for the bulkhead seats. It may be difficult to justify such changes to the aircraft structure on the basis of the incidence of injuries to children in crashes.

3 INFANT CARRIER (SLING) TESTING

3.1 Test methods

3.1.1 Infant carrier selection

The infant carrier styles were chosen to represent the spectrum of prices, sizes and load ratings that are commercially available in Australia. Four commercially available infant carriers were tested under static loading, turbulent conditions and aircraft emergency landing conditions, to evaluate their performance with respect to retention of the child, forward excursion, and crushing by the adult. The infant carriers considered in this series were those that are worn on the chest of an adult, with newborns facing the adult and infants and toddlers facing forward. Such carriers are usually designed to carry infants up to 12 kg in weight. In addition, Qantas Airways supplied two samples of standard ‘supplementary loop belts’ (or belly belts) for comparative testing. A brief description of each carrier style tested and the results are included in Appendix B: Infant carrier profiles.

3.1.2 Static testing

Static testing was performed on a single infant carrier to assess the likely load levels such devices might withstand under a dynamic load. The effects of a static load on the fabric, stitching, and clasps of the sling was evaluated. The various carrier designs were visually inspected for quality and strength of the materials and fittings. The design judged the weakest was tested statically to determine the baseline for the dynamic tests. The selected carrier was suspended by the shoulder straps on rounded horizontal tubing to avoid any sharp edges and catching. The carrier section was then slowly loaded with known masses over a 200 mm diameter area until failure.

3.1.3 Testing facility

The infant carrier dynamic tests were performed at the Crashlab test facility in Rosebery, NSW. Crashlab is an independent test facility operating within the Roads and Traffic Authority (RTA) of NSW; it is accredited with the National Association of Testing Authorities (NATA). The facility includes a dynamic test sled and a rotation rig.

Two adult ATDs, a THOR 50th-percentile, or average, male and a Hybrid III 50th-percentile male adult, were used with the two infant dummies, a TNO P3/4 (9 kg, 9-month-old) and a TARU Theresa (4 kg, 6-week-old). The dummies were not instrumented for any of the tests as they were for observation purposes only. Lateral and over-head high-speed videos were taken of each sled test.

3.1.4 Turbulence test method

This test series was designed to simulate turbulent aircraft conditions by inverting the seated and belted adult 50th-percentile male Hybrid III ATD restrained in a row of aircraft seats with an infant dummy (in an infant carrier) in the rotation rig. The TARU Theresa 6-week-old infant dummy was used to simulate the retention of a smaller infant, the worst case in this situation. For the supplementary loop belt, a TNO P3/4 9-month-old was also tested.

This inversion test was based on the FAA test for certifying CRS within FMVSS 213. The test, in effect, applies an upward acceleration of 1G in the vertical reference plane of the dummy, similar to accelerating the belted passenger upwards toward the ceiling of the cabin. The retention of the infant by the carrier was checked by manipulating the infant dummy and the tension on the adjusting straps of the carrier and the results recorded on video for later observation.

3.1.5 Dynamic sled test method

The dynamic sled test series comprised a lap belt restrained adult ATD, carrying an infant ATD in a carrier, in a double-row of aircraft seats tested to a 9G longitudinal horizontal pulse. The former FAA aircraft seat requirement was 9G and a static requirement of this level is still required for cabin fittings. This less severe pulse was selected based on the results of the static load test. The carriers were not designed for use as child restraints, it was anticipated that a lower sled pulse would be adequate to demonstrate the effectiveness.

High-speed videos of the tests were recorded, including two lateral views and an overhead view. The sled acceleration pulse was also recorded.

3.2 Results

3.2.1 Turbulence testing

Table 3.1. Summary of infant carrier turbulence test results

Crashlab Test No.	Restraint Sample	ATD	Configuration	Infant Retained?
G050042	AMSAFE® loop belt	TNO P3/4 (9 kg)	Forward-facing	Yes
		TARU Theresa (4 kg)	Forward-facing	Yes
G050043	Snugli® Comfort Vent™ Soft Carrier	TARU Theresa (4 kg)	Rearward-facing: arms through holes	Yes
		TARU Theresa (4 kg)	Rearward-facing: arms inside carrier	No
G050044	Infantino® GoGo Rider™	TARU Theresa (4 kg)	Rearward-facing: arms through holes	Yes
		TARU Theresa (4 kg)	Rearward-facing: arms inside carrier	No
G050045	Theodore Bean™ Infant and Toddler Carrier	TARU Theresa (4 kg)	Rearward-facing: arms through holes	Yes
		TARU Theresa (4 kg)	Rearward-facing: arms inside carrier	No
G050046	BabyBjörn® Original Baby Carrier	TARU Theresa (4 kg)	Rearward-facing: arms through holes	Yes
		TARU Theresa (4 kg)	Rearward-facing: arms inside carrier	Yes

The AMSAFE® loop belt (supplementary loop belt) retained both the 6-week-old and 9-month-old dummies when firmly adjusted for a tight fit, so as to allow the insertion of two fingers under the belt. The behaviour of the dummies does not directly relate to that of real infants in these circumstances because the body and joints of the dummies are much stiffer than those of a real child and less likely to slip out of the belt.. The level of the belt tension in the abdominal area is unlikely to be able to be used with a real infant for comfort reasons.

When adjusted for a tight fit and with the arms correctly positioned through the armholes, all of the tested carriers satisfactorily retained the infant dummy when inverted. With the arms placed inside the carrier, the infant dummy slipped through all carriers except the BabyBjörn® Original Baby Carrier.

3.2.2 Static tests

The Snugli® Comfort Vent™ Soft Carrier was tested for static load capacity. The test was to assist in setting the acceleration to be used in the dynamic tests. The carrier was suspended on a rounded tube and the front panel of the sling was loaded with weights over a 200 mm diameter area. At 82.5 kg, or approximately equivalent to 9G, the stitching that joins the 20 mm webbing for the two head support buckles started to come undone. The two hooks for the side entry buckles bent outwards by 10 to 12 mm and began to disengage. The 30 mm shoulder strap buckles and webbing remained intact.

3.2.3 Dynamic sled tests

The THOR 50th-percentile adult male ATD (75 kg weight) was selected to simulate the restrained adult in the dynamic sled test. This ATD was selected because it has a flexible shoulder and spine structure, which would better simulate the behaviour of an adult in a lap belt restraint wearing a baby carrier. This size of dummy was selected as a worst-case scenario in terms of size and weight. The THOR ATD was supplied for testing by the Commonwealth Department of Transport and Regional Services (DOTARS).

An initial sled run with the adult THOR dummy only at 9G (Sled pulse: Max. 8.37G, ΔV = 33.8 km/h) was made with a double row of seats, to assess the behaviour of the adult in the lap-belt restraint. The dummy was positioned in the centre-rear seat in an upright position with feet placed on the floor and the arms just on the armrests. The lap belt was firmly adjusted with access for two fingers. During the test, the dummy moved forward in the seat until the knees impacted the forward seat back. The torso then folded forwards at the pelvis until the face impacted with the forward seat back.

In the next test, the AMSAFE® loop belt was fastened around the TNO P3/4 9-month-old (9 kg) dummy on the lap of the adult THOR dummy, which was positioned in the same attitude as in the first run. The child dummy underwent excessive forward body excursion in the test, resulting in a severe facial impact with the dinner tray of the forward seat back. The THOR dummy then folded forward at the waist over the child dummy before its head impacted with the head rest area of the back of the forward seat back and the child dummy was trapped between the knees and torso of the adult dummy. The force of the adult dummy knee impact with the forward break-over seat back caused the seat hinge guide plates to buckle (see Figure 3.1), allowing the forward seat back to rotate more than normal. The forward row of seats was removed for the remaining tests to avoid misrepresentation of the interaction with an undamaged forward seat back.

Figure 3.1. Damage to the forward seat back hinge

In the next test, the Snugli® Comfort Vent™ Soft Carrier was tested with the TNO P3/4 dummy and adult THOR dummy in the same attitude as in the previous tests. The carrier was adjusted for a tight fit on both the adult and infant. The sled test again resulted in excessive forward excursion of both dummies. The carrier failed and the P3/4 dummy was thrown from the carrier. This test resulted with the adult THOR dummy failing at the right hip joint, rendering the adult dummy unfit for further testing. Due to time constraints, the remaining tests were performed with the 50^{th}-percentile adult male Hybrid III ATD. The Hybrid III is the standard dummy used in frontal automotive crash tests. The adult dummy was positioned in the aircraft seat in a similar attitude to the THOR dummy in previous tests. The two dummies behaved in a comparable manner when restrained in the aircraft lap belt.

The remaining infant carriers all behaved similarly to the Snugli® Comfort Vent™ Soft Carrier, allowing the infant to be ejected forward. The results are detailed in Appendix B: Infant carrier profiles and are summarized in Table 3.2 below. High-speed videos of the tests are in Part 4 of the companion DVD.

Table 3.2. Summary of infant carrier dynamic sled test results

Crashlab Test No.	Restraint Sample	Aircraft Seat Configuration	ATD Configuration	Sled Pulse	Infant Retained?
S050147	AMSAFE® loop belt	Two rows at 31" pitch	THOR adult ATD, lap-held TNO P3/4 ATD forward-facing in carrier.	Max. 8.59G, ΔV = 33.1 km/h	Yes
S050148	Snugli® Comfort Vent™ Soft Carrier	Single row	THOR adult ATD, lap-held TNO P3/4 ATD forward-facing in carrier.	Max. 8.67G, ΔV = 33.5 km/h	No
S050149	Infantino® GoGo Rider™	Single row	Hybrid III adult ATD, lap-held TNO P3/4 ATD forward-facing in carrier.	Max. 8.69G, ΔV = 33.2 km/h	No
S050150	Theodore Bean™ Infant and Toddler Carrier	Single row	Hybrid III adult ATD, lap-held TNO P3/4 ATD forward-facing in carrier.	Max. 8.81G, ΔV = 33.4 km/h	No
S050151	BabyBjörn® Original Baby Carrier	Single row	Hybrid III adult ATD, lap-held TNO P3/4 forward-facing in carrier.	Max. 8.83G, ΔV = 33.5 km/h	No

3.2.4 Sled test repeatability

The sled deceleration pulses for each test in the series are compared in Figure 3.2. The mean peak deceleration was 8.7G and the mean velocity change (ΔV) was 33.4 km/h. The pulse changed shape slightly due to the removal of the forward row of aircraft seats after the belly belt test.

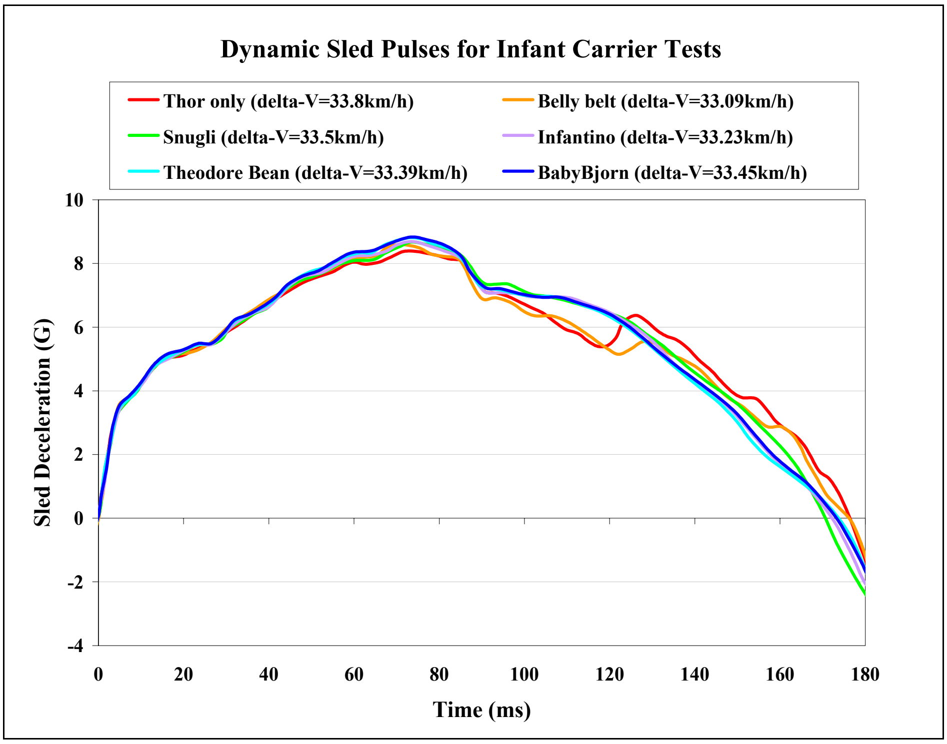

Figure 3.2. Comparison of the sled pulses for the infant carrier tests at Crashlab

3.3 Discussion – Infant carrier use in aircraft

The turbulence tests demonstrated that infants could be adequately retained when exposed to 1G of vertical acceleration provided the carrier was securely fastened. However, the test did not demonstrate the effects of more severe turbulence, which could occasionally be encountered in flight.

The dynamic testing demonstrated that commercially available infant carriers (slings) are not able to restrain infants under crash situations. With a 9G pulse all the carriers failed to retain the infant dummy, which was ejected. If the motion of the infant dummy was limited by a forward seat row, then the motion of the adult dummy head and torso would endanger the lap held infant in an impact. This was demonstrated in the test with the AMSAFE® loop belt, where the forward motion of the adult dummy in a lap belt trapped and crushed the infant in the space between the front row seat back, the head and torso and the knees of the adult.

Current FAA regulation (FAR 25.562) requires that the seats and restraint systems used on aircraft withstand a minimum peak acceleration of 14G vertical and 16G longitudinal for emergency landing conditions. The 9G sled tests conducted in this project demonstrated that the adults are not adequately restrained by the aircraft seat lap belt. The emergency brace positions recommended by airlines could not be demonstrated using the anthropomorphic test dummies.

The infant carriers could be redesigned to be effective in turbulent conditions and to ensure that the infant was restrained in dynamic loads equivalent to the test pulse. If this were done then an infant carrier would form an alternative to the supplementary loop belt. However, for this type of restraint to prevent injury in a crash changes to the adult restraint system would be required to limit torso forward excursion (for example, by adding a shoulder restraint) or to provide rearward-facing seating for adult passengers with lap-held children.

4 SUGGESTED ACTIONS

The following suggestions are made based on the findings of this study and the principle that infants and young children are entitled to the same level of protection, both in flight and during emergency landing situations, that is afforded to adults.

1. The use of CRS by infants and young children on flights in Australia is to be encouraged. The CRS used could be either designed specifically for use in aircraft, or, Australian automotive CRS approved for use in aircraft as per suggestion 3.
2. Testing should be conducted of the system of an upper tether strap for Australian automotive CRS with a non-breakover aircraft seat back, as currently used by Qantas.
3. An approval system should be established to ensure that any Australian automotive CRS to be used in aircraft fits in the aircraft seat and is compatible with the aircraft lap belt. The approval could be in the form of an extra test added to the existing motor vehicle requirements similar to the FAA approval system.
4. Improvements in the crash performance of Australian automotive CRS in aircraft could be achieved by making changes to the seating systems in the aircraft to minimise forward excursion of the CRS in the seat. In order of priority, these suggested improvements are:
    a. Supply a properly mounted upper tether, either as used by Qantas should testing show that this is effective or, by supplying attachment points in the aircraft for CRS use. This could be achieved by restricting CRS use to the seats forward of a bulkhead and by requiring a modified bulkhead design with appropriate attachment points built in for the tether.
    b. Change lap belt geometry (angled at 45 to 60 degrees instead of vertical) for use with a CRS to reduce the initial forward excursion of the base. However, such seat belt geometry may not be appropriate for other users of the belt.
    c. Make changes to the seat base cushion to ensure its retention under CRS dynamic loads.
5. Improvements in the crash protection offered in aircraft to an infant seated on the lap of an adult could be achieved if some seats were fitted with lap sash or harness type seat belts for use by parents holding infants. These seats, possibly adjacent to a bulkhead could be forward- or rear-facing. Controlling the upper torso motion of the adult has the potential to reduce crash loading to an infant seated on the lap of an adult.
6. If suggestion 5 was implemented, then an approval system for infant carriers (slings) for use in aircraft should be put in place. A sling system could be designed and developed as a replacement for the belly belt. This type of infant carrier could offer improved retention and comfort in turbulent conditions; in conjunction with appropriate seating fitted with a lap/sash or harness for the parent, it could offer improved safety for the infant in a crash.
7. The changes resulting from the incorporation of ISO rigid anchorage systems (ISO-Fix or latch systems), which are becoming mandatory worldwide, need to be studied and accommodated for use in aircraft.

5 GLOSSARY

AIS (Abbreviated Injury Scale)

A consensus derived, anatomically based system that classifies individual injuries by body region on a 6-point ordinal severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable, developed by the Association for the Advancement of Automotive Medicine (AAAM 1990).

ATD

Anthropomorphic Test Device (or Dummy)

Booster

Seat or Cushion**:** A device used for raising the child's position in the motor vehicle and adapting an adult seat belt to make it suitable for a child, with or without a back above the seating plane, respectively (AS/NZS 1754:2004).

Child Harness

A six-point restraint for the upper torso and designed for use with a lap-sash seat belt and attached to the upper anchorage point. This system is recommended for use with booster seats and must be used with a booster seat when a lap-only seat belt is present.

CRS

Child Restraint System: A device used in conjunction with an adult seat belt to restrain a child passenger of a motor vehicle in the event of a vehicle impact and thus minimize the risk of bodily injury (AS/NZS 1754:2004). Includes all infant restraints and child seats certified for use in automobiles.

ΔV, delta-V

The change in velocity from initial, sled entry velocity minus final velocity (m/s).

Entry velocity

The peak sled velocity attained prior to impact (m/s).

`fps

Frames per second: The normal video frame rate is 25 fps. High-speed video used in the testing was captured at 500 and 1000 fps.

G

Gravitational acceleration constant (9.81 m/s^2)

Harness

Webbing straps used for restraining the occupant either partly or wholly.

HIC

Head Injury Criterion: A commonly used indicator of head injury based on the acceleration of the head resulting from an impact.

Infant carrier (or baby sling)

A soft-style pouch worn on the chest of an adult, designed for 'hands-free' carriage of an infant.

ISOFIX, ISO-fix

A standard system for the connection of child restraint systems to vehicles, described in ISO 13216-1 Road vehicles – Anchorages in vehicles and attachments to anchorages for child restraint systems – Part 1: Seat bight anchorages and attachments.

Lap belt

A restraint system having two anchorage points (at the hips).

Lap/sash (shoulder) belt

A restraint system having three anchorage points, two at the hips and one at the shoulder, for upper torso restraint.

Loop belt (or belly belt or supplementary loop belt)

A belt device that attaches to the adult aircraft seat lap belt and used for restraint of lap-held infants on Australian and UK aircraft.

N

Newton, the unit of force required to accelerate a mass of one kilogram one meter per second per second ($kg.m/s^2$).

Pitch

As in "seat pitch": The distance between two adjacent rows of seats, at identical or equivalent points on the structure, measured in a plane parallel to the longitudinal axis of the aircraft.

Seat bight

The fold line at the base of the seat back where it connects to the seat base or cushion.

Sled deceleration

The rate at which the sled velocity decreases (m/s^2 or G).

Sled pulse

The deceleration-time curve (reduction in speed with time) of the sled on impact.

Submarining

An occurrence where the lap belt rides up over the iliac crest and into the soft tissue area of the abdomen (AS/NZS 1754:2004).

Top tether (Upper anchorage strap)

The flexible component designed to restrain the top portion of the child restraint (AS/NZS 1754:2004).

Yaw

Angle of rotation about the vertical axis (in degrees).

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APPENDIX A: CRS PROFILES

Safe-n-Sound Unity Baby Carrier

CRS Type: Type A: Rearward-facing infant restraint with harness for infants up to 9 kg

Fit Test: This restraint fits in the aircraft seat with a slight overhang on the armrests of 20 mm. The base mount cannot be installed on the aircraft seat due to the central position of the lap belt latch, which interferes with the carrier engagement vanes (below left). Proper installation requires the shortening of the lap belt on the tongue side by 60-65 mm. Without the base, the lap belt is positioned over the infant with the latch within easy reach (below right).

Dynamic Test: The Safe-n-Sound Unity was sled tested at 20G (entry velocity = 48.18 km/h) with no base and with an uninstrumented TNO P3/4 (9 kg) dummy (Test no. 8165).

The dynamic test showed excessive motion of the restraint. The carrier moved in an initial forward direction until it most likely hits the forward seat back (as shown below left). The back of the aircraft seat on which it is mounted flexed forward and came close to but did not touch the infant occupant. On rebound, the carrier rotated about the lap belt, meeting the aircraft seat back (below right).

Test paint revealed a severe facial impact to the infant occupant with the aircraft seat headrest (below). The infant occupant remained restrained throughout the test.

Babylove Primo 6 in 1 Baby Capsule

CRS Type: Type A: Rearward-facing infant restraint with harness for infants up to 9 kg

Fit Test: This restraint cannot be installed with the base mount due to the central position of the lap belt latch, which interferes with the carrier engagement vanes (below left). Without the base, the lap belt latch locates between the infant's legs in an awkward position (below right).


Dynamic Test: The Babylove Primo was sled tested twice at 18 and 19G (entry velocity = 47.73 and 47.8 km/h) with no base and with a TNO P3/4 (9 kg) dummy (Test no. 8292 and 8298). Video was lost for Test no. 8292. The dummy was instrumented for Test no. 8292 only.

Head x-acceleration (3ms) = 43G

Chest x-acceleration (3ms) = 43G

Lap belt load = 4.3kN

The dynamic tests showed excessive motion of the restraint and aircraft seat back. The carrier moved in an initial forward direction until it most likely hits the forward seat back (below left). The aircraft seat back folds forward, impacting the infants face (below centre). This can be attributed to the buckling of the rebound bar. On rebound, the carrier rotated about the lap belt, however there was no facial impact with the seat back or headrest (below right). The occupant remained restrained throughout the tests.

Safe-n-Sound Royale (Retractor)

CRS Type: Type A/B: Convertible child restraint (rearward- or forward-facing) with harness for infants and toddlers up to 18 kg

Fit Test: This restraint fits between the aircraft seat armrests but is marginal within the seat pitch in reclined rearward-facing mode. Additionally, the lap belt latch locates between the infant's legs in an awkward position in rearward-facing mode (below left). There is little access to engage, adjust and disengage the lap belt latch in forward-facing mode (below right).

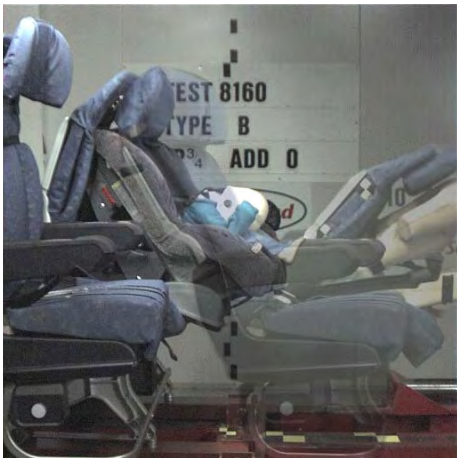
Dynamic Test: Several sled tests were performed on the Safe-n-Sound Royale. The results are summarised as follows:

Test Configuration	Test no. (sample no.)	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Rear recline with TNO P3/4 (9kg)	8161 (1)	20	47.49	59	48	-
	8162 (1)	18.5	47.63	58	49	-
	8163 (1)	19	47.64	59	48	-
	8164 (2)	19	47.7	-	-	3.5
Frontal recline with TNO P3/4 (9kg)	8158 (1)	20	47.56	148	43	4.54
	8159 (1)	19	47.45	-	-	4.25
	8160 (1)	19	46.95	151	44	4.11
Frontal recline with TNO P3 (15kg)	8166 (2)	18	47.63	210	58	4.9
	8167 (3)	19	47.15	173	71	4.68
	8169 (1)	19	47.15	174	142	4.93
Frontal recline with TNO P3 (15kg) and Qantas top tether	8168 (3)	19	48.19	147	99	5.15

In rearward-facing mode, the restraint translates forward until it most likely impacts the forward seat back (below left). On rebound, the restraint rotates about the lap belt and approaches the aircraft seat back. There is no apparent facial impact, although it does come close to contact (below right).

Safe-n-Sound Royale (Retractor) (cont.)

In forward-facing mode, the restraint translates forward until either the front of the seat or the legs of the child is likely to impact the forward seat back. The child's torso rotates forward in the harness until the head possibly impacts the knees (below).

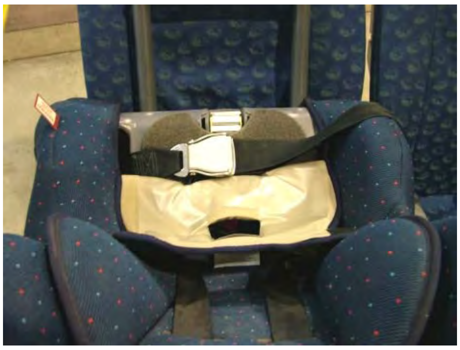


A larger child, in this case a 3-year-old, is more likely to be injured in this restraint. The legs and head experience excessive forward excursion and are likely to impact the forward seat back (below left). The use of the Qantas top tether showed similar results (below right).

Safe-n-Sound Galaxy (Ultra)

CRS Type: Type A/B: Convertible child restraint (rearward- or forward-facing) with harness for infants and toddlers up to 18 kg

Fit Test: This restraint fits between the armrests of the aircraft seat, however it may not fit within the aircraft seat pitch in rearward-facing reclined mode. The aircraft lap belt latch locates between the infant's legs in an awkward position in rearward-facing mode (below). There is little access for engagement, adjustment and release of the lap belt latch in forward-facing mode.

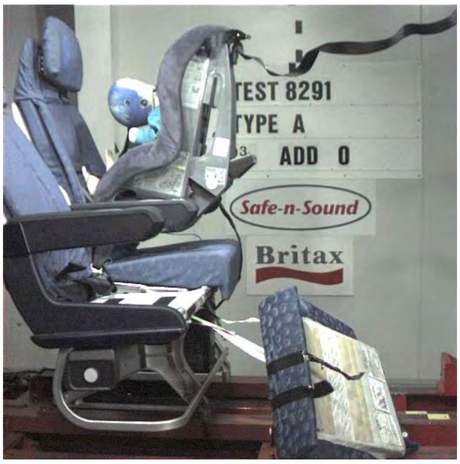


Dynamic Test: The Safe-n-Sound Galaxy was sled tested in three configurations. The results are summarised as follows:

Test Configuration	Test no.	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Rear recline with TNO P3/4 (9kg)	8291	19	47.73	45	47	3.4
Frontal recline with TNO P3 (15kg)	8247	18	47.72	106	48	4.7
Frontal recline with TNO P3 (15kg) and Qantas top tether	8248	19	47.56	130	126	5.9

In rearward-facing mode, the restraint is likely to impact the forward seat back (below left). This impact will not be severe if the restraint is initially touching or very close to the forward seat back. On rebound, the restraint rotates about the lap belt. There is no apparent head impact with the aircraft seat back (below right). The child occupant remained restrained.

Safe-n-Sound Galaxy (Ultra) (cont.)



In forward-facing mode, injury is likely to occur to a larger child (3-year-old), with impact to the legs and possibly the head at some point along the trajectory (below left). The use of the Qantas top tether revealed similar results (below right). The child occupant remained restrained in both tests.

IGC Aunger

CRS Type: Type A/B: Convertible child restraint (rearward- or forward-facing) with harness for infants and toddlers up to 18 kg

Fit Test: This restraint fits in the aircraft seat. Engagement, adjustment and release of the aircraft lap belt are difficult due to poor access. In rearward-facing mode, the lap belt latch must be flipped prior to engagement for later release.

Dynamic Test: The IGC Aunger was sled tested in four configurations. The results are summarised as follows:

Test Configuration	Test no. (sample no.)	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Rear recline with TNO P3/4 (9kg)	8287 (2)	19	47.68	43	48	3.7
Frontal recline with TNO P3/4 (9kg)	8288 (2)	19	47.73	51	46	3.8
Frontal recline with TNO P3 (15kg), lap belt in main belt path	8252 (1)	18	47.02	60	103	4.7
Frontal recline with TNO P3 (15kg), lap belt in alternative belt path	8250 (1)	18	47.54	156	200+	4

The rearward-facing mode, the restraint rotates and translates forward until it impacts with the forward seat back (below left). On rebound, the rotation is effectively minimised by the rebound bar (below right).

In forward-facing mode, there is excessive forward rotation of the restraint about the lap belt. This is likely to cause severe head impact with the forward seat back to a larger (3-year-old) child (below).

IGC Aunger (cont.)

Use of the alternative belt path in forward-facing mode prevents the forward rotation (below).

In test no. 8252, the aircraft lap belt cut right through the seat frame (below). This was the first test on the sample using this main belt path.

Babylove F1-304 Sovereign

CRS Type: Type A/B: Convertible child restraint (rearward- or forward-facing) with harness for infants and toddlers up to 18 kg

Fit Test: This restraint fits with the aircraft seat, however may not fit within the aircraft seat pitch in rearward-facing reclined mode. Engagement of the aircraft lap belt latch is difficult as the lap belt tongue only just reaches the slot. The latch must be flipped before engagement to allow adjustment of the belt length. Once firmly secured, there is little access to release the latch.

Dynamic Test: The Babylove Sovereign was sled tested in three configurations. The results are summarised as follows:

Test Configuration	Test no.	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Rear recline with TNO P3/4 (9kg)	8289	19	47.73	30	37	3.4
Frontal recline with TNO P3/4 (9kg)	8290	19	47.48	60	30	3.5
Frontal recline with TNO P3 (15kg)	8251	19	47.61	90	99	3.7

In rearward-facing mode, the restraint rotates forward until it impacts the forward seat back (below left). This impact may be minor if the restraint is initially touching or very close to touching the forward seat back. On rebound, the restraint rotates about the lap belt until it impacts with the aircraft seat back (below right). Facial impact with the seat back is apparent.

In forward-facing mode, there is forward excursion of the head, torso and legs of the child occupants that is likely to result in impact with the forward seat back (below).

Safe-n-Sound Discovery (Plus)

CRS Type: Type B: Forward-facing child restraint with harness for toddlers 8 to 18 kg

Fit Test: This restraint fits well in the aircraft seat. There were no problems encountered in the installation.

Dynamic Test: The Safe-n-Sound Discovery was sled tested at 18.5G (entry velocity = 47.47km/h) with an instrumented TNO P3 (15 kg) dummy in frontal reclined mode.

Head x-acceleration (peak) = 200G+

Chest x-acceleration (peak) = 200G+

Lap belt load = 5.5 kN

The dynamic test showed an initial forward motion of the restraint with the forward rotation of the aircraft seat back. This motion causes excursion of the child occupant (below left), which is likely to result in impact which the forward seat back (below right).

The occupant's head continued to rotate until it impacted with the knees (below left). On rebound, a second impact occurs to the back of the head on the aircraft seat headrest (below right).

Safe-n-Sound Maxi Rider

CRS Type: Type B/E: Convertible child restraint/booster seat, harnessed for toddlers 8 to 18 kg, booster for children 14 to 26 kg

Fit Test: This restraint fits in the aircraft seat. In child restraint (B) mode, the aircraft lap belt buckle ends up behind the child, in the lumbar region, with only thin padding to cover it. This would be too uncomfortable for a child to sit in. The latch must also be flipped prior to engagement for later release.

Dynamic Test: The Safe-n-Sound Maxi Rider was sled tested in three configurations. The results are summarised as follows:

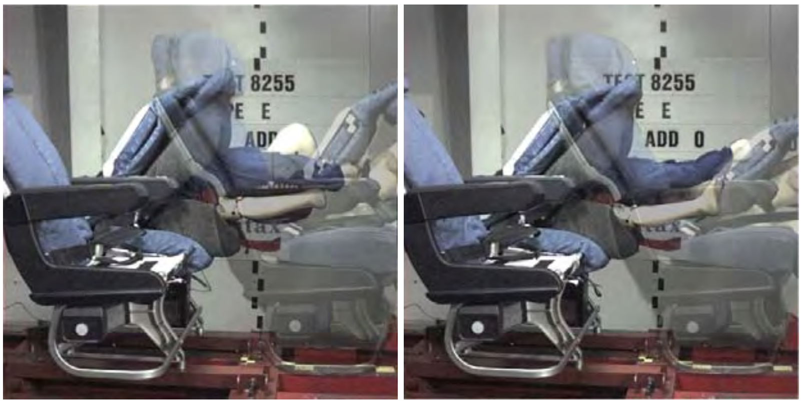
Test Configuration	Test no.	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Frontal recline with TNO P3 (15kg) with harness	8253	19	47.51	91	123	1.7
Frontal recline with TNO P3 (15kg) with harness and Qantas top tether	8294	19	48.1	89	70	2.2
Frontal upright with TNO P6 (22kg)	8255	18	47.65	-	-	4.5

In the testing, the Maxi Rider tended to fold over about the seat bight. The child occupant was thrown forward with the arms and legs likely to impact the forward seat back. In B mode with harness, the head of the dummy still rotates forwards towards the knees or in between the legs (below left). Use of the Qantas top tether showed similar results (below right). Head impact with the forward seat back is likely.

In E mode with the lap belt only, the head of the larger dummy rotates forwards and impacts with the seat cushion between its legs (below).

Safe-n-Sound Maxi Rider (cont.)

This excessive head rotation suggests that impact with the forward seat back is likely in both configurations. The child occupants remained restrained throughout the tests. Illustrated below are the possible points of head impact along the head trajectory.



Safe-n-Sound Maxi Rider 2005

CRS Type: Type B/E: Convertible child restraint/booster seat, harnessed for toddlers 8 to 18 kg, booster for children 14 to 26 kg

Fit Test: This restraint fits well in the aircraft seat. There were no problems encountered in the installation.

Dynamic Test: The Safe-n-Sound Maxi Rider 2005 was sled tested in four configurations. The results are summarised as follows:

Test Configuration	Test no.	Sled peak deceleration (G)	Entry velocity (km/h)	Head peak acceleration (G)	Chest peak acceleration (G)	Lap belt load (kN)
Frontal with TNO P3 (15kg) with harness	8296	18	47.19	65	36	5.6
Frontal with TNO P3 (15kg) with harness and Qantas top tether	8295	19	47.67	83	108	5.6
Frontal with TNO P6 (22kg)	8299	18	48.01	76	109	4.7
Frontal with TNO P6 (22kg) with Qantas top tether	8297	19	47.25	73	42	4.9

The Maxi Rider 2005 is stiffer in design than the previous model. While the restraint did not fold over about the seat bight, the results are similar to those of the previous Maxi Rider. Head rotation is severe and likely to result in impact with the forward seat back. The child occupants remained restrained throughout the tests.

The harnessed occupant experiences head rotation that may not impact with the forward seat back (below left). The use of the Qantas top tether gives similar results (below right).

Without the harness, the child occupant experiences excessive forward rotation of the torso and head, which is likely to result in severe head or facial impact with the forward seat back (below left). The use of the Qantas top tether gave similar results (below right).

Safe-n-Sound Maxi Rider 2005 (cont.)

In the lap belt only configuration, the torso and head of the child occupant continued to rotate until facial impact occurred with the seat cushion between its legs (below).

Safe-n-Sound Olympian

CRS Type: Type E: Child booster seat with high back for children 14 to 26 kg

Fit Test: This restraint fits well in the aircraft seat. There were no problems encountered in the installation.

Dynamic Test: The Safe-n-Sound Olympian was sled tested at 19.5G (entry velocity = 47.82km/h) with an uninstrumented TNO P6 (22 kg) dummy and aircraft lap belt only. The lap belt load was 3.7 kN.

The dynamic test showed excessive forward body rotation due to the lack of upper body restraint. Head impact with the forward seat back is likely (below left). The head of the child occupant continued in its rotation until impact with the seat cushion between its legs (below right). The occupant remained restrained in the test.

Safe-n-Sound Nova

CRS Type: Type E: Child booster seat with no back for children 14 to 26 kg

Fit Test: This restraint fits well in the aircraft seat. There were no problems encountered in the installation.

Dynamic Test: The Safe-n-Sound Nova was sled tested at 18G (entry velocity = 47.82 km/h) with an uninstrumented TNO P6 (22 kg) dummy and aircraft lap belt only. The lap belt load was 3.4 kN.

The dynamic test showed excessive forward body rotation due to the lack of upper body restraint. Head impact with the forward seat back is likely (below left). The head of the child occupant continued in its rotation until impact with the seat cushion between its legs (below right). The occupant remained restrained in the test.

DME PlaneSeat 2000

CRS Type: Type A/B: Convertible child restraint (rearward- or forward-facing) with harness for infants and toddlers up to 18 kg

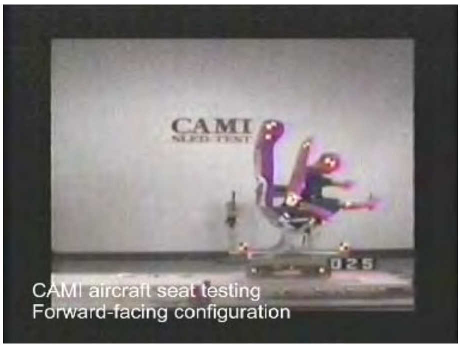
Fit Test: This restraint is designed for installation on aircraft seats. Measuring 340 mm in width, the PlaneSeat fits easily within the aircraft seat armrests. The belt paths allow easy access for installation with the standard aircraft lap belt.

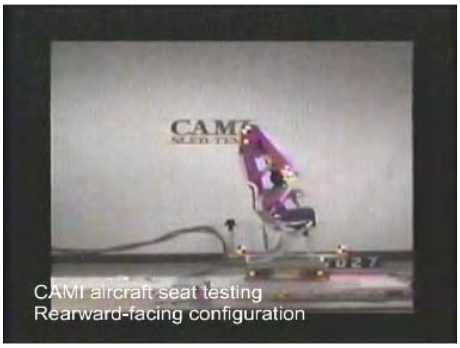
Dynamic Test: The DME PlaneSeat 2000 was not tested in this series. Results of testing conducted at the Civil Aeromedical Institute (CAMI) in 1997, and at CALSPAN Corporation's Transportation Sciences Center in 1998 were provided to HIE for review from DME Corporation.

Test videos of aircraft seat testing at CAMI were examined.

In the forward-facing configuration, the PlaneSeat rotates forward and there is forward rotation of the head and torso. Leg contact with the forward seat back is highly likely, while head contact is also quite likely (below left).

In the rearward configuration, there is excessive rotational motion of the restraint. In the forward motion, restraint contact with the forward seat back is most likely. On rebound, the restraint rotates towards the aircraft seat backrest, causing facial impact with the headrest (below right).





Test videos and test reports of the CALSPAN automotive seat testing were examined.

The tests conducted at CALSPAN involved a rearward acceleration from rest reaching 46.7 km/h and 22.6G.

The PlaneSeat was tested in a rearward configuration with an uninstrumented newborn dummy (3.4kg). The occupant remained restrained with a seat back rotation of 38-degrees.

In the forward-facing configuration, both an uninstrumented TNO P3/4 (9-month old, 9 kg) and an instrumented SA103C (3-year-old, 15 kg) were used. The three-year-old dummy measured a HIC of 756, with a peak resultant chest acceleration of 37.7G. The head and knee excursions for this dummy were 695 mm and 650 mm, respectively. The nine-month old dummy experienced a head excursion of 590 mm.

Inversion tests were also performed on the PlaneSeat using the three dummies in the various configurations. All dummy were retained in both forward and lateral inversions.

APPENDIX B: INFANT CARRIER PROFILES

AMSAFE® Loop Belt

Manufacturer: AM-SAFE Inc
Phoenix, AZ
USA (602) 850 2850

Purchased from: Supplied by Qantas Airways Ltd. (received 4 April 2005).

Age/Weight range: Provided on Australian aircraft for lap held infants up to two years old.

Description: This device is designed for use with the standard aircraft lap belt. The device is made from 50 mm wide webbing, approximately 575 mm in length, and is adjustable giving a maximum circumference of 620 mm (minimum 320 mm). A 240 mm circumference loop made from the same webbing material is sewn to the main loop for attachment to the aircraft lap belt. The device is secured by means of a standard lap belt latch and tongue configuration. The loop belt is labelled as conforming to FAA TSO-C22g, and is rated to 3000 lbs.

Turbulence Test: Test no. G050042, Sample no. 31396, 15 April 2005

The Amsafe loop belt was tested in the turbulence configuration with both a TNO P3/4 (9-month-old, 9 kg) and a TARU Theresa (6-week-old infant, 4 kg) dummy. The device was firmly secured, allowing access for two fingers, at approximately navel position of the child dummies. This firm adjustment may have been too tight for a real child.

Upon inversion, the loop belt retained both infant dummies satisfactorily.


AMSAFE® Loop Belt (cont.)

Dynamic Sled Test: Test no. S050147, Sample no. 31332, 13 April 2005

The Amsafe loop belt was tested in a dynamics sled test configuration at 9G with the 50th-percentile adult male THOR dummy and the TNO P3/4 infant dummy. The test was run with a double row of aircraft seats to evaluate the belt performance and head excursion with interaction with the forward seat back.

The child dummy experienced excessive forward body excursion resulting in a severe facial impact with the dinner tray of the forward seat back. The adult dummy then folded over the child dummy, before its head impacted with the head rest area of the forward seat back. The child dummy was retained in the loop belt throughout the test.

Snugli® Comfort Vent™ Soft Carrier

Manufacturer:	Evenflo Company, Inc. 1801 Commerce Drive, Piqua, OH 45356 Oakville, Ontario L6H4M1, Canada
Purchased from:	Target Australia Pty. Ltd.
Price:	$49.95
Weight range:	3.2 to 11.8 kg (7 to 26 lb)
Description:	The Snugli® Comfort Vent™ Soft Carrier is a polyester baby carrier designed to carry infants in a forward- or rearward-facing configuration on the chest of an adult. The structure of the carrier is made from polyester fabric padded with a polyurethane foam, polyester fibre and polyethylene board. Mesh sections are included for ventilation. The carrier is not designed for aircraft use and the manufacturer warns against use in exercise activities or motorized vehicles.
Static Test:	Tested 22 March 2005 The Snugli® Comfort Vent™ Soft Carrier was tested for static load capacity. The carrier was suspended on a rounded tube and the front panel of the sling was loaded with 82.5 kg over a 200 mm diameter area.

Snugli® Comfort Vent™ Soft Carrier (cont.)

Under this load, the stitching that attaches the 20 mm webbing for the two Head Support Buckles started to come undone. The two hooks for the Side Entry Buckles bent outwards by 10 to 12 mm and began to disengage. The 30 mm shoulder strap buckle and webbing remained intact.


Turbulence Test: Test no. G050043, Sample no. 31397, 15 April 2005

The Snugli® Comfort Vent™ Soft Carrier was attached to the adult THOR dummy and rotated on the rotation rig. The 6-week-old infant dummy (TARU Theresa) was firmly secured in a rearward-facing configuration in the carrier.

When inverted, the carrier retained the infant dummy satisfactorily when the arms were correctly positioned through the armholes.

Dynamic Sled Test: Test no. S050148, Sample no. 31336, 13 April 2005

The TNO P3/4 infant dummy was secured in a forward-facing configuration in the Snugli® Comfort Vent™ Soft Carrier, and sled tested with a single row of seats at 9G with the adult THOR dummy. The carrier was adjusted for a firm fit on both dummies, which meant that the infant was suspended rather that sitting on the lap of the adult.


There was excessive forward excursion of the infant dummy before failure of the carrier. The 20 mm webbing that joins the left Head Support Buckle and Shoulder Strap came away due to failure of the shoulder strap. This was almost mirrored on the right. The effect was to throw the infant from the lap of the adult, although it was caught by the right arm and leg within the carrier. Inspection of the carrier post-test revealed adult head contact with the lower back area of the infant before failure of the carrier.

Infantino® GoGo Rider™

Manufacturer:	Infantino, LLC San Diego, CA 92121 USA
Purchased from:	The Baby Shop Online (http://www.babyshop.com.au)
Price:	$69.95
Weight range:	3.5 to 10.4 kg (8 to 23 lb), minimum height 53 cm (21”)
Description:	The Infantino® GoGo Rider™ is a cotton/polyester baby carrier designed to carry infants in a forward- or rearward-facing configuration on the chest of an adult. The structure of the carrier is made from cotton/polyester fabric padded with a urethane foam and polyester fibre. The carrier is not designed for aircraft use and the manufacturer warns against use in exercise activities or motorized vehicles.
Turbulence Test:	Test no. G050044, Sample no. 31398, 15 April 2005 The Infantino® GoGo Rider™ was attached to the adult Hybrid III dummy and rotated on the rotation rig. The 6-week-old infant dummy (TARU Theresa) was firmly secured in a rearward-facing configuration in the carrier.

Infantino® GoGo Rider™ (cont.)

Dynamic Sled Test:	When inverted, the carrier retained the infant dummy satisfactorily when the arms were correctly positioned through the armholes.

Test no. S050149, Sample no. 31335, 13 April 2005

The TNO P3/4 infant dummy was secured in a forward-facing configuration in the Infantino® GoGo Rider™, and sled tested with a single row of seats at 9G with the adult Hybrid III dummy. The carrier was adjusted for a firm fit on both dummies, with the plastic triangle loop for the head support in the highest position and the infant sitting on the lap of the adult.

The shoulder straps failed at the connection to the carrier seat. This had the effect of catapulting the infant forward from the lap of the adult, still in the carrier, landing on the top of its head before coming to rest on its front at the feet of the adult. There was adult head contact with the lower back area of the infant dummy.

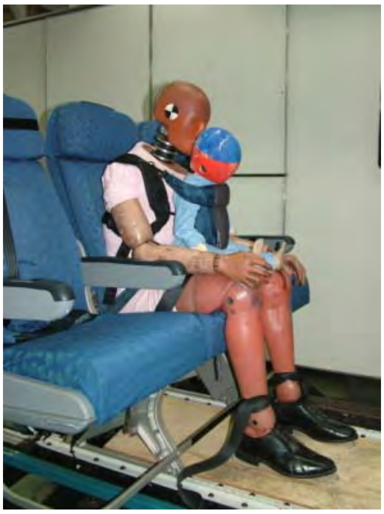
Theodore Bean™ Infant & Toddler Carrier

Manufacturer:	Theodore Bean, Inc 43218 Business Park Dr. Bldg. 108 Temecula, CA 92590 USA
Purchased from:	The Baby Shop Online (http://www.babyshop.com.au)
Price:	$99.95
Weight range:	Infants 3.6 to 5.4 kg (8 to 12 lbs) Toddlers 4.5 to 18.1 kg (10 to 40 lbs)
Description:	The Theodore Bean™ Infant & Toddler Carrier is a nylon/polyester baby carrier designed to carry infants and toddlers in a forward- or rearward-facing configuration on the chest of an adult. The carrier is made from nylon/polyester fabric padded with polyurethane foam. The carrier is not designed for aircraft use and the manufacturer warns against use in exercise activities or motorized vehicles. The carrier features a removable "pod" insert to secure newborn infants in the carrier. The adult shoulder and back harness is reinforced with 50 mm wide heavy-duty nylon webbing, and is designed for even weight distribution.
Turbulence Test:	Test no. G050045, Sample no. 31399, 15 April 2005 The Theodore Bean™ Infant & Toddler Carrier was attached to the adult Hybrid III dummy and rotated on the rotation rig. The 6-week-old infant dummy (TARU Theresa) was firmly secured in a rearward-facing configuration in the pod and carrier. When inverted, the carrier retained the infant dummy satisfactorily when the arms were correctly positioned through the armholes.

Theodore Bean™ Infant & Toddler Carrier (cont.)

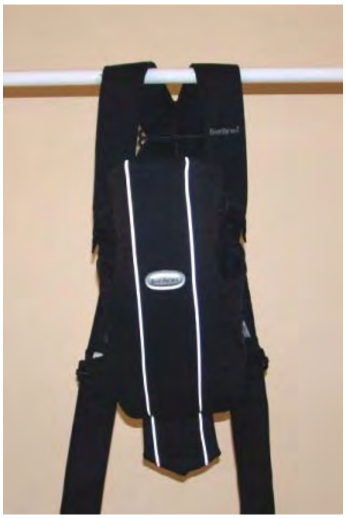
Dynamic Sled Test: Test no. S050150, Sample no. 31334, 13 April 2005

The TNO P3/4 infant dummy was secured in a forward facing configuration in the Theodore Bean™ Infant & Toddler Carrier, and sled tested with a single row of seats at 9G with the adult Hybrid III dummy. The carrier was adjusted for a firm fit on both dummies; with the seat adjustment buckles in the highest position and the infant sitting on the lap of the adult.

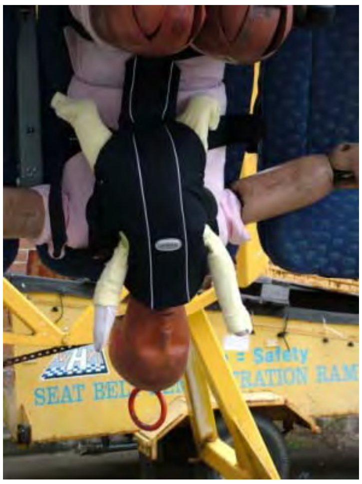
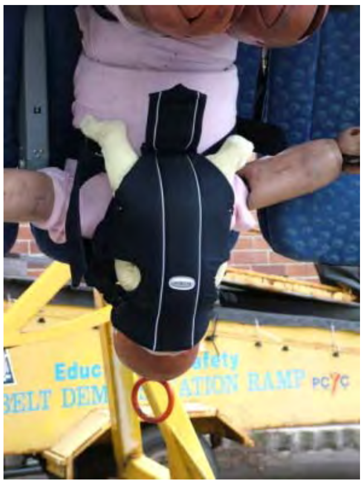


The two seat adjustment clips on the right failed. This caused the infant dummy to dive headfirst to the floor.

BABYBJÖRN® Original Baby Carrier




Manufacturer:	BABYBJÖRN AB, SE-330 10 Bredaryd, Sweden
Purchased from:	Sydney's Baby Kingdom - Bankstown, NSW
Price:	$139.95
Weight range:	3.5 to 10 kg (8 to 22 lbs)
Description:	The BabyBjörn® Original Baby Carrier is a cotton baby carrier designed to carry infants and toddlers in a forward- or rearward-facing configuration on the chest of an adult.
Turbulence Test:	Test no. G050046, Sample no. 31400, 15 April 2005 The BabyBjörn® Original Baby Carrier was attached to the adult Hybrid III dummy and rotated on the rotation rig. The 6-week-old infant dummy (TARU Theresa) was firmly secured in a rearward-facing configuration in the carrier.

BABYBJÖRN® Original Baby Carrier (cont.)

Dynamic Sled Test:	When inverted, the carrier retained the infant dummy satisfactorily when the arms were positioned both through the armholes and inside the carrier.
	Test no. S050151, Sample no. 31333, 13 April 2005
	The TNO P3/4 infant dummy was secured in a forward-facing configuration in the BabyBjörn® Original Baby Carrier, and sled tested with a single row of seats at 9G with the adult Hybrid III dummy. The carrier was adjusted for a firm fit on both dummies with the infant sitting on the lap of the adult.


The right Head Support Buckle attachment and right Sliding Buckle Clip failed, causing the infant dummy to be thrown clear of the adult lap.