Australian Government
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AN INVESTIGATION OF AUTOMOTIVE CHILD RESTRAINT INSTALLATION METHODS IN TRANSPORT CATEGORY AIRCRAFT

AIRFRAMES
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RESEARCH PROJECT

AN INVESTIGATION OF AUTOMOTIVE CHILD RESTRAINT INSTALLATION METHODS IN TRANSPORT CATEGORY AIRCRAFT

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Summary

Whilst Child Restraint System (CRS) performance in motor vehicles has steadily improved over the past thirty years, child restraint use in aircraft has not progressed. To highlight this, many countries around the world allow children under the age of two years to be lap held and if so, they must remain unrestrained. Numerous children have lost their lives around the world in accidents that are regarded as survivable. While Australia requires all occupants to be restrained, the situation is no better. Most infants travel lap held, restrained by a Supplementary Loop Belt. Automotive child restraint use in Australian Regular Public Transport (RPT) may actually have diminished over previous years as they are no longer offered by any domestic carriers, some of which previously provided them for use.

Automotive child restraint use in Australian airlines is extremely limited because of a feature somewhat unique to Australian automotive requirements, that is, the mandatory use of a top tether strap. CASA maintains that operators shall ensure the child restraint is installed in accordance with the manufacturer's instructions, thereby also requiring the use of the top tether in aircraft. A popular method of top tether attachment widely used by the Australian airline industry blocks the use of the tray table for any person sitting in the seat behind the child restraint. An additional operational factor for the child restraint is the fitment time during turnaround.

There were three principle aims to this research. To directly assess the contribution of the top tether strap to the crash performance of the child restraint in an airline seat. To test the viability of an alternative to the top tether restraint mechanism that would increase restraint performance at the same time as negate the negative installation issues associated with the top tether. Finally, to assess the performance of ISOfix child restraint systems in aircraft seats. FAA TSO-C100b allows for rigid prong attachments and CASA wanted to understand the performance advantage for children and any effects on passengers seated behind as there is consideration for the ISOfix system to added to the Australian Standard for Child Restraints. CASA is not aware of any aircraft worldwide fitted with lower anchorage systems for ISOfix CRS though it is aware that some new aircraft types in the 'Very Light Jet' (VLJ) category may soon introduce this feature.

Australian Automotive CRS perform adequately in transport category seats. The two Australian CRS tested met all but head excursion criteria. The test configuration involved placing an airline seat in front of the CRS in a representative arrangement such that any injury levels measured during contact with the forward structure would be representative of real world installations.

Whilst the Australian CRS performed adequately using the top tether, evidence indicates the top tether did not function as designed and provided no useful contribution to the CRS crash performance. The anticipated benefits of an alternate installation method using an extension belt were not realised. For the same reasons as the top tether installations, the lack of breakover resistance by the seat back did not provide for a suitable anchor.

Tests using ISOfix type restraints demonstrate the benefits of the ISOfix system when used in conjunction with a suitably modified transport category aircraft seat. The mechanism that affords the improved performance is the increased stiffness of the installation. This removes most of the probability of occupant impact with surrounding structures. The restraint system is essentially mechanically fixed to the seat by two steel links rather than relying on the seat lap belt for restraint. These links mean the horizontal displacement of the CRS during the impact is virtually eliminated, leaving the integrated 5-point harness of the CRS to perform the function of arresting the child occupant in a controlled manner.

It was determined that the ISOfix system can provide an equivalent level of safety for children as that currently afforded to adults. It may even provide superior protection.

A concern with the ISOfix system investigated by this series of tests was the effect of the ISOfix child restraints on the injury levels to an adult seated behind due to the effective increase in seat back breakover stiffness. This proved to be the one negative outcome for this type of child restraint. Whilst none of the injury criteria for a seat certification were exceeded, video evidence highlighted potentially dire injury levels associated with neck shearing and neck flexion in the adult. Future testing should check to eliminate any particular aspects associated with the aircraft seat type used for this test series.

Recommendations are made concerning changes to CASA advisory material and future research in this field.

1 Introduction

1.1 Purpose

This report does not enter into whether child restraint systems should be mandatory or whether aviation versus automotive systems should be used. The intent is to assess, and try to remove, impediments to the use of Australian automotive child restraints in airline seats. However, some of the outcomes could be relevant to non-Australian airline operations.

One of the impediments, with respect to the aircraft airworthiness, is the modification to the aircraft to allow attachment of the top tether strap required by Australian automotive child restraints. Operationally, a popular method of top tether attachment widely used by the Australian airline industry blocks the use of the tray table for any person sitting in the seat behind the child restraint. An additional operational factor is the fitment time of the child restraint during turnaround.

Figure 1 – Typical top tether installation with strap across tray table

At the time of this report's publication, there was consideration for amendments to the Australian Standard for Automotive Child Restraints, AS/NZS 1754. These were to include the introduction of ISOfix and LATCH attachment systems. CASA was interested in quantifying the perceived benefits of the rigid anchorage ISOfix system given the gross deflections typical of current automotive child restraints worldwide.

Figure 2 - A typical ISOfix child restraint anchorage system | Positioned ready for engagement in a car

Figure 3 - ISOfix attachment lined up in a guide for engagement | Green marking indicating successful attachment.

1.2 The Program

1.2.1 Aims

There were three principle aims of this project:

- To directly assess the contribution of the top tether strap to the restraint performance of a sample of Australian Automotive child restraints in an airline seat.
- To test the viability of an alternative to the top tether restraint mechanism that would increase restraint performance as well as negate the need for the top tether.
- To assess the performance of a sample of European ISOfix child restraint systems in aircraft seats.

1.2.2 Terminology and units

Terminology and conventions used in this report will be a mix of aviation and automotive as well as Australian and international.

Terms used in this report will be aviation based but where there is no aviation equivalent automotive terms will be used. Equally, Australian terminology will be used in preference to international terms. A Glossary of terms is provided in Chapter 7.

As the child restraint system is essentially a 'seat on a seat', for this report the Child restraint system will be referred to as the 'CRS', and the airline seat will be referred to as the 'seat'.

Reference to ‘Australian airlines’ should always be read as a general term referring to the international and domestic airline industry of Australia and not the airline that operated as Australian Airlines that was incorporated from Trans Australian Airlines (TAA) and is currently part of the Qantas Group.

Aviation still operates mostly in imperial units whilst the automotive industry has migrated to metric. The units most appropriate to the subject will be used as the primary unit but the other system will always be added as the secondary unit of measure.

1.3 Background

1.3.1 History to this research

In 2004, the Aviation Safety Forum (ASF) formed a ‘Position in Principle’ that, subject to some practical constraints, infants are entitled to the same level of safety protection, both in flight and during emergency landing situations, that is afforded to adults. The ASF recommended to CASA that it hold an industry meeting along similar lines to that of the NTSB Child Restraint in Aircraft Symposium, held in Arlington, Virginia USA, 15-16th December 1999. A meeting was held in Canberra, ACT, Australia, on the 23rd November 2004. Some of the recommendations/statements that arose out of that meeting were:

- The Supplementary Loop Belt is dangerous in high-energy accidents.
- The Supplementary Loop Belt restraint for a child is not an equal level of protection to an adult with lap belt.
- The Supplementary Loop Belt is not mandated – the requirement is for all passengers to be restrained. The conference agreed that all occupants must be restrained. Lap held infant, without restraint, is not acceptable.
- It appears current regulations are inadequate because they allow the use of the Supplementary Loop Belt. The group recommended the need to start looking at choices and provide information to the public.

1.3.2 Previous research in Australia

In 1995, Mark Bonnici, an RMIT undergraduate conducted a thesis project[1] that compared the performance of a US automotive child restraint and a similarly designed Australian automotive child restraint that used a 3-point attachment. It concluded that the performance was very similar and that the top tether may not be required.

In 1996, CASA conducted informal research with the FAA Civil Aerospace Medical Institute (CAMI). These tests used the same US automotive child restraint as used by Mark Bonnici and was similar in nature to previous CAMI work.[2]

In 2006, Human Impact Engineering & Britax Childcare (Australia) completed research under an Australian Transport Safety Bureau (ATSB) Aviation Safety Research Grant[3]. It investigated the fit, form, and function of a vast range of currently available Australian AS/NZS1754 Child Restraints[4], and additionally tested child Anthropomorphic Test Devices (ATD) in Aircraft Lap Belts, the Supplementary Loop Belt, and Fabric Infant Carriers. This research found numerous Automotive CRS had difficulty in fitting within the space available or could not be adequately installed due to interference with the aircraft lap belt. Approximately half of the CRS were able to be tested and most exhibited significant forward motion, rotation and rebound motion. This is similar to results found previously in overseas research[5 6]. This research made seven recommendations. Two of these recommendations are assessed in this report.

1.3.3 Aviation Child Restraint Requirements

1.3.3.1 Australian Civil Aviation Regulations

CAR(1988) 251(1)[7] states that all occupants must wear a seat belt during take-off, landing, an instrument approach, flight under 1,000 ft above terrain, and during turbulent conditions.

CAR(1988) 251(3) states that CASA may direct that a type of safety harness shall be worn in place of a seat belt. This is the provision under which infants and children may travel held in the lap of an adult, or restrained by an Aircraft or Automotive Child Restraint. The details of this are defined in CAO 20.16.3.[8]

CAO 20.16.3 paragraph 13 allows for the carriage of a child in the lap of an adult passenger, in an infant seat and for the carriage of two children in one seat and lap belt. Sub-paragraph 13.2(2) requires the aircraft seat belt not be passed around both the adult and a lap held child, and thus by default requires the use of a Supplementary Loop Belt. The performance of the Supplementary Loop Belt will not be discussed in this report as it has been previously well documented[3 5 6]. Additionally, the carriage of two children in one seat will not be commented on in this report as the inadequacies of this form of restraint have also been sufficiently documented in the past[9]. Requirements for the use of infant seats are covered by paragraphs 13.3 through 13.6.

CAAP 235-2(1)[10] is an advisory document published by CASA regarding the carriage of infants and children, and provides guidance on the use of infant seats, bassinets and the Supplementary Loop Belt. Included in the advisory are the conditions which infant restraints should be used, including the recomendation that the restraint device be installed in accordance with its manufacturer's instructions. The implications of this are discussed further in Section 1.3.4. It also lists the acceptable standards for infant restraints.

For the purposes of the Australian Civil Aviation Regulations, CAO 20.16.3 defines an infant as a passenger who has not reached their third birthday and a child as a passenger who has reached their third but not their thirteenth birthday.

1.3.3.2 Australian requirements compared to other National Airworthiness Authorities.

Australia aligns with almost all other countries by allowing the use of aircraft and automotive child restraints. FAA FAR 121.311(b)(2)[11], JAA JAR-OPS 1.730(a)(3)[12] and TCCA CAR 605.28[13] are examples of national regulations that cover this issue. However, the Australian requirement for the restraint of lap held children is diametrically opposed to the regulation of most other western nations.

Australia also varies in its definition of an infant and a child. Most countries define the upper age limit of an infant, that is a child able to be lap held, as a passenger who has not attained their second birthday. CASA's definition of an infant however, is a passenger who has not attained their third birthday. Nevertheless, most Australian airlines choose to enforce a second birthday limitation to align with world practice.

1.3.4 Child Restraint Standards

1.3.4.1 Australian Standard AS/NZS 1754

AS/NZS 1754[4] is the standard to which all automotive child restraints are manufactured for retail sale within Australia. For many years, the design and performance criteria specified in AS/NZS 1754 have been considered the most demanding in the world. In comparison to other published automotive standards, AS/NZS 1754 has additional requirements for dynamic testing, including side impacts and inverted impacts for roll over/ejection assessment. Additional features of the standard since 1975 are the mandatory use of a top tether strap for the restraint system and a harness for the child of not less than 5 points. A large issue with respect to child restraints made to this standard and their use in airline seating is the requirement to use the top tether strap. Whilst many child restraints have a seat belt path that passes through lower aft portion of the shell, some have seat belt paths that pass through or around the front of the restraint, making them unstable in a forward or upward acceleration if the top tether strap is not used. For these restraints, the top tether anchorage and top tether strap path must be an effective part of the restraint system. Typically, these restraints can be upset with only hand pressure applied to the top of the restraint when installed in an airline seat.

Figure 4 - IGC Alternate belt path | IGC Standard belt path | Unstable nature of forward belt paths without effective top tether.

1.3.4.2 Comparison of AS/NZS 1754 to worldwide standards

The following table compares some features of child restraint standards accepted for use by CASA in aircraft in accordance with CAAP 235-2(1).

			AS/NZS 1754[4]	FAA TSO-C100b[14]/ SAE AS5276/1[15]	FMVSS 213[16]	CMVSS 213[17]	ECE R44[18]
Test Pulse	Frontal*		24 g / 49 km/h	16 g / 48.3 km/h	19 g / 48 km/h	20 g / 48 km/h	20 g / 48 km/h
	Sideways*		14 g / 32 km/h†	-	-	-	-
	Rearwards*		14 g / 32 km/h	-	-	-	14 g / 30 km/h
	Inverted*		8 g / 16 km/h	1 g ‡	1 g ‡	1 g ‡	1 g ‡
Configuration	Lower Anchorages		Seat belt only (Proposal to add ISOfix & LATCH)	Seat belt, ISOfix, LATCH	Seat belt, ISOfix, LATCH	Seat Belt ISOfix, LATCH	Seat belt, ISOfix
	Anti-rotation device		Mandatory (top tether)	Not allowed	Optional (top tether)	Optional (top tether)	Optional (top tether, foot prop, dashboard)
Injury Criteria	Head	FF	-	HIC < 1000	HIC < 1000	-	-
		RF	< 150 g	HIC < 1000	HIC < 1000	-	-
	Chest	FF	-	< 60g (3ms)	< 60g (3ms)	< 60g (3ms)	< 55g (3ms)
		RF	-	< 60g (3ms)	< 60g (3ms)	-	< 55g (3ms)

* For general comparative purposes only. Minimum peak acceleration and minimum velocity change is listed. The table does not detail test pulse shape, maximum acceleration limits, or minimum acceleration time periods.

† This direction is subject to two tests, one is with a child restraint only, the second is with a child restraint and simulated car door.

‡ This test involves a rollover jig that simulates a +1g to -1g event.

There is a proposal to add ISOfix and LATCH to AS/NZS 1754. Whilst still in draft form at the time of writing this report, it is anticipated that the mandatory use of top tethers for all forward facing and rearward facing CRS will continue and will apply to CRS featuring ISOfix and LATCH attachment methods.

2 Testing

2.1 Test Methodology

2.1.1 Standards

Whilst the research was focused on CRS installation methods and assessing, to a certain extent, real world performance, all dynamic testing was carried out using a combination of the following standards:

- FAA TSO-C100b 'Child Restraint Systems'[14], and
- Australian Standard AS/NZS1754:2004 'Child Restraint Systems for use in motor vehicles'[4].

TSO-C100b and it's main reference source, SAE Aerospace Standard AS5276/1 'Performance Standard for Child Restraint Systems in Transport Category Airplanes'[15], were used to define the test severity, instrumentation and pass/fail criteria. AS/NZS 1754:2004 and it's main reference, AS/NZS 3629.1:2004 'Methods of testing child restraints – Method 1: Dynamic Testing'[19], were used to define the ATDs, ATD installation, and supplemental pass/fail criteria.

The main variation was the use of an airline seat rather than a test fixture as defined by both standards.

2.1.1.1 Child Restraint categories

Considering the international selection of child restraints tested, all the restraints could be approximately allocated to the categories stipulated in TSO-C100b/SAE AS5276/1; however, none of the restraints completely encapsulated all the requirements.

2.1.1.2 Test Fixture

Rather than the test fixture described in TSO-C100b/SAE AS5276 or AS/NZS 1754/3629.1, a B/E Aerospace 'Innovator' Economy class two place seat was used. A typical airline seat is vastly different to the standard test fixture and it was thought more useful information would be gained from testing on an aircraft seat. Additionally, most tests were performed with another identical seat for assessment of head impacts. A 30-inch seat pitch was chosen to represent a typical airline seating arrangement. One of these seats was modified for a lower anchorage system for ISOfix CRS. The seats complied with the recommendations of SAE ARP4466[20].

2.1.1.3 Passenger Seat Restraint

Lap belts meeting the requirements of SAE AS5276 were used, i.e. FAA TSO-C22g. The belt assemblies met the recommendations of SAE ARP4466.

2.1.1.4 Test Severity

The prescribed test pulse of TSO-C100b/SAE AS5276 paragraph 4.6 was aimed for, for all tests. That is, a peak acceleration of 16 g with a minimum rise time of 90ms, and a minimum velocity change of 44 ft/s. Yaw and floor deformations were not performed.

2.1.1.5 CRS and ATD Installation

The CRS and ATD were installed in accordance with AS/NZS 3629.1. Specifically, the CRS were installed in accordance with the manufacturer's instructions but the aircraft seat lap belt was tightened using a force gauge on the free end of the adjustable belt to a force of 70N (15.7 lb), the mid range of the allowable force range specified in AS/NZS 3629.1. This is slightly in excess of TSO-C100b/SAE AS5276 requirement of 67N (15 lbs). The CRS, in forward facing configuration, were tested in the upright rather than recline position. In an attempt to replicate real life situations, AS/NZS 3629.1 requires the use of a spacer behind the ATD to duplicate a relatively loose adjustment the child harness. The ATD was placed in the CRS with the appropriately sized 25mm flexible polymer spacer placed between the ATD's back and the restraint. The harness was then buckled up and tightened firmly. The harness adjusting strap free end was chalk marked at the adjuster and the buckle released. The spacer was removed, the ATD replaced to it's proper position and the harness rebuckled with no adjustment made to the harness. This method ensured equality to the method by which the Australian CRS would have been originally certificated. The same method was applied to the European CRS for equivalence.

Figure 5 - Flexible polymer spacer

2.1.1.6 Pass/Fail criteria

Primarily TSO-C100b/SAE AS5276 was used as the criteria for acceptable levels of injury, however the somewhat simplified criteria of AS/NZS 1754 was also assessed. Because of the use of a seat in front, assessment of knee excursion in most cases could not be made. For the same reason, Head Impact Criterion (HIC) was affected. In many cases the HIC would be worse, caused by direct interaction with the seat back and from knees riding up to meet the head because of foot engagement with the seat back. HIC36 was used for assessment which is at variance to the FAA method of 'first head impact onwards' maximum time period for HIC.

2.1.1.7 Miscellaneous

Dynamic performance was the primary focus for this research, thus compliance with such items as flammability, toxicity and labelling were not assessed. Buckle release forces were subject to qualitative assessment only.

2.1.2 Facilities

All dynamic testing was carried out at the RTA Crashlab[21] facilities in Huntingwood, Sydney, NSW. Crashlab is an independent test facility operating as a commercial business unit within the Roads and Traffic Authority of NSW (RTA), which is an Australian State Government department. Crashlab is accredited to the National Association of Testing Authorities (NATA).

2.1.2.1 Test Sled

Crashlab's Monterey Horizontal Crash Simulator (test sled) was used to generate the required impact conditions. This "Impact-with-rebound" type sled is described in FAA AC 25.562-1A[22], paragraph 7(d). Manufactured by Monterey Research Laboratory Incorporated of California, it was designed for dynamic testing of seat belts and small components up to 680 kg (1500lbs), and is ideally suited to the research and testing of child restraints and adult seating systems.

The sled is propelled by elastic shock cords and the system produces the required pulse waveform using an impact programmer mounted to a rail carriage (sled table) which rebounds. Although the dynamics of this approach are less obvious than with a non-rebound type sled, the economical and operational benefits of this design enables varied and repeatable simulation of crash pulses, with a short track system and no disassembly of the machine required.

The programmer is designed to act as a resilient spring. When the sled contacts the reaction mass (a fixed concrete block), the programmer is compressed until it absorbs all the kinetic energy of the carriage and has decelerated the carriage to zero velocity. The programmer then expands to its original length, returning the stored energy back to the carriage and accelerating it back to its original starting position. The first half of the total pulse occurs during the time the carriage is being stopped and the second half of the pulse occurs during rebound. This provides a velocity of the carriage at the end of the rebound portion of the pulse approximately equal to the velocity just before impact, but in the opposite direction.

2.1.2.2 Instrumentation

Electronic and photographic instrumentation met the recommendations of SAE J211[23] parts 1 and 2 respectively. ATD and sled instrumentation was linked to computers via an umbilical cord and data downloaded in real time. Numerous samples of test data suffered from intermittent noise however in all but two cases the noise did not coincide with peak acceleration/load periods. The source of the noise was associated with the P series ATDs and affected the head acceleration measurements mostly. Three cameras were used – side (1000fps), overhead (500 fps) and a reverse front quartering view (500fps).

Figure 6 - Crashlab test sled facilities

2.1.3 Equipment

2.1.3.1 Airline Seat

To mount the CRS, B/E Aerospace 'Innovator' Economy class two place seats were acquired. These seats were marked as TSO-C39b Type I compliant. However, the seatbacks were fitted with limited breakover devices. A check of B/E Aerospace product data reveals substantially similar mechanisms installed in seats categorised as TSO-C127/SAE AS8049A compliant, although, the variations would result in different loads to initiate breakover. A test was performed to assess the static force required to initiate breakover. A force applied at the top of the tray table of 160 lbs (715 N) was required, which equates to a required breakover moment of 301 ft.lb (408 Nm). After each test, the seats were repaired. In general, this only required replacement of the buckling plates in the breakover limiting mechanism.

2.1.3.2 Airline Seat Restraints

Amsafe lap belt assemblies conforming to TSO-C22g, rated at 3000 lbs were used. These belt assemblies were of a good used condition and met the requirements of SAE AS5276 paragraph 4.2.1.

2.1.3.3 AS/NZS 1754 CRS

The two models of Australian child restraints tested were Type A/B restraints. These are known as ‘convertible’ type restraints. These restraints can be used in both the forward facing and rearward facing directions. These are by far the most popular type of child restraint used in Australia. In type A mode, the restraints differed slightly in that they fitted into different sub-categories. One was a Type A1, which is designed for rearward facing restraint up to a child weight of 9 kg (20 lb). The second restraint Type A2 category, which allows rearward facing restraint up to 12 kg (26 lb). Both restraints fit the one Type B category of forward facing restraint from 8 kg (18 lb) to 18 kg (40 lb).

These two restraints were chosen for similar reasons. One was chosen because it is one of the most popular brands in Australia. The other is one of the most popular types, being designed for small (compact) cars. See Appendix 2 for the CRS specifications. For information purposes only, both restraints were evaluated against the recommendations of SAE ARP4466[20].

Both CRS are required to use a top tether in both modes of operation as required by AS/NZS 1754.

2.1.3.4 ECE R44/04 CRS

Two models of CRS were imported from Europe, one a rearward facing capsule with base plate, the other a forward facing CRS. Both restraints were ISOfix type complying with ECE R44/04 whilst the base plate for the rearward facing capsule complied with the earlier ECE R44/03.

The rearward facing capsule base plate was fitted with a ‘foot prop’. This type of device is not currently allowed in AS/NZS 1754 and is unlikely to be added to the standard. The intention was to test the CRS in a configuration as close as likely to be seen in Australia when the ISOfix system is added to the standard. As there is an interlock mechanism, the foot prop was rotated to its deployed position but the extendable leg was left fully retracted. However, after the first test, video evidence showed the foot prop had almost struck the sled floor so the base plate was modified to remove the foot prop completely for the subsequent test.

Whilst wanting to test in a configuration as close to the probable revision details of AS/NZS 1754, the ISOfix CRS were tested without top tether straps because of the anticipated performance increase of the ISOfix and because tether straps are a major impediment to CRS use in Australian aircraft. The forward facing restraint was available with an optional top tether.

Again, for information purposes only, both restraints were evaluated against the recommendations of SAE ARP4466[20].

See Appendix 2 for the CRS specifications.

2.1.3.5 ATDs

TNO P series dummies were used. The TNO P¾ was used for all rearward facing restraint tests and the TNO P3 was used for all forward facing restraint tests. These are the ATDs as required by AS/NZS 1754. TSO-C100b/SAE AS5276 requires the use of the TNO P¾ for child categories TYPE I and II (rearward facing restraints), however, specifies the Hybrid III for Type III restraints (forward facing). This difference was not expected to greatly affect the results.

2.2 Top Tether

One of the stated aims was to assess the performance contribution of the top tether strap of Australian Automotive child restraints. Tests were performed using the two models of Australian CRS and were tested in the forward and rearward facing modes. Particular attention was paid to replicating a typical installation method and the airworthiness of the aircraft seat, which were subject to multiple tests.

A top tether was manufactured from 1in (25mm) cargo type webbing with a load rating of 1000 lbs (4.4 kN). The simple cam buckle adjuster is typical of that used in service with a D-ring for attachment to the CRS top tether clip. Whilst the D-ring is not the correct attachment plate, it was not anticipated to be an issue given the low loads involved. A 'dog leash' type loop was sewn into the other end to allow attachment to the rear leg of the aircraft seat. One of the advantages of this type of top tether attachment is the vast range of adjustment available. See Appendix A2.6 for more details.

2.3 Alternate to top tether

In an effort to provide options, an alternate attachment method was investigated that aimed to improve the horizontal restraint of the CRS and remove the need for a top tether. Because of the need to restrain all occupants (see discussion in section 1.3.3), there is widespread use of supplemental loop belts. These belts have a dual purpose being used additionally as adult lap belt extensions, their original design intent. As all airlines worldwide carry these belts (in either extension belt form or dual purpose supplemental loop belt form), it was thought they might be successfully used to improve restraint of a CRS.

One of the installation issues associated with automotive CRS is the poor belt angle generated by the generally more forward anchor points on aircraft seat when compared to automotives seats for which they were designed. When installed in an aircraft seat, the lap belt will typically make an angle longitudinally to the aircraft of between 60º and 100º. This leads to poor dynamic performance allowing large deflections during a severe forward deceleration. Equally, for forward facing restraints, the top tether strap will typically follow the contour of the headrest making a final angle in the vicinity of -90º.

Figure 7 - Belt Angles - Rear facing | Forward facing | Forward facing top tether

Thus, it would be advantageous to have an additional restraint mechanism that was arranged in a horizontal manner that would provide immediate retardation at the onset of any forward deceleration. Once the CRS was attached using the lap belt, a supplementary loop/extension belt was looped around the seat back and through the CRS belt path. This provided a horizontal belt restraint regardless of the height of the CRS belt path. Although this would appear to suffer from the same issue as the top tether in terms of interfering with the tray table operation, a seat with no vertical tray table surround, such as the ones used in the testing, can loop the belt around behind the seat back but in front of the tray table. A CRS was tested restrained by a lap belt and an extension belt in lieu of a top tether beside an identical CRS installed with a lap belt only.

Figure 8 - Extension belt installation

2.4 ISOfix

2.4.1 CRS

Due to the proposal to introduce ISOfix type restraints systems to the Australian Standard AS/NZS 1754 and owing to a lack of published research data worldwide on ISOfix type restraint performance in aircraft seating, two ISOfix type restraints were purchased with a view to gauging the viability of the required airline seat modifications and assessing the dynamic performance when compared to Australian AS/NZS 1754 CRS.

The two ISOfix type restraints were sourced from Europe. Because the Australian Standard AS/NZS 1754 is unlikely to allow for an anti-rotation device other than a top tether strap, it was planned to source restraints that would best fit the standard as proposed. Whilst a rear-facing capsule was found in North America that relied on no anti-rotation device, it was temporarily out of production. Thus, it was planned to not use or somehow disable the anti-rotation device (foot prop) of the rear facing capsule subsequently purchased.

Because the two main aims of the project were to investigate dynamic performance improvements and removing a principal hindrance to Australian use of CRS in aircraft, namely the top tether, it was decided to test the ISOfix CRS without a top tether, despite its use likely to be required by AS/NZS 1754 in motor vehicles.

The potential effects on occupants seated behind such rigid installations required assessment. Pre-test, there were three principle concerns. Firstly, potential for the CRS to be released from the seat by failure of the seat lower anchorage or CRS ISOfix lug due to the additional loading of the adult occupant's lower limbs (push on effect). Secondly, for increased lower limb injury of the adult occupant due to interaction with the seat lower anchorage. Finally, increased head injury for the adult occupant due to reduced breakover performance of the seat back in front.

The North American LATCH system is also programmed to be added to AS/NZS 1754, which allows the use of either flexible or rigid links. It is acknowledged that installation of a CRS with flexible LATCH in an aircraft seat appropriately modified would be simplified. Additionally, the ability of the CRS manufacturer to tailor the LATCH webbing material stiffness could lead to performance benefits. For completeness it would have been beneficial to have tested a flexible LATCH CRS in addition to ISOfix, but this was not possible due to budget limitations.

2.4.2 Seat Modification

The aircraft seat required modification for the installation of lower anchorage bars. TSO-C100b refers to FMVSS 225 S9[24], which was complied with, with the exception that rather than two individual 6mm bars with centres spaced 280mm (11in) apart, the 6mm bar was continuous across the seat span. The lower anchorage was screwed to the seat frames via welded tags.

Surprisingly, no modification to the seat upholstery was required. Lateral positioning of the CRS was adequately defined by the armrests of the aircraft seat. The bars were sufficiently recessed so as not be felt by an adult occupant seated in either the upright or reclined positions.

The modification to add lower anchorages to both seating positions introduced a weight penalty to the seat assembly of 340 grams (12 oz). A full description of the modification to the aircraft seat is detailed in Appendix 3.

3 Results

3.1 General overview

3.1.1 Minimum Test pulse requirements

All but the final test essentially met the minimum test pulse intensity requirements of TSO-C100b/SAE AS5276. However, the pulse shape was not ideal and is a function of the test equipment. As can be seen from Figure 9, the Monterey Horizontal Crash Simulator contains a characteristic steep ramp up of deceleration over the first 4-5 milliseconds. This represents the first 6-10g of acceleration. After this point, the acceleration profile can be tailored quite satisfactorily to the triangular pulse shape. That said, the first four tests met the velocity change, peak acceleration and minimum rise time requirements.

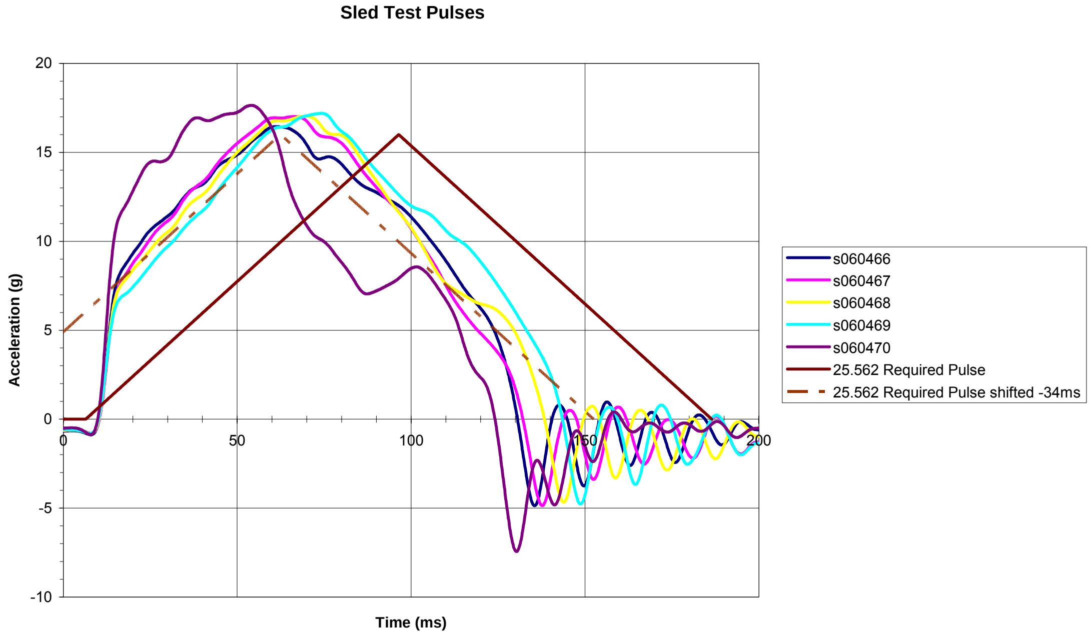


Figure 9 - Comparison of test pulses

However, the final test had poor deceleration control and failed to meet the required velocity change by nearly 10%. Despite having a separate calibration run with fixed masses performed due to the heavier weight on the sled of the two additional Hybrid III ATDs, the poor pulse shape was a result of flail by the adult ATDs. Remembering that the sled is an impact-with-rebound type, inbound velocity of the sled can be tightly controlled, whilst the outbound is a function of the programmer response and the amount of mass movement on the sled during impact. The sled decelerated quickly due to the Hybrid III ATDs being essentially unrestrained until the lap belt started to restrain the ATDs from the hip at approximately 60ms. This initiates the first drop in acceleration, the second decline occurs after the adult ATD head impact.

3.1.2 Top Tether

For both Australian CRS in rear-facing mode, reasonable protection was provided to the occupants. All injury levels were assessed to be within the allowable ranges. The main point of note was that this was performed without any notable contribution from the top tether. The top tethers remained visibly slack throughout the test pulse. Head protection provided by the IGC Gosafe for the P3/4 ATD was marginal. Near peak rotation and displacement, it was possible that some direct head contact could have resulted if a seat had been placed in front.

For both Australian restraints in forward facing mode, protection was just adequate. The IGC Gosafe had very marginal performance with regards to head injury. The Safe-n-sound restraint inflicted chest accelerations that were also marginal. Both restraints exceeded head excursion limits specified by TSO-C100b/SAE AS5276. For both systems, the restraint fell off the front of the structural support for the seat cushion, which accentuated the rebound. Lower limb interaction with the seat in front was substantial.

Again, in forward facing mode the top tether did not contribute to the retention of the CRS. The top tether was seen to lay flat on the headrest of the seat back throughout the test impact. With the seat back breaking over, this provided no horizontal resistance.

See Appendix A1.1 and A1.2 for detailed aspects of these tests.

3.1.3 Extension Belt

With an extension belt looped through the CRS and around the seat back, performance of the Australian CRS in forward facing mode was slightly improved over the standard installation with a top tether. Whilst injury levels were within acceptable limits by some margin for this seat pitch, head excursion was still beyond the acceptable limits of TSO-C100b/SAE AS5276. The CRS did not slide off the front of the seat structure for this configuration. Apart from the reduced injury and excursion values, two other measures indicate the extension belt method assisted in reducing CRS excursion. The extension belt pulled the seat back to which it was mounted further forward, buckling the breakover mechanism more than on any other test. Secondly, the seat back of the seat in front only folded forward to the vertical position due to a lack of interaction from the ATD, which was the least seen.

These results were designed to be compared against a similar CRS installed without a top tether. Unfortunately, a failure occurred with the ATD mounted in this comparative CRS unrelated to the test configuration that meant the instrumentation data generated should all but be excluded. Analysis of the video taken during the test yielded some useful data.

See Appendix A1.3 for detailed aspects of this test.

3.1.4 ISOfix

With a seat modified for lower anchorages (see Appendix 3), the forward and rearward facing European ISOfix CRS performed extremely well. This can be attributed to the 5-point harnesses of both CRS and the complete lack of interaction with the surrounding structures due to rigid links between the seat and the CRS. A point that highlights the vast improvement in performance of these type of restraints, particularly for the forward facing CRS, is the head and knee excursions. Knee excursion was assessed to be 28.2 in (716 mm). The limit, as specified by TSO-C100b/SAE AS5276, is 36 in (915 mm). Considering that, at the start of impact, the knee was positioned at 21 in (533 mm), the knee excursion was less than half of that available. See Appendix A1.4 for more details.

During a second test, an assessment of the potential effects on occupants seated behind such rigid installations was performed. Pre-test, there were three principle concerns. The first two concerns associated with interaction of the adult occupants lower limbs with the lower anchorages were proven unfounded as no contact occurred. The position of the lower anchorages is high enough on the seat for the limbs of a standard height person to flail below the modification. Injury levels for the femurs of both adult ATDs was well below allowable levels. Potential for the CRS to be released by push on forces overloading the restraint also seems unfounded. However, from video evidence, a 95^{th} percentile male may interact with the bars.

The one negative aspect to result from this test was the perceived increase in head/neck injury levels to the adult occupant. Because the seat back in front was effectively stiffened by the CRS, the head and torso of the adult where not allowed to ride down together, inducing large aft head rotations. The difference in measured injury levels between the ATDs seated behind the forward and rearward-facing CRS was notable, the ATD behind the forward facing CRS being worse. Whilst the exact increase in injury cannot be quantified as no comparative testing with an unoccupied front seat was performed, qualitatively, video evidence suggests that neck flexion/shearing and head rotation may be an issue. While head injury criteria was met, injury criteria not assessed by certification requirements were clearly in excess of human limits. Unfortunately, neck instrumentation was not specified for this test series but from video evidence, neck injury and head rotation needs to be quantified for occupants seated behind CRS using the ISOfix system.

See Appendix A1.5 for more details.

Figure 10 – ISOfix CRS potential interference with injury levels for adults seated behind - Point of maximum head rotation for the Hybrid III ATD

3.2 Comparison of test configurations

3.2.1 Rearward Facing CRS

3.2.1.1 Head Injury

Head injury values were very acceptable, all being less than 50% of levels acceptable to certification. Interestingly, the two test runs with the ISOfix CRS had clearly higher head injury levels than the conventionally installed CRS. Whilst well below allowable limits, the difference is probably attributable to the stiffer installation of the ISOfix system. Had a seat been placed in front of the conventionally installed CRS, higher head injury values may have been produced due to the inevitable contact of the CRS with the seat back.

Head Injury				
CASA Test No.	06/04		06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	Britax 'Cosy-Tot' (ISOfix)	Britax 'Cosy-Tot' (ISOfix)
TSO-C100b/AS5276 FMVSS 213 (HIC < 1000)	280 (28%)	295 (30%)	436 (44%)	419 (42%)

3.2.1.2 Chest Injury

Chest values were similarly below all allowable limits though not by the same margins. Again, had the conventionally restrained Australian CRS been placed in behind another seat, chest injury may have been higher.

Chest Injury				
CASA Test No.	06/04		06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	Britax 'Cosy-Tot' (ISOfix)	Britax 'Cosy-Tot' (ISOfix)
TSO-C100b/AS5276 FMVSS 213 (<60g, 3ms)	39.7g (66%)	53.0g (88%)	35.2g (59%)	41.0g (68%)

3.2.1.3 CRS displacement and rotation

Whilst the displacements of only two CRS were able to be calculated, there was a clearly quantifiable difference in the amount of CRS excursion. Conventionally restrained rearward facing CRS generally have better displacement performance than forward facing CRS due to the better seat belt angle, as discussed in section 2.3. However, being a flexible link, it modulus of stiffness is far less than the steel link of the ISOfix system.

CRS Displacement		
CASA Test No.	06/04	06/01
CRS	IGC Gosafe'	Britax 'Cosy-Tot' (ISOfix)
Maximum Displacement	~6.5 in (165mm)	~1.5 in (38 mm)

Whilst none were excessive, from video evidence, the lap belt restrained CRS suffered from slightly more rotation. This was due to the larger displacement allowing the CRS to pivot over the seat front crossmember.

3.2.1.4 Comparison of results to ATSB research

Comparing the results of the similar Australian CRS models test by Human Impact Engineering and Britax Childcare in 2006[3], the injury levels imparted were very comparable considering the slight variations in test severity. The main difference between the test methodologies were the previous work performed testing without the top tether strap, whilst this work did use the tether strap. This further indicates that the top tether does not contribute to the retention and protection of an infant in rear facing CRS when install in an airline seat.

3.2.2 Forward Facing CRS

3.2.2.1 Head Injury

As has been found with previous research, forward facing restraints typically suffer gross excursions resulting in poor head injury, from both head whip and through direct contact with structures. For all three lap belt restrained CRS test articles, head contact with the ATD's own knees occurred. Because of the gross lower limb interaction with the seat in front, the knees tended to pivot upward about the ankles engaged with the seat back pocket area to meet the head. However, the ISOfix CRS had cursory lower limb contact with the seat in front thus providing more space for the head. Regardless of the ISOfix attachment, upper torso retention was far superior for the Britax 'Duo-plus' contributing to the reduced head excursion. Interestingly, the only test to involve a head strike on the seat in front was the lap belt restrained CRS with the least head excursion, test 06/05. In this test, lower limb interaction with the seat in front was less than for the two CRS in test 06/03, which meant the P3 ATD did not push the seat back forward as much. Due to the gearing effect on the seat back of the low impact of the limbs, horizontal displacement of the seat back at the ATD head height was substantially less. That said, the impact was close to 90º to the tray table, being a glancing blow rather than a direct impact, which is reflected in the head injury values.

Head Excursion					
CASA Test No.	06/03		06/05	06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	IGC Gosafe	Britax 'Duo-Plus' (ISOfix)	Britax 'Duo-Plus' (ISOfix)
TSO-C100b/AS5276 FMVSS 213 (< 32 in [813 mm])	35.5 (111%)	36.7 (115%)	33.6 (105%)	27.0 (84%)	25.6 (80%)

The elevated levels of head injury with the lap belt restrained CRS occurred due to interaction with the lower limbs. The ISOfix CRS however, recorded extremely low values of head injury. Because of the uncompromised survival space and the lack of displacement and rotation provided by the ISOfix CRS, the head stayed high and was well controlled and restrained throughout its motion.

Head Injury					
CASA Test No.	06/03		06/05	06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	IGC Gosafe	Britax 'Duo-Plus' (ISOfix)	Britax 'Duo-Plus' (ISOfix)
TSO-C100b/AS5276 FMVSS 213 (HIC < 1000)	499 (50%)	944 (94%)	501 (50%)	276 (28%)	148 (15%)

3.2.2.2 Chest Injury

Chest Injury was reasonably uniform across all forward facing test samples, the ISOfix CRS slightly lower than lap belt restrained CRS, probably due to a superior 5-point harness.

Chest Injury					
CASA Test No.	06/03		06/05	06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	IGC Gosafe	Britax 'Duo-Plus' (ISOfix)	Britax 'Duo-Plus' (ISOfix)
TSO-C100b/AS5276 FMVSS/CMVSS 213 (<60g, 3ms)	53.0g (88%)	42.9g (72%)	37.8g (63%)	32.4g (54%)	34.0g (57%)

3.2.2.3 Lower Limb Injury

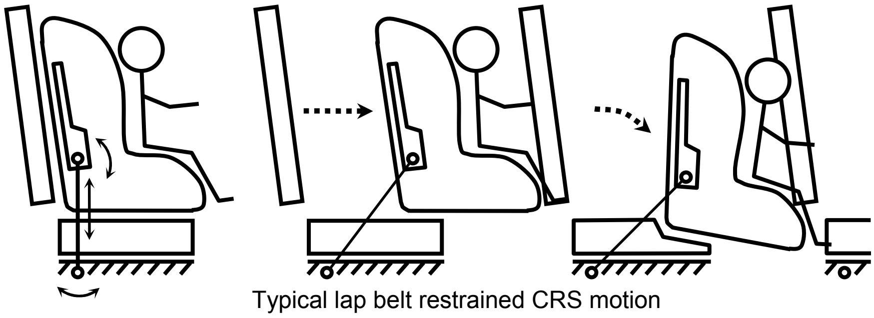
Whilst not measured, severe lower limb interaction with the seat in front was a common feature of the tests involving lap belt restrained forward facing CRS. This interaction, whilst poor in itself, had the additional disadvantage of tending to drive the knees higher, into the head arc. No injury would have occurred to the lower limbs of the occupant seated in the ISOfix CRS due to the negligible contact with the seat in front.

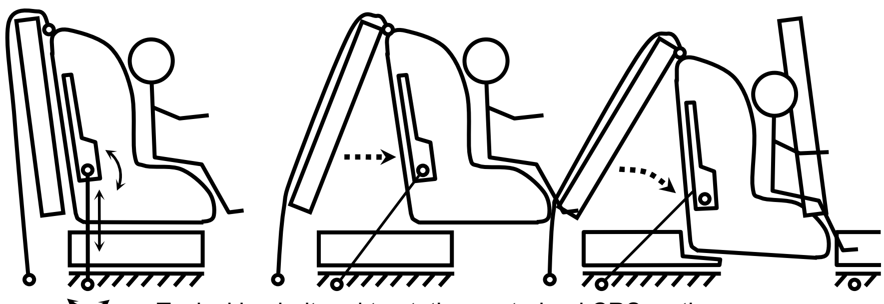
3.2.2.4 CRS displacement and rotation

Whilst not measured for any requirements of aviation or automotive certification, the displacement of the CRS directly correlated to the overall injury level sustained by the occupant of the CRS. The measurement is affected by the reference point used due to a combination of displacement and rotation occurring. Regardless, this aspect clearly provided the largest margin in performance between the lap belt restrained and the ISOfix CRS.

CRS Displacement					
CASA Test No.	06/03		06/05	06/01	06/02
CRS	Safe-n-Sound	IGC Gosafe	IGC Gosafe	Britax 'Duo-Plus' (ISOfix)	Britax 'Duo-Plus' (ISOfix)
Maximum Displacement	~12 in (305 mm)	~13 in (330 mm)	~10 in (254 mm)	~2.5 in (64 mm)	~3 in (76mm)

The superior stiffness of the ISOfix link resulted in numerous benefits. Firstly, the substantially reduced displacement provided adequate clearance for the head and limbs from the seat in front. Secondly, the CRS rotation is limited due to there being only one point of rotation on the ISOfix CRS, at the attachment in the seat bight. On conventional lap belt restrained CRS (or a LATCH CRS), there are two points of rotation, one at the lap belt anchor point, the other at the CRS belt path/attachment. This aspect is exacerbated by the fact that the link between the two hinge points is webbing based and quite stretchy relative to the steel link of the ISOfix system. Thirdly, the lack of CRS displacement allows the CRS to bear correctly on the seat cushion and the supporting structure beneath. With conventional systems, the CRS is allowed to slide forward until the seat belt arrests the movement, which then results in a pitching of the CRS off the front of the seat, the line of action of the lap belt now being below the combined occupant/CRS vertical centre of gravity. Note, in an automotive situation, the top tether stops this occurring, that being an additional horizontal restraint mechanism. However, in the airline situation the top tether is not effective, as discussed previously.


Typical lap belt restrained CRS motion


Typical lap belt and top tether restrained CRS motion

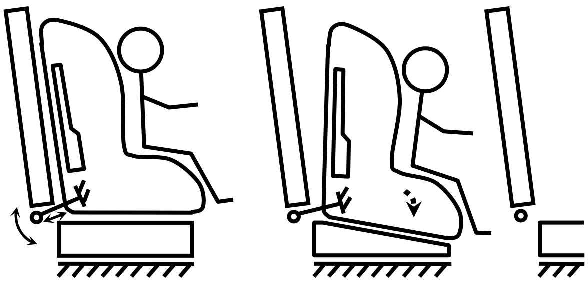

ISOfix restrained CRS motion

Figure 11 - Graphical representation of the motion of various CRS types

3.2.2.5 Comparison of result to ATSB research

Unlike for the rearward facing restraints, the results varied for the forward facing restraints between this work and that conducted by Human Impact Engineering and Britax Australia[3]. Whilst this research found injury levels that were marginally acceptable, the previous work found much more severe injury levels for similar CRS. It is hypothesized there are three reasons for this. Both Australian CRS tested had a recline facility for use in the forward facing mode. The previous work tested the forward facing CRS in the recline position whereas this work tested in the upright position. Secondly, careful attention was paid to repairing the seat back breakover mechanism after each test. For the previous work, the seat had essentially no seatback breakover limitation. Finally, the Australian IGC Gosafe CRS has the choice of two belt paths. The previous work tested both belt paths. This work tested only the rearmost belt path as the front belt path is unstable if used without an effective top tether. A combination of these three differences is most likely to be the basis for the variation in results.

4 Conclusions

The test series was successful in advancing knowledge of the performance of Australian Automotive CRS when installed in a transport category aircraft seat. All three aims of the research were successfully achieved. The intent of the research was met, with logical conclusions developed for all aspects, and recommendations have been provided.

Australian Automotive CRS perform adequately in transport category aircraft seats. Whilst the two CRS tested met all but the head excursion criteria, the test configuration involved using seats placed in front of the CRS in a representative arrangement such that any injury levels measured during contact with the structure would be somewhat representative of real world installations.

Whilst the Australian CRS performed adequately using the top tether, evidence indicates the top tether did not function as intended and provided no useful contribution to the CRS performance. In rearward facing restraint mode, the top tether quickly became slack as the test pulse started and remained so throughout the entire impact. For the forward facing mode, because the top of the CRSs were both well below the top of the seat, the top tether followed the profile of the headrest, i.e. with a vertical intercept. This alignment with the headrest was maintained throughout the test pulse, despite the CRS moving forward on the seat because the top of the seatback moved further. Therefore, if any tension were maintained in the tether strap, the CRS would be pulled forward.

Using an aircraft seat, rather than the test fixture required by automotive and aviation standards, was beneficial in highlighting real world interaction of the CRS and the seat. Unforseen for the seat used in this research, was the seat breakover limiting mechanism activating under the weight of the seat back alone. Therefore, a seat with energy absorbing breakover limiting features is not adequate justification for being included as a structural part of the top tether restraint. However, a seat with higher breakover resistance may provide limited benefit to a CRS installed with a top tether.

This research found similar motion of the CRS during impact to that of the ATSB research[3] and overseas work[5 6]. The fact that the CRS motions, and injury levels, were similar can be assigned to the top tether not being able to perform its intended function. From this, the current practice of looping a top tether strap from the lower seat structure up the seat back on over the top is not an effective engineering solution for CRS top tethers. Optimising the installation of CRS with a top tether, while advantageous, is most likely impracticable and unfeasible in most large regional, domestic, and intercontinental aircraft.

The anticipated benefits of the extension belt installation method were not realised. For the same reasons as the top tether installations, the lack of breakover resistance by the seat back did not provide a suitable anchor. Though performance was marginally better than the traditional installation method for the CRS models tested, the change is too radical and difficult to implement for the limited benefit. If higher breakover loads were guaranteed, then this should provide real benefit, though installations involving the top tether would benefit as well.

Figure 12 and Figure 13 clearly demonstrate the benefits of the ISOfix system when used in conjunction with a suitably modified transport category seat. The main mechanism that affords the improved performance is the increased stiffness of the installation. This removes most of the probability of impact with surrounding structures. The restraint is essentially mechanically fixed to the seat by two steel links. The ISOfix system results in a simplified system from a crashdynamics perspective. Rather than having to control both the motion of the CRS in the seat, and, the child in the CRS, the ISOfix restraint manages the arresting motion alone. The ISOfix links mean the horizontal displacement of the CRS during the impact is virtually eliminated, leaving the integrated 5-point harness of the CRS to perform the function of arresting the occupant in a controlled manner.

Additional operational benefits are obtained with the ISOfix system. It is less likely to be installed incorrectly, and the time to install the ISOfix CRS is vastly reduced, especially when installed without the top tether. This will aid airline operations during tight turnarounds.

The weight penalty for the airline operator is negligible. The modification for the purposes of this research totalled 340g (12 oz), for a two-place modification. In reality, only one place in a double or triple place seat assembly would be modified. Thus conceivably any modification or incorporation of ISOfix lower anchorages could add as little as 200g (7 oz) per placement.

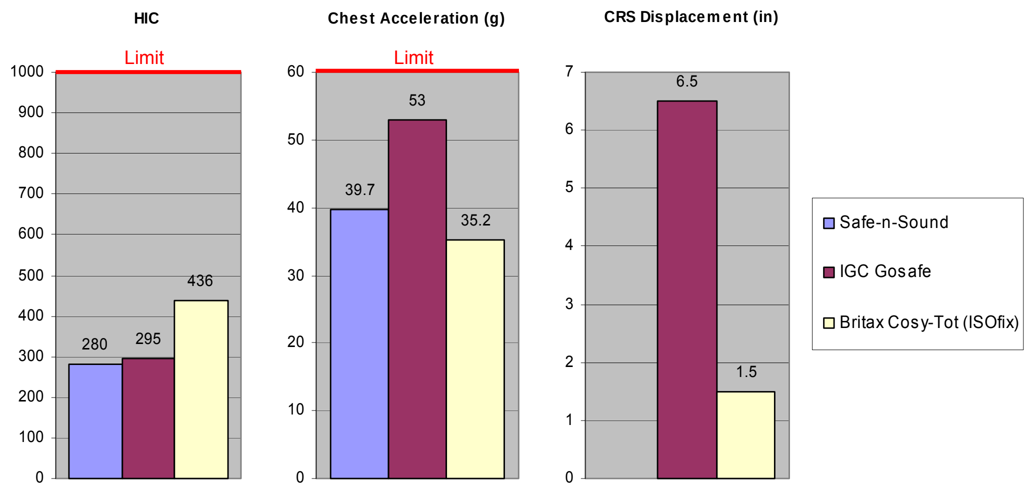


Figure 12 - Rearward facing CRS injury assessment comparison

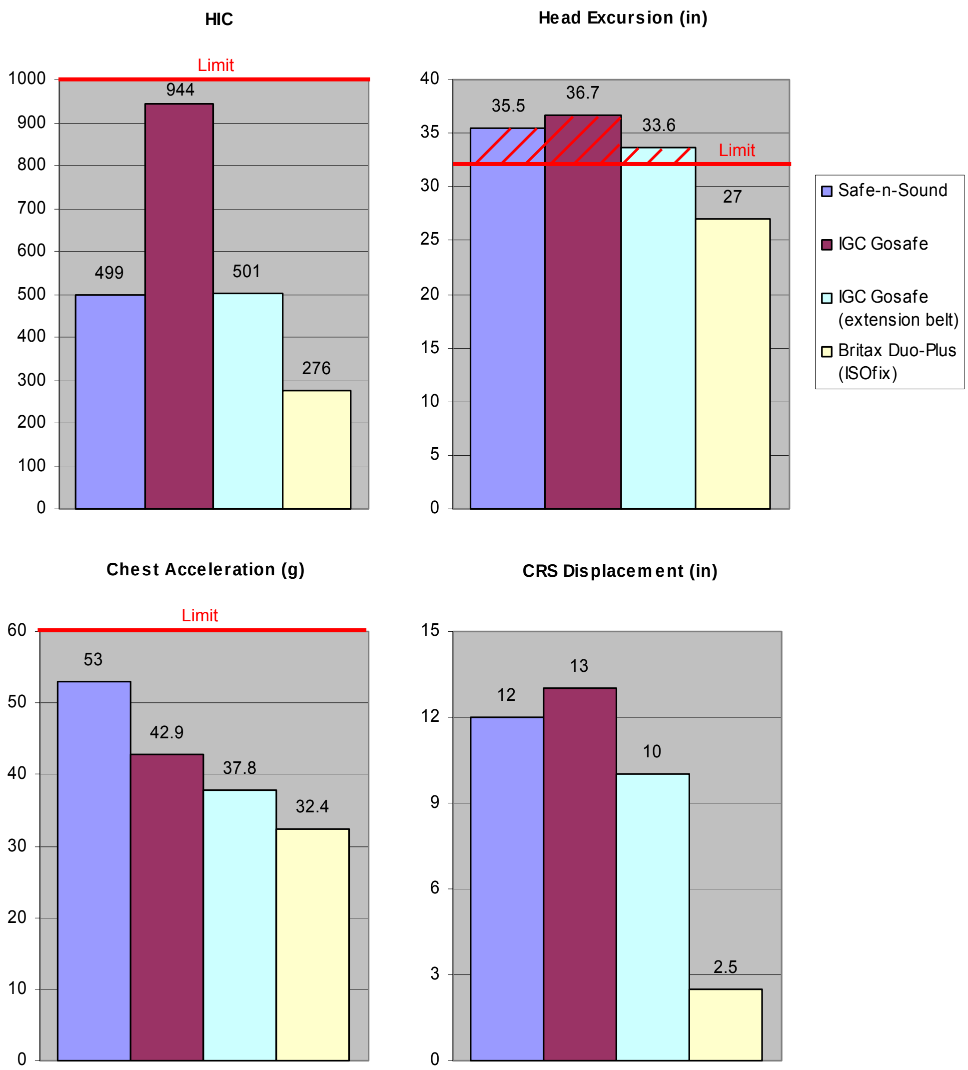


Figure 13 - Forward facing CRS injury assessment comparison

One concern leading to the research was the effect an adult seated behind might have on an ISOfix CRS. Of particular concern was whether the lower limbs of the adult occupant may impart additional loads to the lower anchorages to the point of premature failure or, head and upper torso interaction with the seat back may cause the CRS to be levered out of the seat through overload of the lower anchorages or, tension or bending failure of the ISOfix links of the CRS. The testing showed the lower anchorages is positioned sufficiently high enough and is sufficiently well protected from a 50th percentile male occupant. The forced seat back displacement by loading from the rear occupant was also not an issue for the test performed.

In opposition to that, the other concern was the interference of the ISOfix CRS on the injury levels of an adult seated behind due to the effective increase in seat back stiffness. This proved to be the one negative outcome for this type of CRS. Whilst none of the injury criteria for a seat certification were exceeded, video evidence highlighted potentially dire injury levels associated with neck shearing and neck flexion. Future testing should check to determine whether this effect is peculiar to this seat design or a more general effect.

As is typical of research, it always raises more questions. Aspects that need to be addressed are retesting with neck instrumentation to quantify the injury levels imparted to an adult seated behind an ISOfix CRS due to possible increases in head rotation. Additionally, benefit would be gained from testing with a 95th percentile male ATD behind an ISOfix CRS. This would be needed for assessment of damage to the CRS attachment and potential interference effects on the adult occupant. If ISOfix/LATCH type restraints are to be allowed, standards need to be developed for lower anchorages in aircraft seats.

A general observation regarding beneficial configuration features is the use of an aft belt path on a conventionally restrained CRS. The use of a belt path in the forward half of the CRS leads to the restraint being highly unstable. This works in the automotive situation in Australia because of the mandatory use of the top tether and strict design rules for cars on the placement and line of action for the top tether ensuring its effectiveness. No such system exists in aviation and cannot exist, it could be argued, with the current technology of aircraft seating. If shoulder harnesses were to be incorporated in low and high capacity regular passenger transport aircraft, then seat back strength or other anchor point should have sufficient capacity to integrate a top tether anchor.

Additionally it can be suggested that for a child in a forward facing CRS, seating the child in the most upright position available on the CRS during takeoff and landing may be beneficial.

The most exciting outcome from the program was the performance benefit for the child when seated in an ISOfix type child restraint. Airlines should be encouraged to fit ISOfix lower anchorages to window seats, and the centre seats of twin aisle aircraft, were there is no risk of head injury for anybody seated behind. Therefore, seating positions in front of bulkheads or lav/galleys, in front of floor level exits or floor mounted rear facing cabin crew positions should be considered. For Australian airlines, some time is available before the Australian Standard AS/NZS 1754 and Australian Design rules for cars are revised for ISOfix and/or LATCH type attachments, and thus these restraints enter the Australian marketplace. For many overseas operators, fitting of these attachments will have immediate benefits for travelling infants and small children.

Regardless of the mix of comparatively positive and negative aspects of this research, one fact remains unchanged. The use of CRS by infants and small children produces better survival and injury prospects over that of a restrained or unrestrained lap held child.

5 Recommendations

1. Infants and small children should travel in aircraft in their own seat, in an appropriately sized and fitted child restraint system.

2. No changes need to be made to CASA's aviation regulations. The other recommendations of this report are already adequately covered by regulatory documentation. For example, Civil Aviation Order 20.16.3 paragraph 13.5(b) already caters for CRS attached to the seat by methods other than the seat belt.

3. CAAP 235-2(1) 'Carriage and restraint of small children in aircraft' needs revision:
    a. To remove the requirement for mandatory use of the top tether strap for Australian Automotive CRS and revise to recommend their use when an effective tether anchor is available.
    b. To recommend the use of an aft belt path if the choice of two is available even if the aft belt path is an alternate for the CRS. If the CRS only has a belt path through or around the forward half of the child restraint, that the restraint only be allowed to be used if an effective top tether anchorage is available.
    c. To encourage the use of ISOfix and LATCH type CRS.
    d. To recommend when seating a child in a forward facing CRS that the child be placed in the most upright position available on the CRS during takeoff and landing.

4. An Airworthiness Bulletin should be written containing technical guidelines regarding modifications to aircraft interior with respect to lower anchorages and top tethers.

5. CASA and CASA Authorised persons who have approved modifications in transport category aircraft as required by CAAP 235-2(1) Para. 4.5, should review that approval.

6. Minimum standards for lower anchorages in aircraft seats for ISOfix and LATCH type child restraints needs to be developed.

7. In the interests of infant and child safety in aircraft, CASA would encourage the revision of Australian Standard AS/NZS 1754 to require the ISOfix attachment method for all future child restraints in Australia. Subject to further research, this suggestion may be revised to include the LATCH system as an alternate.

8. Further testing should be carried out to assess the injury potential for an adult seated behind an ISOfix or LATCH CRS:
    a. The configuration tested in this research should be reconducted with neck instrumentation in the Adult ATDs. Neck instrumentation should be included in all future related research to assist in the assessment of injury.
    b. Severe neck rotation should be confirmed to not be a function of the airline seat chosen for this research.
    c. Assessment should be made of the effects of a 95th percentile male seated behind an ISOfix CRS.
    d. Similar assessment to that carried out for ISOfix CRS is required for LATCH CRS.

9. Airlines are encouraged to fit lower anchorages to window seats, and the centre seats of twin aisle aircraft, were there is no risk of injury to anybody seated behind, i.e seats in front of bulkheads and floor level exits.

6 Abbreviations

AS	(SAE) Aerospace Standard
AS/NZS	Australian Standard/New Zealand Standard
ASF	Aviation Safety Forum
ATD	Anthropomorphic Test Device
ATSB	Australian Transport Safety Bureau
CAA	Civil Aviation Act (1988) *(CASA)* Civil Aviation Authority *(United Kingdom)*
CAMI	Civil Aerospace Medical Institute *(FAA)*
CAO	Civil Aviation Order *(CASA)*
CAR	Civil Aviation Regulations (1988) *(CASA)* Civil Aviation Regulations *(TCCA)*
CASA	Civil Aviation Safety Authority *(Australia)*
CASR	Civil Aviation Safety Regulations (1998) *(CASA)*
CRS	Child Restraint System
FAA	Federal Aviation Administration *(USA)*
FMVSS	Federal Motor Vehicle Safety Standard *(USA)*
ISOfix	International Organization for Standardization Fixture
JAA	Joint Aviation Authorities *(Europe)*
LATCH	Lower Anchorages and Tethers for CHildren
NAA	National Airworthiness Authority
NHTSA	National Highway Traffic Safety Administration *(USA)*
NTSB	National Transportation Safety Board *(USA)*
RPT	Regular Public Transport
SAE	Society of Automotive Engineers
TCCA	Transport Canada – Civil Aviation

7 Glossary of Terms

AS/NZS 1754	Child Restraint Systems for use in Motor Vehicles. In Australia, this is the only standard to which child restraints for cars can be manufactured for sale.
Anthropomorphic Test Device	A mechanical structure representative of the human form. They are weighted and articulated to simulate the behaviour of a human body. Known also as ATDs or 'Crash test dummies'.
Anti-rotation device	Either, a top tether, a support leg or the vehicle dashboard intended to limit the rotation of the CRS during a frontal impact. The vehicle seat itself does not constitute an anti-rotation device.
Aviation Safety Forum	A consultative body who advise CASA on important strategic issues to improve aviation safety in Australia. The ASF comprises experienced people from passenger transport, engineering, aerial agriculture and general aviation; both fixed wing and helicopter sectors. There is also an aviation consumer representative. The ASF provides strategic advice directly to the CASA CEO.
Child	A passenger who has reached their third but not their thirteenth birthday. (Refer CAO 20.16.3.2)
Child Restraint System	A device (seat) designed to provide a suitable interface between a vehicle seat and an infant or child. They may contain an integrated restraint harness or modify the use of the vehicle's harness system. In some parts of the world, they are referred to as a Child Restraint Device (CRD). The FAA recently introduced a new acronym ACSD, or, Aviation Child Safety Device to differentiate aviation specific devices from automotive designs.
Convertible CRS	A Child Restraint System designed to span more than one category of child restraint. Typically these refer to CRS able to be used as a rear facing CRS for children up to approximately the age of 12 months and then turned around to be used as a forward facing CRS until the child exceed 18 kg. Another type of convertible CRS is the combination forward facing CRS/booster seat.
FMVSS213	Federal Motor Vehicle Safety Standard No. 213 - Child Restraint Systems. A standard developed by the National Highway Traffic Safety Administration (NHTSA) for use in the USA.
Foot prop	A support leg from the CRS to the vehicle floor intended to limit the rotation of the restraint during a frontal impact.
Infant	A passenger who has not reached their third birthday. (Refer CAO 20.16.3.2)
ISOfix	A system developed in Europe to attach a CRS to a Motor Vehicle seat by a rigid quick release mechanism that engages fixed steel bars in the car seat instead of relying on the seat belt.
LATCH	A North American variation on ISOfix that allows for flexible webbing based links or the European style rigid links. The lower anchorages in the Motor vehicle are common with the European standard.

Lower anchorage FMVSS 225: Lower anchorage, TSO-C100b: Rigid bar lower anchorage, ECE44: ISOfix lower anchorage, Britax: ISOfix anchorage points. In cars consists of two Ø6mm bars placed in the seat bight for attaching ISOfix or LATCH CRS.

Seat Bight The juncture between the top of the seat base cushion and the front face of the seat back cushion.

Supplementary Loop Belt An airline extension belt with an additional small loop of webbing stitched to it. The extension belt is wrapped around the lap held child's waist and the adult's lap belt is slipped through the small loop of webbing, thereby restraining the infant via the adult's lap belt. This device is also known as a 'supplementary belt', 'infant loop-type restraint', 'lap-held child restraint', or colloquially as a 'belly belt'.

Transport category aircraft Generally, an aircraft with a passenger seating capacity of 20 people or more.

Top Tether Strap A strap, in addition to the seat belt, ISOfix or LATCH attachment, fixed between the top of the CRS and a point on the motor vehicle. The aim of the device is to provide an addition horizontal restraint mechanism and to remove the tendency of a CRS to pitch over when restrained by a lower anchorage only.

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Appendix 1 Test Results

A1.1 CASA Test No. 06/04

RTA Crashlab Test No.: S060469

Test Purpose: To test the dynamic performance of rearward facing automotive AS/NZS 1754 type child restraints in a airline seat, with particular attention being paid to the contribution of the top tether to the dynamic restraint performance.

Test configuration: Two AS/NZS 1754 child restraints in rearward facing (Type A) mode. The child restraints were installed in accordance with the manufacturer's instructions. The top tether strap was used and attached to a lead designed to replicate the type of device used by the Australian airline industry.

Child Restraints: Safe-n-Sound 'Premier' Convertible restraint, rearward facing mode for 0kg – 12kg children. Left hand position.

IGC Gosafe 'Boulevard' Convertible restraint, rearward facing mode for 0kg – 9kg children. Right hand position.

ATDs: TNO P3/4 child ATD (9kg)

Required Test Pulse: FAR 25.562(b)(2)/TSO-C100b - A change in forward longitudinal velocity (ΔV) of not less than 44 feet per second, peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g.

Test Results: Achieved the required test pulse. A peak acceleration of 17.2g @ 74 ms achieving a total velocity change of 47.6 ft/s (52.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS displacement†	Max. CRS Rotation†
Safe-n-Sound (RF) – P3/4	51.1g# (49.2g)	280	43.0g (39.7g)	-	-
IGC Gosafe (RF) – P3/4	51.1g# (50.1g)	295	56.8g (53.0g)	~6.5in (165 mm)	12°

* 3ms clip values included in brackets.

† The CRS displacement and rotation was measured at the CRS attachment and was relative to its position at the initial point of impact. It was approximated from video capture.

\# Due to electrical noise, the peak head acceleration values are filtered to Class 100.

Description of results: Safe-n-Sound 'Premier' Convertible (RF) – P3/4: Due to the slightly better lap belt angle, displacement of the CRS was less than that typically found in the forward facing configuration. Rotation of the CRS was minimal and rebound was controlled.

IGC Gosafe 'Boulevard' Convertible (RF) – P3/4: The CRS performed very similarly to the Safe-n-Sound with adequate CRS displacement, rotation and rebound. The airline tether strap slipped by 30mm in this test but interestingly, the CRS tether attached to it shortened by 80mm. This resulted from the packed excess adjustment strap, known as the sock, being loose throughout the test and whipping forward then backward with the sled deceleration. The mass of the sock was enough to tighten the adjustment strap (see Figure 18).

Top Tether performance – For both CRS the most surprising aspect was the lack of top tether performance. From a time point of approximately 40ms, both top tethers can be seen to going slack. At this point, the sled had only reach 11g and both ATD head and chest resultant accelerations were all below 1g. Both CRS were sliding on the seat and the lap belts were yet to have rotated to a point of being useful for forward restraint. Both tethers are slack throughout the remaining portion of the test showing they provided no useful contribution. This occurred because the seat backs were breaking over at a faster rate and displacing further than CRS thus constantly reducing the distance between the top of the seat back and the top of the CRS where the tether attaches.

Figure 14 - Configuration tested, at point of impact

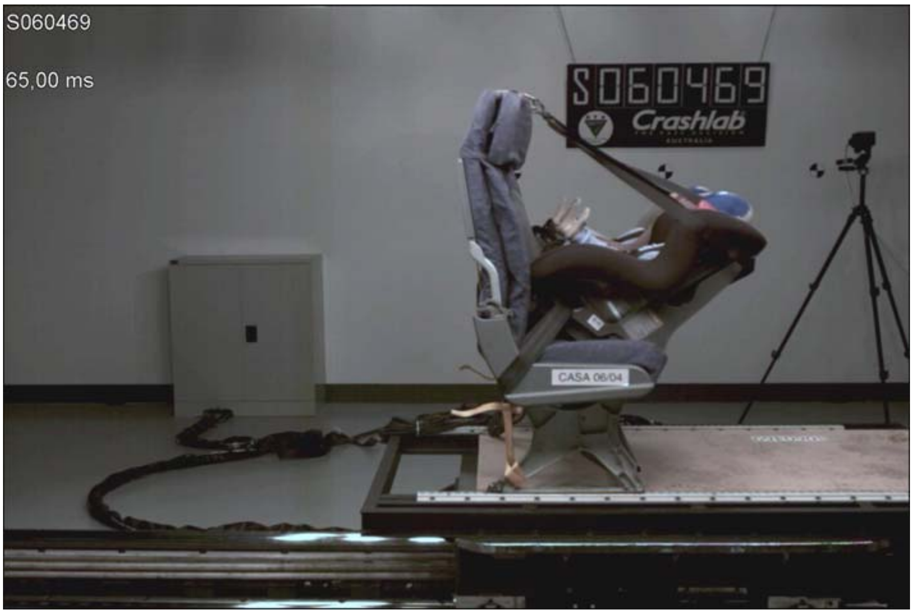

Figure 15 - Maximum Gosafe head protrusion

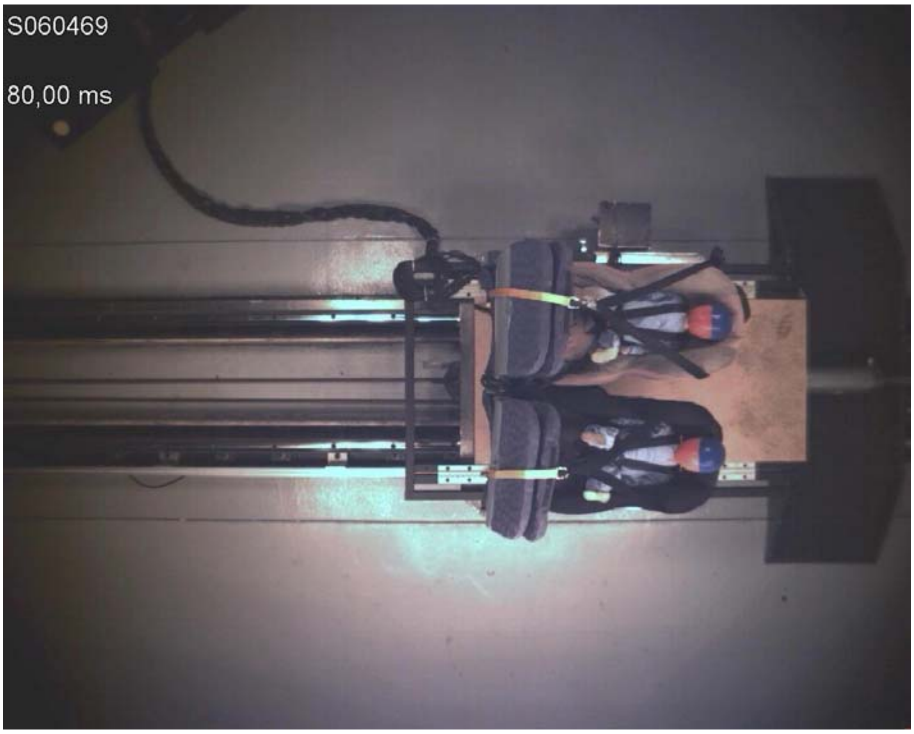

Figure 16 - Maximum horizontal head protrusion

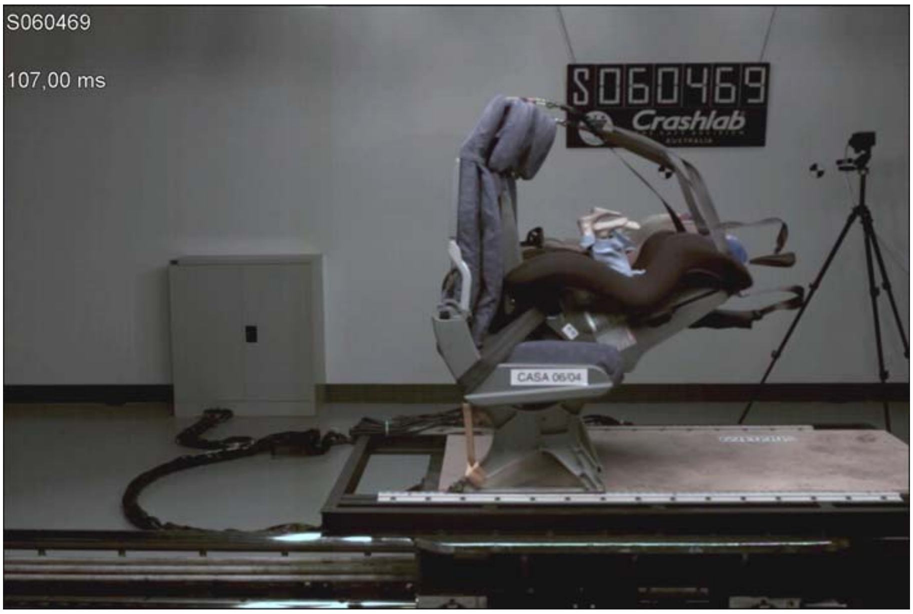

Figure 17 - Maximum CRS rotation. Note slack top tethers

Figure 18 - Sock whip. Note strap adjustment chalk mark (arrowed)

A1.2 CASA Test No. 06/03

RTA Crashlab Test No.: S060468

Test Purpose: To test the dynamic performance of forward facing automotive AS/NZS 1754 type child restraints in a airline seat, with particular attention being paid to the contribution of the top tether to the dynamic restraint performance.

Test configuration: Two AS/NZS 1754 child restraints in forward facing (Type B) mode. The child restraints were installed in accordance with the manufacturer's instructions. The Gosafe restraint was installed using the alternate (rear) belt path. The CRS were adjusted to the upright seating position. The top tether strap was used and attached to a lead representative of the type of device used by the Australian airline industry. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: Safe-n-Sound 'Premier' Convertible restraint, forward facing mode for 9kg – 18kg children. Left hand position.

IGC Gosafe 'Boulevard' Convertible restraint, forward facing mode for 8kg – 18kg children. Right hand position.

ATDs: TNO P3 child ATD (15kg)

Required Test Pulse: FAR 25.562(b)(2)/TSO-C100b - A change in forward longitudinal velocity (ΔV) of not less than 44 feet per second, peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g.

Test Results: Achieved the required test pulse. A peak acceleration of 17.0g @ 69 ms achieving a total velocity change of 45.3 ft/s (49.7 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS displacement†	Max. Head excursion‡
Safe-n-Sound (FF) – P3	99.5g (80.8g)	499	55.1g (53.0g)	~12in (305 mm)	35.5 in (902 mm)
IGC Gosafe (FF) – P3	155.6g (113.9g)	944	44.4g (42.9g)	~13in (330 mm)	36.7 in (932 mm)

* 3ms clip values included in brackets.

† The CRS displacement was measured at the CRS attachment and was relative to its position at the initial point of impact. It was approximated from video capture.

‡Maximum head excursion was referenced to what would be the equivalent of the seat pivot axis of a standard FMVSS213 seat fixture. (Horizontal distance from the Cushion Reference point plus 6 inches). Head Excursion is conservative due to lower limb interaction with the seat in front.

Description of results: Safe-n-Sound 'Premier' Convertible (FF) – P3: The ATD head excursion was slightly less than for that in the Gosafe despite the ATD being further forward in the static position due to the CRS's larger size. After the feet engaged the seat back in front, the knees hinged upward. The head impacted the right knee with at glancing blow. Whilst the CRS displacement could not be measured directly, from the reverse angled camera it could clearly be seen to slide off the front crossmember of the seat and drop more than an inch (25mm). Rebound was substantial with the top of the ATDs head passing above the height of the airline seat back.

IGC Gosafe 'Boulevard' Convertible (FF) – P3: The ATD suffered a substantial head strike. The head just missed the tray table striking the knee. The lower limbs impacted heavily on the seat in front. The right knee and lower leg passed below the tray table. The left knee impacted the tray table crossmember deflecting below and under the tray table. The left hand follows, punching the tray table crossmember. The right hand, which was positioned slightly below the left, can be clearly seen to punch the seat back, rebounding visibly. A large spike in head acceleration coincided with impact of the right knee. It is suspected that the right lower leg was pushed far enough into the seat back for the right foot to act somewhat as a brace on the front seat's aft structural crossmember. The amount of lower limb interaction with the seat in front increased the angle to which the seat back hinged forward. The lower tray table crossmember was also bent. Like the Safe-n-Sound, the Gosafe slipped off the front of the seat cushion structure but to a lesser extent. However, because of the CRS base lower surface, the CRS was seen to catch on the seat structure before bouncing over when the seat lap belt retracted the CRS.

Top Tether performance – At the point of impact the top tether straps on both CRS were seen to be flat against the headrest surface in a completely vertical orientation. During the impact both seat backs hinged forward with the top tether straps remaining flat against the headrest to a point that any tension would have had a forward component with respect to the CRS. The top tether on the Gosafe CRS was seen to flap briefly at about the point of maximum head excursion.

Figure 19 – Note vertical orientation of top tether to CRS | note also different styles of CRS top tether (single strap vs. V arrangement) and method of top tether anchorage to seat.

Figure 20 - Maximum displacement of Gosafe CRS

Figure 21 - Safe-n-Sound CRS at maximum displacement. Note the position of the front edge of the CRS base (arrowed).

Figure 22 - Maximum Head excursion

A1.3 CASA Test No. 06/05

RTA Crashlab Test No.: S060467

Test Purpose: To investigate whether dynamic performance of automotive AS/NZS 1754 type child restraints in an airline seat could be improved by use of a supplemental restraint strap.

Test configuration: Two Gosafe AS/NZS 1754 child restraints, both forward facing, mounted onto an aviation airline economy class passenger seat. The child restraints were installed in accordance with the manufacturer's instructions with the exception that neither CRS used a top tether strap. Both restraints were installed using the alternate (rear) belt path. The near side CRS additionally had an extension belt looped around the seat back and through the rear CRS belt path. The extension belt was tightened in a similar manner to the airline seat lap belt as prescribed by AS/NZS 3629.1. Both restraints were adjusted to their upright seating position. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: IGC Gosafe 'Boulevard' Convertible CRS in forward facing mode (Type B) 9kg – 18kg children.

ATDs: TNO P3 child ATD (15kg)

Required Test Pulse: FAR 25.562(b)(2)/TSO-C100b - A change in forward longitudinal velocity (ΔV) of not less than 44 feet per second, peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g.

Test Results: Achieved the required test pulse. A peak acceleration of 17.0g @ 66 ms achieving a total velocity change of 44.0 ft/s (48.3 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS displacement†	Max. Head excursion‡
#LHS (lap belt only)	-	-	48.2g (44.6g)	-	-
RHS (Lap belt and extension belt)	61.5g (58.8g)	501	41.8g (37.8g)	~10 in (254 mm)	33.6 in (853 mm)

* 3ms clip values included in brackets.

† The CRS displacement was measured at the CRS attachment and was relative to its position at the initial point of impact. It was approximated from video capture.

‡ Maximum head excursion was referenced to what would be the equivalent of the seat pivot axis of a standard FMVSS213 seat fixture. (Horizontal distance from the Cushion Reference point plus 6 inches). Head Excursion is conservative due to lower limb interaction with the seat in front.

\# This data is flawed as the ATDs head detached at the neck just prior to the head striking the tray table.

Description of results: LHS (lap belt only) – P3: Unfortunately, during this test the ATD broke a swaged ball end of a cable that essentially replicates the spine due to poor manufacture. The result of this failure was the head of the ATD separating from the torso at around the point of peak chest acceleration and just prior to head contact with the seat back tray table. Therefore, the only useful information to result from this test article was a measurement of peak chest acceleration however; this too was probably affected to minor degree by the detachment of the head. This CRS was seen to move further forward than the RHS by an inch or so allowing its base to drop over the edge of the seat front crossmember. The rebound motion was seen to be more vigorous and forceful than for the RHS. The extra displacement allowed the lower limb to be driven further into the seat in front, pushing the seat back further forward than the RHS.

RHS (Lap belt and extension belt) – P3: The CRS moved forward like many conventional CRS installed on an airline seat. However, the CRS movement did seem restrained by the extension belt, pulling the seat back in which the CRS was installed further forward than that seen on other tests. Post test the breakover limiting plates of that seat position were more highly buckled than seen in previous tests. Additionally, the CRS did not slide off the front of the seat cushion structure. These observations are reflected in the maximum CRS displacement measurement. The feet and knees were driven into the seat back in front, hinging the knees upwards to meet the arcing head. Upward knee motion was seen to be more than that of the LHS ATD but this is not thought to be a characteristic of the configuration but peculiar to this test. The head contacted the tray table in a glancing motion before hitting the right knee. The lack of lower limb penetration meant the seat back in front only hinged forward to a vertical position.

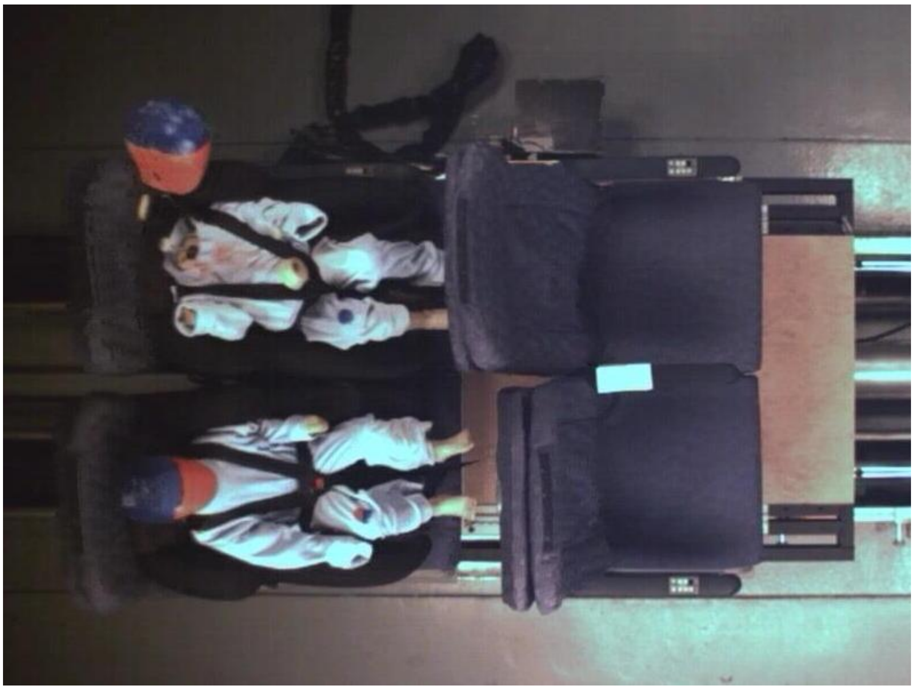

Figure 23 - Video capture of LHS ATD head departing during rebound

Figure 24 – Post-test showing head attached only by instrumentation wiring. The broken spinal cable can be seen protruding from the neck region.

Figure 25 - Point of maximum head excursion, prior to knee contact.

Figure 26 - Witness marks of head strikes on the knee and tray table

A1.4 CASA Test No. 06/01

RTA Crashlab Test No.: S060466

Test Purpose: To test the dynamic performance of automotive ISOfix type child restraints in an airline seat modified with ISOfix lower anchorages.

Test configuration: Two ISOfix child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat modified for ISOfix lower anchorages. The ISOfix child restraints were installed in accordance with the manufacturer's instructions. The forward facing restraint was adjusted to the upright position. The optional top tether strap was not installed. The Foot-prop of the Cosy-Tot ISOfix base was retracted to its up-most position giving approximately 165mm static clearance to the floor. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: Britax 'Cosy-Tot' ISOfix rearward facing restraint for Birth – 13kg children using the Britax ISOfix base.

Britax 'Duo-Plus' ISOfix forward facing restraint for 9kg – 18kg children.

ATDs: TNO P3/4 child ATD (9kg) – Britax 'Cosy-Tot' ISOfix

TNO P3 child ATD (15kg) – Britax 'Duo-Plus' ISOfix

Required Test Pulse: FAR 25.562(b)(2)/TSO-C100b - A change in forward longitudinal velocity (ΔV) of not less than 44 feet per second, peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g.

Test Results: Achieved the required test pulse. A peak acceleration of 16.4g @ 61 ms achieving a total velocity change of 44.1 ft/s (48.4 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS displacement†	Max. Head excursion‡	Max. Knee excursion‡
Britax 'Cosy-Tot' ISOfix (RF) – P3/4	70.3g (57.2g)	436	35.7g (35.2g)	~1.5 in (38 mm)		
Britax 'Duo-Plus' ISOfix (FF) – P3	63.6g (45.9g)	276	33.0g (32.4g)	~ 2.5 in (64 mm)	27.0 (686 mm)	28.2 (716 mm)

* 3ms clip values included in brackets.

† The CRS displacement was measured near the CRS attachment and was relative to its position at the initial point of impact. It was approximated from video capture.

‡ Maximum head and knee excursions are referenced to what would be the equivalent of the seat pivot axis of a standard FMVSS213 seat fixture. (Horizontal distance from the Cushion Reference point plus 6 inches).

Description of results: Britax 'Cosy-Tot' ISOfix (RF) – P3/4: At the 30in (762mm) seat pitch, the CRS before the test cleared the seat in front by only a few millimetres. However, throughout the impact little-to-no contact was made with the seat in front until the seat back rebounded into the CRS. Due to the lack of whipping action of the rigid anchorage system, the rebound motion was relatively small. The head of the ATD just emerged above the surrounds of the CRS and due to the rotation of the CRS, the ATD came close to direct head contact with the seat back tray table. However, considering the initial head position, rate of closure was relatively small. Rotation was not excessive at approximately 10º from the static position.

Britax ‘Duo-Plus’ ISOfix (FF) – P3: The ATD was well restrained. No head or knee contact occurred. Only foot contact with the seat back pocket occurred along with the possible grazing of fingertips on the seat back tray table (the hands were obscured by the ATD clothing). Due to the minimal excursion of the CRS and lack of contact with structures surrounding the ATD, peak head acceleration values and HIC calculations were both well below allowable limits. From the video, upper torso movement in the 5 point harness is the least of that observed in any of the forward facing CRS. Again, rebound motion of the CRS was minimal.

Airline Seat – The modification to the airline seat to attach ISOfix lower anchorages held up well to the test. The lower anchorages did not fail but did suffer permanent set. The LHS lower anchorage deformed in a trapezoid fashion to a depth of 9mm inboard and 17mm outboard. The reason for the uneven distortion is the bar bore on the arm to the seat back recline actuator on the right hand side of each seat placement, thereby reducing the bending arm. The RHS lower anchorage deformed in a similar manner to a depth of 20mm outboard and 26mm inboard, the extra deflection a result from the increased weights of both the P3 ATD and forward facing CRS. The lower anchorage attaching hardware was not distressed and was reused on a subsequent test. The only evidence of damage to the original airline assembly was some slight looseness of the window and aisle spreader assemblies on the seat crossmembers.

Figure 27 - At point of impact

Figure 28 - Maximum head excursion of the P3 ATD and forward facing CRS

Figure 29 - ISOfix lower anchorage bent by the P3/4 ATD and rear facing CRS

Figure 30 - ISOfix lower anchorage bent by the P3 ATD and forward facing CRS

A1.5 CASA Test No. 06/02

RTA Crashlab Test No.: S060470

Test Purpose: To assess the effects on dynamic performance of an airline seat for the standard adult passenger seated behind an automotive ISOfix type child restraint in an airline seat modified with ISOfix lower anchorages.

Test configuration: Two ISOfix child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat modified for ISOfix lower anchorages. The ISOfix child restraints were installed in accordance with the manufacturer's instructions. The forward facing restraint was adjusted to the upright position. The optional top tether strap was not installed. The Cosy-Tot ISOfix base was modified to remove the Foot-prop. Another airline economy class passenger seat was mounted behind at 30 inches in pitch seating two Hybrid III ATDs.

Child Restraints: Britax 'Cosy-Tot' ISOfix rearward facing restraint for Birth – 13kg children using the Britax ISOfix base.

Britax 'Duo-Plus' ISOfix forward facing restraint for 9kg – 18kg children.

ATDs: TNO P3/4 child ATD (9kg) – Britax 'Cosy-Tot' ISOfix

TNO P3 child ATD (15kg) – Britax 'Duo-Plus' ISOfix

2 x standard Hybrid III ATDs (50th percentile male) – no modification for FAA spine.

Required Test Pulse: FAR 25.562(b)(2)/TSO-C100b - A change in forward longitudinal velocity (ΔV) of not less than 44 feet per second, peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g.

Test Results: Did not achieve the required test pulse. A peak acceleration of 17.6g @ 54 ms achieving a total velocity change of 40.2 ft/s (44.1 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. Femur Load	Max. CRS displacement†	Max. Head excursion‡
Britax 'Cosy-Tot' ISOfix (RF) – P3/4	56.8g (53.6g)	419	48.5g (41.0g)			
Adult ATD (seated behind 'Cosy-Tot')	124.1g (92.2g)	813	26.1g (25.3g)	2.11, 1.21 kN (957, 549 lbs)		
Britax 'Duo-Plus' ISOfix (FF) – P3	36.7g# (36.0g)	148	39.1g (34.0g)		~3 in (76 mm)	25.6 in (650 mm)
Adult ATD (seated behind 'Duo-Plus')	146.9g (90.2g)	902	31.1g (26.4g)	1.30, 1.89 kN (590, 857 lbs)		

* 3ms clip values included in brackets.

† The CRS displacement was measured at the CRS attachment and was relative to its position at the initial point of impact. It was approximated from video capture.

‡ Maximum head excursion is referenced to what would be the equivalent of the seat pivot axis of a standard FMVSS213 seat fixture. (Horizontal distance from the Cushion Reference point plus 6 inches).

Due to electrical noise, this peak head acceleration value is filtered to Class 100.

Description of results

Britax ‘Cosy-Tot’ ISOfix (RF) – P3/4: For this test the foot prop was removed because on the previous test it nearly touch the floor due to CRS rotation and seat cushion compression. Peak head and chest acceleration values were lower than for the previous test with this ISOfix CRS, a reflection of the slightly lower test severity and lack of influence from the ATD seated behind. CRS displacement was similar but rebound was suppressed when compared to the previous test due to the ATD pushing the seat back forward, applying pressure to the anti-rebound bar on the CRS.

Britax ‘Duo-Plus’ ISOfix (FF) – P3: Again, the ATD was well restrained and injury levels were extremely low. Influence from the adult ATD impacting from behind was minimal. However, the adult ATD head strike transferred measurable accelerations to the P3 ATD, though the magnitude was lower than those imparted by the sled.

Adult ATD (LHS, seated behind ‘Cosy-Tot’): The ATD suffered from severe head accelerations, though the values were still in an acceptable range from a seat certification point of view. Damage was sustained by the tray table. Chest acceleration was low and femur loading was well below certification limits despite both shins contacting the aft seat crossmember, severely enough to crease the member in one case. Seat back breakover was limited by the CRS body and anti-rebound bar. This caused severe head rotation as it was dragged downwards by the torso resulting in extremely large neck flexion.

Adult ATD (RHS, seated behind ‘Duo-Plus’): Injury levels for this ATD were similar to the ATD seated adjacent, but with slightly higher head accelerations. This was most likely caused by the extremely restricted seat back breakover, a function of the forward facing ISOfix CRS placed in front. The seat back only progressed to a few degrees forward of vertical and most of this rotation occurred due to the seat backs own weight before the head impact. The result of this effectively ‘stiff’ installation was very large aft head rotation resulting in large neck flexion. Unfortunately, no neck instrumentation was installed in the adult ATD but the peak angle was estimated to be in excess of 90 degrees aft rotation.

Airline Seats – The modification to the airline seat to attach ISOfix lower anchorages held up well to the test. The lower anchorages did not fail but suffered permanent set similar to amounts in the previous test. No knee/shin impact from the Adult ATDs seated behind was found on the lower anchorages. The lower anchorage attaching hardware was not distressed. The seat in which the Adult ATDs were seated deformed a predictable manner. There were no unexpected breakages associated with the second seat and it performed in line with its certification.

Figure 31 - At point of impact

Figure 32 - Point of maximum seat back break over and maximum P3 head excursion

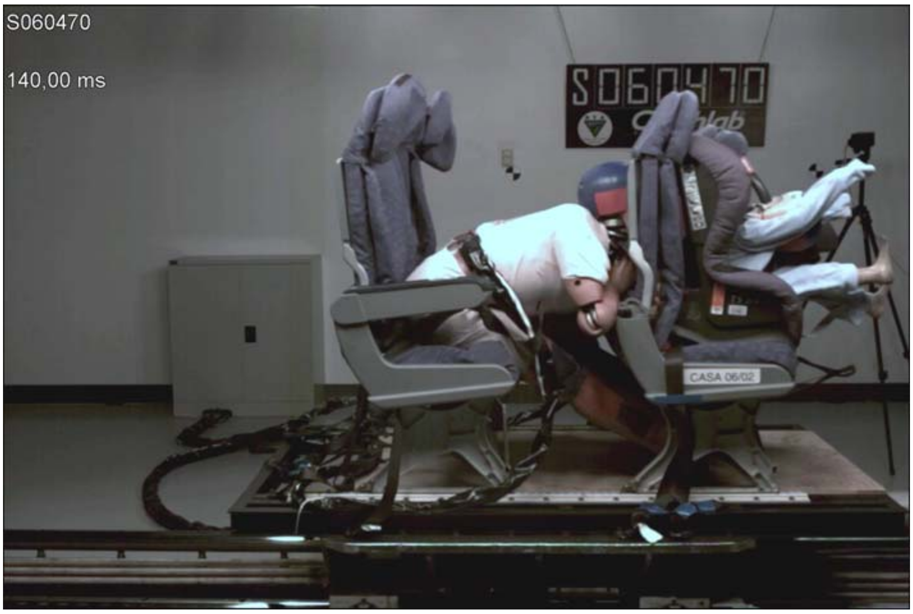

Figure 33 – RHS Adult ATD maximum neck flexion

Figure 34 - Adult ATD head impacts

Appendix 2 Child Restraint Equipment

A2.1 Britax 'Duo Plus' ISOfix

Manufacturer	Britax Römer
Series Name	Römer Duo
Orientation	Forward Facing
Allowable weight range	9kg – 18 kg (20 lb – 40 lb) [Mass group I, ISOfix size B1]
Design Standard	ECE R44/04 (Universal and specific vehicle)
Weight	8.5 kg (18.7 lb)
Does the CRS comply with SAE ARP4466[20]?	Technically, ARP 4466 is not applicable as "Child Restraint Systems which require special fittings on the passenger seat…..are excluded from this document." Additionally, the Pelvic Restraint path and Installation Guidance sections of the ARP are not appropriate as it details the attachment of the CRS via the use of a pelvic restraint, which is not the method by which this CRS is attached to the airline seat. However, from a dimensional perspective (ARP4466 figure 1), the CRS complied with the recommendations.

Figure 35 - Britax 'Duo Plus'

A2.2 Britax ‘Cosy Tot’ ISOfix and ISOfix Base

Manufacturer	Britax Römer
Series Name	Römer Baby-Safe
Orientation	Rearward Facing
Allowable weight range	0kg – 13 kg (0 lb – 28 lb) [Mass Group 0+, ISOfix Size E]
Design Standard	ECE R44/04 (Universal and Semi-Universal) [ISOfix Base – ECE R44/03 (Semi-Universal)]
Weight	8.8 kg (19.4 lb) total [CRS 4 kg (8.8 lb), ISOfix base 4.8 kg (10.6 lb)]
Does the CRS comply with SAE ARP4466[20]?	Technically, ARP 4466 is not applicable as a “Child Restraint Systems which require special fittings on the passenger seat…..are excluded from this document.” Additionally, the Pelvic Restraint path and Installation Guidance sections of the ARP are not appropriate as it details the attachment of the CRS via the use of a pelvic restraint, which is not the method by which this CRS with its ISOfix base is attached to the airline seat for the purposes of this research. However, from a dimensional perspective (ARP4466 figure 1), the CRS with ISOfix base complied with the recommendations.
Comment:	This unit is sold in the USA as a Britax Baby Safe and is approved for Aircraft Use under the FMVSS 213 provision. However, only the capsule is to be installed in the aircraft seat using the aircraft’s lap belt. It is not approved for aircraft use using the ISOfix base.

Figure 36 - Britax 'Cosy Tot' (mounted on the ISOfix base)

Figure 37 - Britax 'Cosy Tot' ISOfix base

A2.3 Safe-n-Sound 'Premier' Convertible

Manufacturer	Britax Childcare Pty. Ltd.
Series Name	7000-H-2004
Orientation	Forward or Rearward Facing
Allowable weight range	0kg – 12 kg (0 lb – 26 lb) [Rearward Facing, Type A2]
	9kg – 18kg (20 lb – 40 lb) [Forward Facing Type B]
Design Standard	AS 1754
Weight	6.5 kg (14.3 lb)
Does the CRS comply with SAE ARP4466[20]?	Generally, the CRS met the recommendations of ARP4466. Of note was the CRS is wider than 405 mm (16 inches). Clearance in the forward facing upright and rear facing positions from the upper leading edge of the test fixture armrest was within a few millimetres. Additionally, in both upright and recline forward facing configurations, the distance from the belt path entry to the pelvic restraint attachment of the seat was, again, within a few millimetres of the upper limit (section 6.1.1). In forward facing mode, minor difficulties occurred with release of the pelvic restraint lift type buckle in the confined space at the rear of the restraint.
Comment:	In rearward facing mode the seat belt path is such that the buckle is placed under the child's legs, in this case centrally in the groin area. This would be uncomfortable for the child over any length of time.

Figure 38 - Safe-n-Sound 'Premier' Convertible

Figure 39 - Buckle position on the Safe-n-Sound in rear facing mode

A2.4 IGC Gosafe 'Boulevard' Convertible

Manufacturer	IGC (Australia) Pty. Ltd.
Series Name/ Part No.	2931-82
Orientation	Forward or Rearward Facing
Allowable weight range	0kg – 9 kg (0 lb – 20 lb) [Rearward Facing, Type A1 (Maximum Height 700mm)] 8kg – 18kg (18lb – 40 lb) [Forward Facing Type B]
Design Standard	AS 1754
Weight	4 kg (8.8 lb)
Does the CRS comply with SAE ARP4466[20]?	The CRS met the recommendations of ARP4466 with two exceptions. In upright mode the distance from the belt path entry to the pelvic restraint attachment of the seat was in excess of the upper limit by 12 mm (0.5 in) (section 6.1.1). The buckle position was poor in both forward facing and rearward facing modes, and access for unlatching was extremely difficult (section 7.3).

Figure 40 - IGC Gosafe 'Boulevard' Convertible

A2.5 Extension Belt

Manufacturer	Air Safety Solutions
Series Name	N210-L
Design Standard	CASA CAO 108.42 (FAA TSO-C22f)
Weight	220 g (7.8 oz)

Dimensions Maximum 1400 mm (55 in) loop length

Figure 41 - Extension Belt

A2.6 Top Tether

Manufacturer Air Safety Solutions

Design Standard 1000lb (4.45kN) minimum strength

Weight 185 g (6.5 oz)

Dimensions 500 mm (20 in) –> 1650 mm (65 in) working length

Figure 42 - Top Tether

Appendix 3 ISOfix lower anchorage modification to airline seat

A3.1 Description

The initial design idea called for Ø0.75in (19mm) Chrome Molybdenum steel tube to span the width of the seat assembly off which appropriately positioned U-bent 6mm (0.24in) round bars meeting the requirements of FMVSS 225 S9[24] would be welded. The tube would interface the seat structure via machined fittings. There were a couple of potential issues with this configuration:

- Correct positioning of the lower anchorages would be difficult. Particularly, locating the lower anchorages aft enough to meet the FMVSS 225 requirements whilst not encroaching on the legroom of any occupant seated behind.
- The installation would be particularly stiff.
- The potential increased risk of lower leg injury for an adult seated behind due to the lower anchorage assembly projecting further aft than the existing seat structure.

A revised design was developed which effectively strung a length of 6mm steel rod to the aft side of the seat structure at the appropriate height. The design was much simpler, had some inherent flexibility, and should not be injurious to an occupant seated behind. However, because of these characteristics, the principle concern was that the lower anchorage would not be strong enough to withstand both the loads imparted by the CRS and those applied by the lower limbs of an occupant seated behind.

Figure 43 - ISOfix lower anchorage installation (seat back sub-assemblies removed)

Figure 44 - ISOfix lower anchorage installation, LHS

The lower anchorage was positioned under the coverings forward of the seat back pocket. The seat back cushion lower edge naturally sat over the interfacing bar, hiding it from view, but when required was easily tucked behind the bar to reveal its full length.

Figure 45 - ISOfix lower anchorage installed with upholstery refitted

Figure 46 - The seat on the left shows the lower anchorage covered by upholstery | The seat on the right shows the lower anchorage revealed.

The total modification detailed in this section weighed 340 grams (12 oz).

A3.2 Standards

As per TSO-C100b[14], the aircraft seat was modified in accordance with the configuration referred in FMVSS 225 S9[24] with the following exceptions:

- §9.1.1 – the lower anchorage consisted of one continuous bar instead of two separate bars.
- §9.1.1(c) – the lower anchorage exceeded 40mm in length as it spanned the width of the seat.
- §9.4 – the lower anchorage was not tested to the required load. With only limited seat assemblies, a static test rig was manufactured and a test article representing one seat place was tested in excess of the maximum anticipated dynamic load. See section A3.4.
- §9.5 – labelling requirements were not adhered to as this program was for research purposes only.

A3.3 Materials and hardware

The 6mm (0.25 in) steel bright round bar met Australian Standard AS1443 / 1214 material specifications. This is approximately equivalent to AISI/SAE 1213 or 1215, and is a free machining low tensile, low hardenability carbon steel. The tags were made from 25mm (1 in) x 3mm (⅛ in) flat low-grade commercial mild steel. The tags were TIG welded to the round bar with ER70S2 filler rod.

The ISOfix lower anchorage was mounted to the seat assembly using MS27039-0812 structural screws, AN960-8 washers, and MS 21042-08 nuts.

A3.4 Static Testing

Due to the limited number of seats available, a single place test sample was manufactured along with a test rig to assess strength and deflection characteristics. A static load equating to the maximum anticipated dynamic load was applied. The permanent deformation was similar to that found subsequently during dynamic testing.

Figure 47 - Prototype lower anchorage showing permanent set after load application