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

- PHASE II

AIRWORTHINESS & ENGINEERING BRANCH
STANDARDS DEVELOPMENT & FUTURE TECHNOLOGIES GROUP

RESEARCH PROJECT

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

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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. Many countries around the world allow children under the age of two years to be lap held and if so, they remain unrestrained. Numerous infants and small 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 should 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 has been shown to be ineffective at contributing to the accident performance of automotive child restraints.

There were three principle aims to this research. To assess the comparative performance of ISOfix, LATCH and lapbelt restrained Automotive Child Restraint Systems in airline style seating against aircraft forward emergency landing dynamic conditions. Additionally, assessment of a supplementary loop restrained lap held child and a child in its own seat was conducted as a baseline measurement. Secondly, to measure loads generated in the various attachment mechanisms during those conditions. Finally, to assess the injury levels to occupants seated behind a child restraint system and document the variation with the different attachment methods, if any.

Most Australian Automotive CRS will perform adequately in transport category seats. ISOfix and LATCH systems perform better than lap belt restrained CRS. However, the level of occupant protection provided to the child by all automotive CRS, no matter the attachment method, was vastly superior to contemporary systems, i.e. Lap Belt or Supplementary Loop Belt. For the Supplementary Loop Belt, evidence from tests show unsatisfactory interactions between the adult and the child.

A most interesting discovery was that when sitting in a CRS, overall child injury levels were reduced when an adult occupant was seated behind. It was a clear trend identified across numerous CRS types, CRS attachment methods, adult occupant sizes and injury mechanisms.

Lower Anchorage loading profiles were obtained for individual loops in two dimensions (fore/aft and vertical) for ISOfix and LATCH attachment methods. This data provides for future standards development of Lower Anchorages. The peak load developed in any Lower Anchorage was 5.08kN (1142 lb_f).

Injury assessments to adults seated behind CRS were made for ISOfix, LATCH, and lap belt CRS restraint methods as well as for variations in adult size. Additionally, assessment was conducted of injury to adults nursing children and for an adult with no CRS in front, for baseline data. The injury levels to adults seated behind CRS were higher than when not seated behind a CRS, but not by a large margin. This was principally measured by head injury score however, other injury measures reduced. Other injury mechanisms not traditionally measured in aircraft certification were identified as potential hazards. The severe head rotation seen in previous testing was not repeated, however, measurements indicate Upper Neck extension/compression may exceed limits. The other injury mechanism of concern was Upper Tibia bending moment, which may reach the limits of human tolerance when interacting with potential Lower Anchorage structures.

The project successfully identified favourable CRS and attachment method attributes. New CRS attachment methods have the ability to improve CRS accident performance provided Lower Anchorages are installed. To that, the project identified strength requirements and possible criteria for Lower Anchorage installations. Indications are that injury levels to occupants seated behind CRS increased slightly and non-traditional injury mechanisms may need to be measured during any certification because of Lower Anchorage structures and the CRS itself.

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 will be relevant to non-Australian airline operations.

One of the impediments, with respect to the aircraft airworthiness, is the modification of the aircraft to allow attachment of the top tether strap required by Australian automotive child restraints. It was previously assessed that this top tether installation method in airline style seating is ineffective in contributing to the deceleration of the restraint and child system[1]. Operationally, it blocks the use of the tray table for any person sitting in the seat behind the child restraint and there can be an excessive fitment time of the child restraint during turnaround.

In the same research, a preliminary look at the ISOfix attachment method was performed. For the child restraint systems tested, the ISOfix system showed better decelerative performance. This research program expands on this aspect, looking at comparative performance of ISOfix, LATCH and lapbelt attachment methods for numerous automotive child restraints and assessing the loads generated in each attachment method as data for any potential future standards. Additionally, a more expansive assessment of the potential for an increase in injury to occupants in row-to-row seating behind these restraints was carried out, as initially highlighted and recommended by the previous work.

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 and flexible anchorage LATCH systems given the gross deflections typical of current automotive child restraints worldwide when installed in airline seating.

Baseline testing for all popularly used child seating configurations was performed. This way comparison of injury scores for currently used configurations could be made against certification standards for child restraint systems. Configurations tested were, a child in their own airline seat, lap held infants restrained by a Supplementary Loop Belt, and a child in a lap belt attached Automotive Child Restraint System. Additionally, a baseline test of an adult in their own seat with no child restraint in front was conducted for comparison purposes of adult occupant injury.

1.2 The Program

1.2.1 Aims

There were three principle aims of the project:

- To assess the comparative performance of ISOfix, LATCH and lapbelt restrained Automotive Child Restraint Systems in airline style seating against aircraft forward emergency dynamic landing conditions. Additionally to assess baseline performance of a supplementary loop restrained lap held child and a child in their own seat.

- To measure loads generated in the various attachment mechanisms during those conditions.

- To assess the injury levels to occupants seated behind a child restraint system and document the variation with the different attachment methods, if any.

To fully understand the basis for these aims, the previous research conducted by CASA should be read first[1].

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'.

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[2] 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 were similar in nature to previous CAMI work.[3]

In 2006, Human Impact Engineering & Britax Childcare (Australia) completed research under an Australian Transport Safety Bureau (ATSB) Aviation Safety Research Grant[4]. It investigated the fit, form, and function of a vast range of currently available Australian AS/NZS1754 Child Restraints[5], 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 have difficulty fitting within the space available and could not be adequately installed due to interference with the aircraft lap belt. Approximately half of the CRS could be tested and most exhibited significant forward motion, rotation and rebound motion. This is similar to results found previously in overseas research[6 7]. This research made seven recommendations. Two of these recommendations have been assessed by CASA.

In 2007, CASA published a technical paper[1] that looked at the top tether aspect, an alternative installation method, and a preliminary assessment of the value of the ISOfix system in a specially modified airline seat. The program showed the top tether, as typically installed in row-to-row airline seating, did not contribute to the decelerative performance of the CRS. The CRS that used the ISOfix system showed vastly reduced excursion during the test pulse removing the ability for the child to strike the seat in front. The report made numerous recommendations of which two are addressed in this research.

1.3.3 Child Restraint Standards

1.3.3.1 Australian Standard AS/NZS 1754

AS/NZS 1754 [5] 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. Numerous issues exist with the top tether strap when the CRS is installed in an airline seat and have been covered previously[1]. All testing for this program used the CRS with the most stable belt path and no top tether strap.

Figure 1 - IGC Alternate belt path | IGC Standard belt path | Unstable nature of forward belt paths without effective top tether.

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 in motor vehicles for all forward facing and rearward facing CRS will continue and will apply to CRS featuring ISOfix and LATCH attachment methods.

1.3.3.2 ECE-R44 (ISOfix)

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 types of ISOfix 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 restraints were sourced from Europe, which contained rigid link ISOfix attachment methods and met the ECE-R44 standard[12]. The forward facing CRS had an optional top tether strap that was not used in line with the previously identified issues. The rearward facing CRS was a 2-part capsule and ISOfix base unit. The base unit used a foot prop for an Anti Rotation device. Because the Australian Standard AS/NZS 1754 is unlikely to allow for an anti-rotation device other than a top tether strap, the base unit was modified to remove the foot prop.

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 from the adult occupant's lower limbs, i.e push-on effect. Secondly, for increased lower limb injury of the adult occupant due to interaction with the seat Lower Anchorage. Finally, increased head or neck injury for the adult occupant due to reduced breakover performance of the seat back ahead of the occupant.

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.

1.3.3.3 FMVSS 213 (LATCH)

The North American 'Lower Anchors and Tethers for Children' system (LATCH)[11] was also programmed to be added to AS/NZS 1754, which allows the use of either flexible or rigid links. A vast majority of FMVSS 213 compliant CRS use a flexible webbing based system with most of those using a strap that is routed through the seat belt path and retained on the CRS via a secondary link. The AS/NZS 1754 and ECE-R44 CRS were used in conjunction with loose LATCH straps to assess this system.

Figure 4 - LATCH strap installed

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’[9], and
- Australian Standard AS/NZS1754:2004 ‘Child Restraint Systems for use in motor vehicles’[5].

TSO-C100b and it’s main reference source, SAE Aerospace Standard AS5276/1 ‘Performance Standard for Child Restraint Systems in Transport Category Airplanes’[10], 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’[13], 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.

For adult injury, FAR25.562[20] and FMVSS 208[21] were used as a guide to acceptable injury tolerance.

2.1.1.1 Test Fixture

Rather than the test fixture described in TSO-C100b/SAE AS5276 or AS/NZS 1754/3629.1, B/E Aerospace ‘Innovator’ Economy class two and three place seats were used and mounted via an adapter frame. The three place seats were modified into doubles matching the configuration of the original two place seats. 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, all tests were performed with two rows of seats for assessment of head and lower limb impacts. A 30-inch seat pitch was chosen to represent a typical airline seating arrangement. The seats complied with the recommendations of SAE ARP4466[14].

2.1.1.2 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.

2.1.1.3 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.

2.1.1.4 Lower Anchorages

For assessment of the comparative performance of the various CRS attachment methods and for collection of Lower Anchorage loads, a rigid Lower Anchorage system was developed that was mounted independent of the seat. The Lower Anchorage loops conforming to FMVSS 225[19] were attached to a frame that resolved the loads into fore/aft and vertical load directions that were independently measured with load cells. For the assessment of injury to occupants seated behind a CRS, the Lower Anchorage loops were attached to a steel tube that spanned the rear of the arm spreader structures. See Appendix 3 for full details.

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 where appropriate. When installing the CRS with an aircraft lap belt or LATCH strap, it 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 lb_f). When installing the CRS with the ISOfix system, the catches were engaged with the Lower Anchorage and CRS pushed back in to the seat with enough pressure to lightly engage the seat back.

The CRS, in forward facing configuration, were tested in the upright rather than recline position except for the IGC Gosafe, whose mechanism would slip to the recline position when tension was applied to the aircraft lap belt or LATCH strap. These CRS had already been used in previous tests and the manufacturer has since modified the mechanism.

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 was 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.

2.1.1.6 Injury criteria

Primarily TSO-C100b/SAE AS5276 was used as the criteria for acceptable levels of injury, however the somewhat simple criteria of AS/NZS 1754 was also assessed. Because of the use of a seat in front, assessment of knee excursion 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.

Additionally, injury criteria from FAR25.562 and FMVSS 208 were used to gauge levels of adult occupant injury. Head Injury Criterion (HIC), Neck Injury Criterion (Nij), Maximum Chest Acceleration, Maximum Chest Deflection, and Maximum Femur Compression were used to measure injury levels.

2.1.2 Facilities

All dynamic testing was carried out at the Autoliv Australia[15] facilities in Campbellfield, Melbourne, VIC. Autoliv is international commercial organisation specialising in automotive safety products. Autoliv Australia is accredited to the National Association of Testing Authorities (NATA) for AS3629.1 testing and Hybrid III ATD calibration.

2.1.2.1 Test Sled

An Aries 'Crash Simulation System' was used to generate the required impact conditions. This "deceleration" type sled is described in FAA AC 25.562-1B[16], paragraph 6(b). Manufactured by Aries Ingeniería Y Sistemas S.A. of Madrid, Spain, it was designed for dynamic testing of seat belts and seating systems.

An adaptive velocity control system places the sled in the appropriate "fire" position using an auxiliary sled along the guided rails connected to the Sled, carrying it to the right position of the track and straining the bungee cords to produce the final pre-set velocity. The required deceleration pulse is achieved by means of re-usable polyurethane tube devices placed in parallel inside steel pipes. Deceleration occurs when a set of steel bars fitted to the sled, and which have olive-shaped ends, are pushed inside the polyurethane tubes with an interference fit, which absorb the impact energy. Different deceleration pulses are obtained by altering the length of the tubes, tube hardness, impact speed, and the shape and diameter of the olives knobs screwed to the end of changeable shafts[17].

The aircraft seats were mounted via Ancra heavy duty aircraft seat track and a custom steel frame to adapt them to the sled bed.

2.1.2.2 Instrumentation

Electronic and photographic instrumentation met the recommendations of SAE J211[18] parts 1 and 2 respectively. ATD and sled instrumentation was linked to computers via an umbilical track and data downloaded in real time. Two cameras were used – side (1000fps) and an overhead (1000 fps) with an additional elevated rear quartering view (1000fps) used for two tests.

Hybrid III and TNO P series ATDs were fitted with standard instrumentation. Additionally, the Lower Anchorages for the load gathering series of test were attached directly to the sled frame instrumented with a pair of A-2121-D Denton Hybrid III Femur load cells for each anchorage.

Figure 5 - Autoliv 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 and three place seats were acquired. The three place seats were 'cut down' to two place configuration and modified to match the two place seats. These seats were marked as TSO-C39b Type I compliant. However, the seatbacks were fitted with breakover limiting 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. Previous testing found a force applied at the top of the tray table of 160 lb_f (715 N) was required to initiate breakover, which equates to a required breakover moment of 301 ft.lb (408 Nm). After each test, the seats were either discarded or repaired depending on the nature of the damage.

2.1.3.2 Airline Seat Lap Belts

Amsafe lap belt assemblies conforming to TSO-C22g, rated at 3000 lb_f 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.

Both CRS are required to use a top tether in both modes of operation as required by AS/NZS AS/NZS 1754 but for this series of tests they were not used in line with arguments presented in section 1.3.3.1.

2.1.3.4 LATCH Restraints

LATCH straps were acquired from Britax Australia removed from USA FMVSS213 CRS. They were manufactured from 40mm webbing with appropriate quick release anchorage catch and adjustable buckles. These LATCH straps use the existing CRS belt path and, as such, were able to be used to install all of the CRS. For the ECE-R44 rear facing capsule, when the CRS was installed with the LATCH straps it did not use the base plate in line with the instruction for aircraft use with a lap belt.

2.1.3.5 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 ISOfix base was fitted with a ‘foot prop’ which was removed. Whilst wanting to test in a configuration as close to the possible 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.

See Appendix 2 for the CRS specifications.

2.1.3.6 Supplementary Loop Belt

A Supplementary Loop Belt was manufactured for the purposes of testing and was representative of that used by airlines in Australia. It is in essence an Aircraft Lap Extension Belt with an additional small loop of webbing sewn at 90º for the adult lap belt to thread through. This essentially creates a chain type connection for the child to the aircraft seat.

2.1.3.7 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. The P3 was instrumented with head and chest acceleration whilst the P¾ was not instrumented. A TNO P1½ was used for the final supplemental loop belt test, as it was the smallest instrumented ATD available.

Hybrid III 5th percentile Female, 50th percentile Male and 95th percentile Male ATDs were used to replicate Adult occupants. All Adult ATDs were instrumented for head and chest acceleration, upper neck force and moment, femur compression and chest deflection.

2.2 Test Configurations

2.2.1 Lower Anchorage loads gathering tests

2.2.1.1 Seating configuration

For this series of tests, the CRS were installed in the aft row of a two-row set of airline seats. The forward row was set at a 30 inch pitch to represent a typical seating configuration. ATDs representing 3 year old (TNO P3) and 9 month old (TNO P3/4) children were used in forward and rearward facing CRS respectively.

Figure 6 - Seating configuration for Lower Anchorage Loads gathering

2.2.1.2 Instrumentation

The TNO P3 series ATD was instrumented with tri-axial Head and Chest accelerometers. The TNO P3/4 was uninstrumented.

An instrumented frame was designed to measure loads generated by the CRS through the Lower Anchorage attachments during the deceleration pulse. Each Lower Anchorage loop was measured independently and arranged to measure the fore/aft and vertical components separately. The Lower Anchorages were positioned from behind the seats protruding through the seat bite in a position representative of where seat mounted Lower Anchorages would be. The structure was very rigid which would be conservative in that it should generate high inertial ATD and CRS accelerations and loads. This arrangement was used for testing both the ISOfix and LATCH systems.

Figure 7 - Instrumented Rigid Lower Anchorages

For tests using the aircraft seat lap belt for CRS restraint, webbing load transducers were used to measure the loads generated.

2.2.1.3 Test matrix

For both the forward and rearward CRS configurations, all the CRS were installed using the LATCH strap. Additionally, the ISOfix CRS were tested with installation via the ISOfix link and the aircraft seat lap belt for comparison of injury levels against attachment method.

	Forward Facing			Rearward Facing		
	Lap belt	LATCH	ISOfix	Lap belt	LATCH	ISOfix
Cosy-Tot				X	X	X
Duo-Plus	X	X	X			
Safe-n-Sound		X			X	
Gosafe		X			X	

Table 1 - CRS attachment matrix

2.2.2 Injury assessment tests

2.2.2.1 Seat configuration

For assessment of injury, a series of tests were performed, again with two rows of airline seats at 30 inch pitch. For the child restraints, TNO P3, P1½, and P3/4 ATDs were used. For Injury assessment of adults, Hybrid III 50th percentile male ATDs were used except for one test conducted with a 5th percentile female and a 95th percentile male ATD.

The aircraft seat required modification for the installation of Lower Anchorage bars. TSO-C100b refers to FMVSS 225 S9[19] for testing with Lower Anchorages which was complied with. That is, two individual 6mm bars with centres spaced 280mm (11in) apart, were welded to a 20mm diameter Mild Steel tube that was continuous across the seat span. The tube was screwed to the seat frames via welded tags.

Figure 8 - Lower Anchorage Installation for Adult Injury Assessment

No modification to the seat upholstery was required. The bars were sufficiently recessed so that they would not be felt by an adult occupant seated in that seat either with the seat in the upright or the reclined positions.

For baseline tests, no lower anchorage systems were installed and the seats were essentially standard. The seated occupants were restrained by the seat lap belt and, if used, the lap held Infants restrained by a Supplementary Loop Belt.

2.2.2.2 Instrumentation

For assessment of injury to adults seated behind CRS, Hybrid III 5^{th} percentile female, 50^{th} percentile male and 95^{th} percentile male ATDs were used. All adult ATDs were fitted for tri-axial head acceleration, tri-axial neck force and moment, and femur compression. Additionally, the 50^{th} percentile male ATD was fitted with tri-axial chest acceleration and deflection.

The 3 year child ATDs were instrumented with tri-axial Head and Chest accelerometers. The 18 month Infant ATD was instrumented with tri-axial Head and Chest accelerometers and tri-axial neck force and moment.

2.2.2.3 Test matrix

Injury to both child and adult occupants was assessed concurrently. Different combinations of child restraints, attachment methods, and occupant sizes were compared. The following tables outline the injury assessment.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Forward Facing Attachment Method</td></tr>
<tr><td>ISOfix</td><td>LATCH</td><td>Lap belt</td><td>Supplementary Loop Belt</td></tr>
<tr><td rowspan="4">No occupant seated behind</td><td>Safe-n-Sound</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Gosafe</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Duo-Plus</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Aircraft Seat</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="6">With occupant seated behind</td><td>Safe-n-Sound + HIII 50% male</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Duo-Plus + HIII 50% male</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Duo-Plus + HIII 5% female</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Duo-Plus + HIII 95% male</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>P1½ Lap held + HIII 50% male</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>P3/4 Lap Held + HIII 50% male</td><td></td><td></td><td></td><td>X</td></tr>
</table>

Table 2 – Child Injury assessment

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Forward Facing Attachment Method</td><td colspan="2">Rearward Facing Attachment Method</td></tr>
<tr><td>ISOfix</td><td>LATCH</td><td>Lap belt</td><td>Supplementary Loop Belt</td><td>ISOfix</td><td>Lap belt</td></tr>
<tr><td rowspan="6">HIII 50% male</td><td>Cosy-Tot</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>Safe-n-Sound</td><td></td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Duo-Plus</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>P1½ Lap held child</td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>P3/4 Lap held child</td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>No CRS</td><td colspan="6">X (Baseline test)</td></tr>
<tr><td>HIII 5% female</td><td>Duo-Plus</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>HIII 95% male</td><td>Duo-Plus</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3 – Adult Injury assessment

3 Results

3.1 General overview

3.1.1 Minimum Test pulse requirements

All tests essentially met the minimum test pulse requirements of TSO-C100b/SAE AS5276. However, the pulse shape was not ideal and is a function of the test equipment. Essentially, the system is limited in the distance over which it can decelerate the sled. By integration, the stopping distance for the ideal deceleration pulse is 1271mm. The Aries 'Crash Simulation System' is limited to 700mm. For a margin of error, the tests conducted typically used 650mm. As can be seen from Figure 9, the system also featured a dip in deceleration at around the 25 ms mark caused by the interface between the standard and extension pieces used in the polyurethane based arresting system.

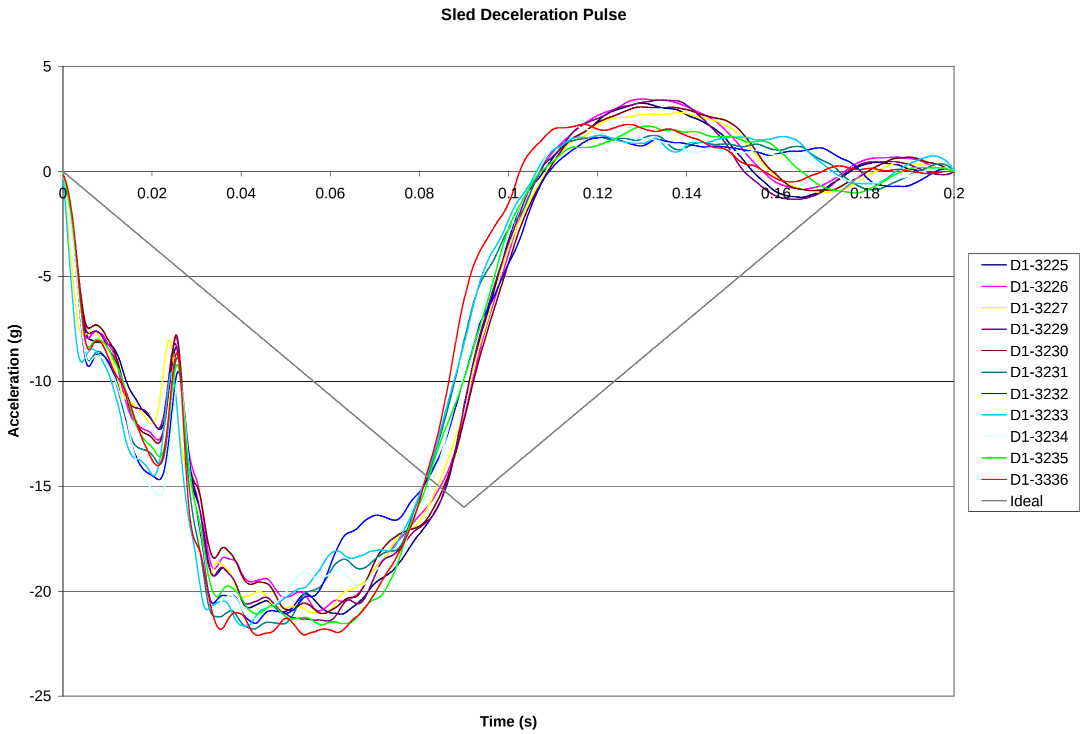

Figure 9 - Comparison of test pulses

All tests met the peak acceleration and minimum rise time requirements. However, half the tests fell short of meeting the velocity change requirement but only by 0.3%.

3.1.2 Lap Belt restrained CRS

Being that there is no Injury Criteria for Type A CRS (rearward facing) in AS/NZS 1754, the P3/4 ATD was not instrumented and as such no injury levels were recorded for the rearward facing CRS. That said, previous research shows that rearward facing CRS provide a good level of protection for the occupant.

Forward facing CRS provided good protection for the occupant when compared to the same sized occupant restrained by a lapbelt. All injury criteria were met by the Britax Duo Plus used during the two lapbelt restrained CRS tests conducted. The lap belts did however allow for quite some displacement of the CRS, more than other attachment methods. This allowed the lower limbs to engage the seat in front and allowed for a substantial rebound of the CRS.

See Appendix A1.5 and A1.8 for detailed aspects of these tests.

3.1.3 LATCH

Installation and removal of the CRS with the LATCH strap was generally easier than the lap belt because the connection is on the side of the CRS, and more readily visible and accessible.

All injury criteria were acceptable except for head injury criterion for the AS/NZS 1754 CRS installed with LATCH straps attached to the rigid instrumented lower anchorages. This was not due to the installation method but rather due to the CRS shoulder harness allowing the ATD upper torso to rotate to the point that a head strike occurred on the ATD's lower limbs. The same effect was seen with one of the AS/NZS 1754 CRS mounted with LATCH and the in-seat Lower Anchorages but did not result in a HIC score that exceed limits. This phenomenon has been recorded in previous research[1]. The Britax Duo Plus did not exhibit the same behaviour, in all cases keeping the head away from the lower limbs. All LATCH installed Forward facing CRS allowed displacement of the CRS during the impact but not to the same extent as that seen for lapbelt installed CRS. This can be attributed to the more aft anchorage point the LATCH system was provided by the seat.

The only item of concern was the severe rebound allowed by capsule type Rear-facing CRS due to it not being installed on the base plate (with its integrated anti-rebound bar) with this attachment method.

See Appendix A1.2, A1.3, A1.4, and A1.9 for detailed aspects of these tests.

3.1.4 ISOfix

Installation of ISOfix CRS is far easier and quicker than the other attachment methods due to its rigid nature and lack of adjustments. After some tests conducted with in-seat Lower Anchorages, there was an issue with release due to distortion of those anchorages. In practice, this is not an issue. All CRS harnesses released as anticipated.

All measured injury levels with the ISOfix type restraints were well within recognized limits. CRS displacement was minimal, again due to the rigid nature of the link with the seat. Impact from an occupant seated behind was not detrimental the child ATD's injury levels. Additionally, no substantial variations in injury levels were detected for various sizes of aft adult occupant.

See Appendix A1.1, A1.6, and A1.7 for detailed aspects of these tests.

3.1.5 Conventional Restraint

Three conventional restraint conditions were tested to give a baseline against which the CRS and CRS attachments methods could be measured.

For infants, ATDs representing 9 month and 18 month old children were restrained on the lap of a 50th percentile male ATD with a Supplementary Loop Belt. The 9 month old (P3/4) was uninstrumented, whilst the 18 month old (P1½) was instrumented with head and chest accelerometers, as well as, neck force and moment transducers. Injury levels registered by the P1½ were excessive with HIC and neck Injury exceeding, and chest just within, recognised limits. Video footage of the impacts however revealed evidence of extreme head contacts, and occupant-to-occupant interactions. The child head acceleration trace showed larges changes in acceleration from a head strike on the seat back and a head strike from behind by the adult head (see Figure 73).

Representing children, a 3 year old ATD (P3) was restrained in its own aircraft seat placement with a lap belt. This ATD registered an extremely high HIC score and high chest injury. The large head injury was a result of the ATDs head striking its own outstretched lower limbs (shins). This head strike probably stopped the head rotating far enough to strike the forward seat crossmember.

See Appendix A1.10 and A1.11 for detailed aspects of these tests.

3.1.6 Adults

Injury assessments to adults seated behind CRS were made for ISOfix, LATCH, and lap belt CRS restraint methods as well as for variations in adult size. Additionally, assessment of injury to adults nursing children was also carried out. For baseline data, an injury assessment for an adult with no CRS in front was conducted.

Injury to the adult ATD for the baseline test involving no child ATDs or CRS was in excess of limits for certification of an aircraft seat. This can be associated with the test being well in excess of the minimum test pulse. See the discussion in section 3.1.1. Head and chest accelerations, and neck injury were in excess of recognised limits.

Interestingly, for the Adult ATDs nursing lap held children, initial assessment of the results suggests injury levels lower than that for tests with no lap held child. For both cases, the HIC scores were extremely low, lower than for any other tests. This was the result of no head strike occurring on the seat in front. Although a head strike occurred with the child, the child's head had already struck the seat back initiating the seat back movement forward. Chest displacements were substantial, though with limits specified in automotive requirements[19]. However, the biofidelity of the Adult ATDs concerning forced inflexion over a lap-restrained body is questionable.

Adult injury levels where a CRS was mounted in front produced head injury scores above acceptable limits but not excessively above the baseline test. Chest accelerations were all acceptable, but, in all but one case neck injury exceeded FMVSS 208 limits. Whilst maximum Femur Compression were all well within aircraft seat certification limits, point loading by the Lower Anchorage bar may have exceeded the bending limit of typical occupant's upper tibia[8].

See Appendix A1.6 through A1.11 for detailed aspects of these tests.

3.1.7 Adult/CRS interaction

For cases where a CRS was installed in front of an adult, any real trend is limited by the minimal sample size. However, it could be concluded that for the child seated in a CRS, it is in fact advantageous to have an adult occupant seated behind. See section 3.2.2. No adult ATD applied sufficient loads to the CRS or Lower Anchorage to break any structure and all measures of child injury reduced with an adult seated behind when compared to no adult seated aft.

For Adults, the research shows mixed response to injury. Whilst head injury for the adult only baseline test was the lowest, this test also contained the worst neck and chest injury scores and the second worst peak femur loads. No trends could be associated with the CRS attachment method.

3.1.8 Lower Anchorage Design and Loads

The instrumented lower anchorage gave good results in terms of loads generated by a configuration that was considered conservative, i.e. the rigid, independently mounted anchorage would be the configuration most likely to generate the highest loads in the anchorage. Both the sled mounted and seat mounted lower anchorage designs performed well. The seat mounted lower anchorage bar distorted under loading from both the CRS and adult lower limb interaction but always retained its structural integrity.

3.2 Comparison of test configurations

3.2.1 Lower Anchorage Loads

3.2.1.1 CRS Attachment Method

The first four tests were designed to record loads generated in the Lower Anchors. For comparison, one test was also performed with the lap belt attachment method where the peak tension developed in the lap belt was measured. The following table lists the peak load (and angle of load from the horizontal) for each Child Restraint anchor and attachment method.

Lower Anchorage Loads

Orientation (ATD)	Attachment Method	CRS	Peak Anchor/belt tension Load [kN] and (peak load angle)	
			Left	Right
Rearward facing (P3/4)	ISOfix	Britax Cosy-Tot	3.76 (18º)	4.33 (18º)
	LATCH	IGC Gosafe	3.09 (20º)	3.20 (21º)
		Safe-n-Sound	3.57 (23º)	3.26 (25º)
		Britax Cosy-Tot	3.61 (21º)	3.24 (21º)
	Belt	Britax Cosy-Tot	*1.91**	
Forward Facing (P3)	ISOfix	Britax Duo Plus	4.92 (29º)	5.03 (25º)
	LATCH	IGC Gosafe	3.48 (29º)	4.16 (26º)
		Safe-n-Sound	3.92 (31º)	3.92 (31º)
		Britax Duo Plus	5.08 (30º)	4.91 (30º)
	Belt	Britax Duo Plus	6.45	

* The webbing transducer for this test could only be mounted between the guides of the capsule. This value is underexposed due to frictional losses through the guide.

The peak loads determined were as expected. The IGC Gosafe produced the smallest loads due to it being the lightest CRS. The forward facing configurations produced generally higher loads than rearward facing configuration due to the heavier ATD used. The angle of load was also higher for forward facing configurations than rearward facing due to the higher centre of gravity.

3.2.2 Child Injury

3.2.2.1 Head Injury

The P3/4 ATD was not instrumented, so head injury values could not be evaluated. However, based on previous testing, the inherently better orientation provided by capsules and rear facing restraints should have produced lower injury level when compared to forward facing restraints. Below is a table that compares P3 Head Injury Criterion (HIC) for various forward facing CRS, attachment methods, and Lower anchorage/rear occupancy configurations. Additionally, P1½ Supplementary Loop Belt configuration injury level is added for comparison.

<table>
<tr><th colspan="5">Head Injury Criterion</th></tr>
<tr><th rowspan="2">Orientation (ATD)</th><th rowspan="2">Attachment Method</th><th rowspan="2">CRS</th><th colspan="2">Seating configuration</th></tr>
<tr><th>Rigid Mount</th><th>Occupant behind</th></tr>
<tr><td rowspan="6">Forward Facing (P3)</td><td>ISOfix</td><td>Britax Duo Plus</td><td>528</td><td>344</td></tr>
<tr><td rowspan="3">LATCH</td><td>IGC Gosafe</td><td>1028</td><td>-</td></tr>
<tr><td>Safe-n-Sound</td><td>1269</td><td>339</td></tr>
<tr><td>Britax Duo Plus</td><td>557</td><td>230</td></tr>
<tr><td rowspan="2">Belt</td><td>Britax Duo Plus</td><td>475</td><td>261</td></tr>
<tr><td>Aircraft Seat</td><td>1601</td><td>-</td></tr>
<tr><td>Forward Facing (P1½)</td><td>Supplemental Loop Belt</td><td>Lap held</td><td>1078</td><td>-</td></tr>
</table>

Firstly, the IGC and Safe-n-Sound have higher HIC values because both CRS allowed the head to strike the ATD’s own femur/s. Secondly, the HIC values are lower when an adult occupant sits behind a CRS for equivalent configurations for two reasons. When occupants were sitting behind, the attachment for CRS was to the seat via a mild steel tube as compared to a very rigid attachment direct to the sled. This allowed extra displacement of the CRS in a controlled manner resulting in lower bodily peak accelerations. Additionally, the impact from behind of the rear adult occupant also pushed the CRS forward, again allowing deceleration of the child ATD over a greater distance resulting in lower deceleration values. The highest injury value recorded was for the child ATD seated in an aircraft seat restrained by a lap belt rather than in a CRS. Whilst the lap held P1½ ATD recorded a significant injury, this was not a true indicator of the total head injury. The true injury was due to the nursing adult’s head striking the back of the child’s head at the time nearing peak head acceleration for the child ATD as a result of the child hitting the seat back. This had the effect of reducing the HIC value but not necessarily the head injury. It is estimated that approximately 4.5kN of compressive force was momentarily applied to the Child ATD’s head generated between the Adult ATD’s head and the seat back/tray table. See Appendix A1.11 for more details.

A limited comparison of aft occupant size on the head injury of the child seated in front shows no perceptible trend.

Child Head Injury variation with aft Adult Occupant size					
Orientation (ATD)	Attachment Method	CRS	Aft Adult Occupant Size		
			5th percentile female	50th percentile male	95th percentile male
Forward Facing (P3)	ISOfix	Britax Duo Plus	374	344	365

3.2.2.2 Chest Injury

The chest injury values for forward facing ATDs were all acceptable. The P3/4 used in the rear facing restraints was not instrumented. The chest acceleration measured in the P1½ was the closest to recognised limits.

Chest Injury				
Orientation (ATD)	Attachment Method	CRS	Seating configuration	
			Rigid Mount	Occupant behind
Forward Facing (P3)	ISOfix	Britax Duo Plus	40.7g	40.9g
	LATCH	IGC Gosafe	39.6g	-
		Safe-n-Sound	39.8g	33.6g
		Britax Duo Plus	47.6g	32.9g
	Belt	Britax Duo Plus	43.5g	40.2g
		Aircraft Seat	48.7g	-
Forward Facing (P1½)	Supplemental Loop Belt	Lap held	57.2g	-

In line with the head injury data, there was an indication that chest injury was reduced if an adult occupant was seated behind.

Child Chest Injury variation with aft Adult Occupant size					
Orientation (ATD)	Attachment Method	CRS	Aft Adult Occupant Size		
			5th percentile female	50th percentile male	95th percentile male
Forward Facing (P3)	ISOfix	Britax Duo Plus	38.7g	40.9g	40.9g

No perceivable variations in chest injury were shown with varying aft occupant size.

3.2.2.3 CRS rotation and excursion

CRS rotation was determined from high-speed video capture and measured relative to the CRS angular position at the initial point of impact.

CRS Rotation				
Orientation (ATD)	Attachment Method	CRS	Seating configuration	
			Rigid Mount	Occupant behind
Forward Facing (P3)	ISOfix	Britax Duo Plus	20º	34º
	LATCH	IGC Gosafe	6º	-
		Safe-n-Sound	6º	N/A
		Britax Duo Plus	4º	15º
	Belt	Britax Duo Plus	7º	18º

The CRS when attached by ISOfix exhibited more rotation than LATCH or belt attached CRS by default of its system of attachment. As has been shown previously[1], the ISOfix system due to it rigid nature produced substantially lower CRS excursion. Rotation and excursion of Rear facing CRS were not able to be determined due to them always being positioned on the far side from the camera.

More rotation occurred for each comparable configuration test with an adult occupant seated behind. The head impact of the Adult ATD induced a further rotation in each case, often when the CRS was at the point of maximum displacement.

3.2.3 Adult Injury

3.2.3.1 Head Injury

Below is a comparison of head injury levels to Adult ATDs with variation in CRS model and attachment methods, as well as head injury measured with lap held infants.

Adult Head Injury Criterion, 50th percentile male ATD				
Orientation (ATD)	Attachment Method	CRS	HIC	Peak Head Acceleration*
Rearward facing (P3/4)	ISOfix	Britax Cosy-Tot	1513	112.6g (106.6g)
	Belt	Britax Cosy-Tot	1377	115.6g (95.3g)
Forward Facing (P3)	ISOfix	Britax Duo Plus	1651	122.6g (109.7g)
	LATCH	Safe-n-Sound	1468	151.5g (119.7g)
		Britax Duo Plus	2025	169.1g (135.0g)
	Belt	Britax Duo Plus	1714	142.4g (126.2g)
No CRS	-	-	1313	135.6g (109.5g)
		Supplemental Loop Belt (P3/4)	464	65.1g (62.3g)
		Supplemental Loop Belt (P1½)	711	110.2g (89.8g)

* The first number is peak recorded acceleration in g. Numbers in brackets are 3ms max values.

Mixed results make it hard to gauge a trend. No trends were identifiable between CRS attachment methods. It could be interpreted that there is a slight rise in adult head injury with a CRS mounted in front. The low Head Injury scores when lap holding a child restrained by Supplementary Loop Belt can be explained by the Adult not suffering a head strike on the seat in front due to the child ATD restricting upper torso and head flail.

Head Injury variation with Adult Occupant size					
Orientation (ATD)	Attachment Method	CRS	Aft Adult Occupant Size		
			5th percentile female	50th percentile male	95th percentile male
Forward Facing (P3)	ISOfix	Britax Duo Plus	1626	1651	3659
			148.6g (110.2g)	122.6g (109.7g)	189.6g (178.5g)

* The upper row is the Head Injury Criterion (HIC) score. In the lower row, first number is peak recorded acceleration in g, the numbers in brackets are 3ms max values.

Again, from the limited data it is hard to explain the variations in injury with occupant size.

3.2.3.2 Neck Injury

Neck Injury was determined using criteria and limit values from FMVSS 208.

Adult Chest Injury, 50th percentile male ATD			
Orientation (ATD)	Attachment Method	CRS	Nij
Rearward facing (P3/4)	ISOfix	Britax Cosy-Tot	1.07
	Belt	Britax Cosy-Tot	1.02
Forward Facing (P3)	ISOfix	Britax Duo Plus	1.44
	LATCH	Safe-n-Sound	0.76
		Britax Duo Plus	1.08
	Belt	Britax Duo Plus	1.21
No CRS	-	-	1.38
		Supplemental Loop Belt (P3/4)	0.87
		Supplemental Loop Belt (P1½)	1.21

A similar result occurred with Neck injury. It was hard to determine, from the limited results, any trends.

Neck Injury variation with Adult Occupant size					
Orientation (ATD)	Attachment Method	CRS	Aft Adult Occupant Size		
			5th percentile female	50th percentile male	95th percentile male
Forward Facing (P3)	ISOfix	Britax Duo Plus	0.58	1.44	1.42

3.2.3.3 Lower Limb Injury

All femur compression measured were within certification limits.

Femur Compression Loads, 50th percentile male ATD				
Orientation (ATD)	Attachment Method	CRS	Peak Femur Compression Load (kN)*	
			Left	Right
Rearward facing (P3/4)	ISOfix	Britax Cosy-Tot	2.45	3.37
	Belt	Britax Cosy-Tot	1.21*	2.12*
Forward Facing (P3)	ISOfix	Britax Duo Plus	1.89	2.30
	LATCH	Safe-n-Sound	1.49	2.25
		Britax Duo Plus	2.19	2.03
	Belt	Britax Duo Plus	1.71*	1.61*
No CRS	-	-	2.53*	3.24*
		Supplemental Loop Belt (P3/4)	1.57*	2.12*
		Supplemental Loop Belt (P1½)	2.20*	2.66*

* No Lower Anchorage Bar fitted.

Although some tests, from the Adult ATD perspective, were conducted with and without lower anchorage bars, there was no trend perceptible in the femur compression data.

Femur Compression variation with aft Adult Occupant size					
Orientation (ATD)	Attachment Method	CRS	Aft Adult Occupant Size		
			5th percentile female	50th percentile male	95th percentile male
Forward Facing (P3)	ISOfix	Britax Duo Plus	0.50, 0.52	1.89, 2.30	2.89, 3.35

Maximum allowable femur compression load for aviation certification is 1500lb_f (6.67 kN). Whilst femur compression is the only lower limb injury criteria measured in aviation certification, and other injury mechanisms were not measured, estimates indicate that Upper Tibia bending may have been around the levels of human tolerance for some cases.

3.3 Comparison of results to previous research

The results varied from the first phase of testing due to the different sled facilities used. The combination of a different sled action (deceleration type versus rebound type), different arresting systems, and different facilities (techniques, personnel) contributed to results that varied. However, some results and features were replicated in both series of testing.

Motion of the CRS and child ATDs for the replicated cases were very similar. In general, the measured injury levels were higher for this phase of testing but this can be attributed to the more severe test pulse applied, and for the ISOfix restraint the more rigid Lower Anchorage systems.

Motion and injury levels of the Adult ATDs were different for the comparative tests. Again, this testing resulted in more severe injury levels being recorded, but again, this can be associated with more severe test pulse. One feature, not seen during this testing was the very large head rotation. It is surmised that a different initial placement of the Adult ATD combined with different test pulse and CRS installation stiffness, led to a variation in results. That stated, the neck injury levels recorded during this phase of testing exceeded recognised levels[21].

Features that were replicated were in the CRS motion. The more flexible installation methods allowed the child’s feet to engage the seat in front driving the knees and femur up to meet the arcing head. In stiffer installations, this engagement was not featured, thus giving more room for head motions. Additionally, a feature highlighted by this phase of testing, but also seen in the first phase, was that child injury levels reduce if an adult is seated behind over those if no adult is seated behind. It would seem that the interaction of the adult occupant with the seat back and the subsequent ‘push’ on the CRS reduces the child injury levels.

4 Conclusions

The testing was successful in identifying features of various child restraint methods and their effects on the child as well as for an adult seated behind a CRS. This experience has led to conclusions being drawn about ways to reduce child injury in transport category aircraft and recommendations for their implementation.

Automotive CRS can provide good levels of protection for an infant or child in an accident situation and far superior levels of protection than those afforded children by contemporary transport category aircraft restraint methods. In most cases, CRS tested here provided superior levels of protection to that currently offered adults sitting in an aircraft seat restrained by a lap belt.

The testing was successful in measuring the loads generated in the Lower Anchorages. Heavier CRS tended to generate higher loads. The largest individual Lower Anchorage peak load measured was 5.08kN (1142 lb_f). Loop load in a similar CRS restrained by a lap belt was 6.45kN (1450 lb_f). Peak load angles were around 25º-30º above the horizontal. Loading angles for forward facing CRS were slightly higher than rearward facing CRS, which can be easily explained by their higher centre of gravity. In addition, forward facing CRS generated higher peak loads than rearward facing CRS due to their greater combined CRS and occupant mass. The anchorage load data should provide information for the generation of minimum design load standards for Lower Anchorages in aircraft seating.

All testing was conducted without anti-rotation devices. For the forward facing restraints tested, performance was deemed adequate without the use of a top tether. It must be highlighted though that only aft belt paths were used for webbing based attachment methods and that, based on automotive experience, an effective top tether attachment to the aircraft structure would improve the CRS performance in a severe deceleration. For general aviation aircraft, where typical severe crash decelerations are higher than transport category aircraft and of similar magnitude to motor vehicle decelerations, a top tether anchorage and top tether use is recommended.

For rear facing CRS, rotation did not seem to be a problem for the initial restraint of the CRS. However, rebound proved substantial for the capsule type restraint when not installed with a base plate. The anti-rebound bar was contained in the base plate. For both LATCH and lap belt attachment methods, the capsule type restraint suffered from severe rebound. The infant was only protected from a rebound impact by the carry handle placed in the upright position.

The excursion of the LATCH restrained CRS was less than for lap belt restrained CRS principally because the lower anchorage is further aft than the lap belt attachment. Obviously, excursion of the ISOfix restraint system was less again, but this did not necessarily result in the lowest injury levels to the child. Some excursion by the CRS is clearly valuable in reducing the acceleration levels subjected to the child, i.e. stopping over a longer distance means lower deceleration values. The limit to this concept is that the excursion of the CRS must be controlled, and the CRS or its occupant cannot be allowed to engage surrounding structures.

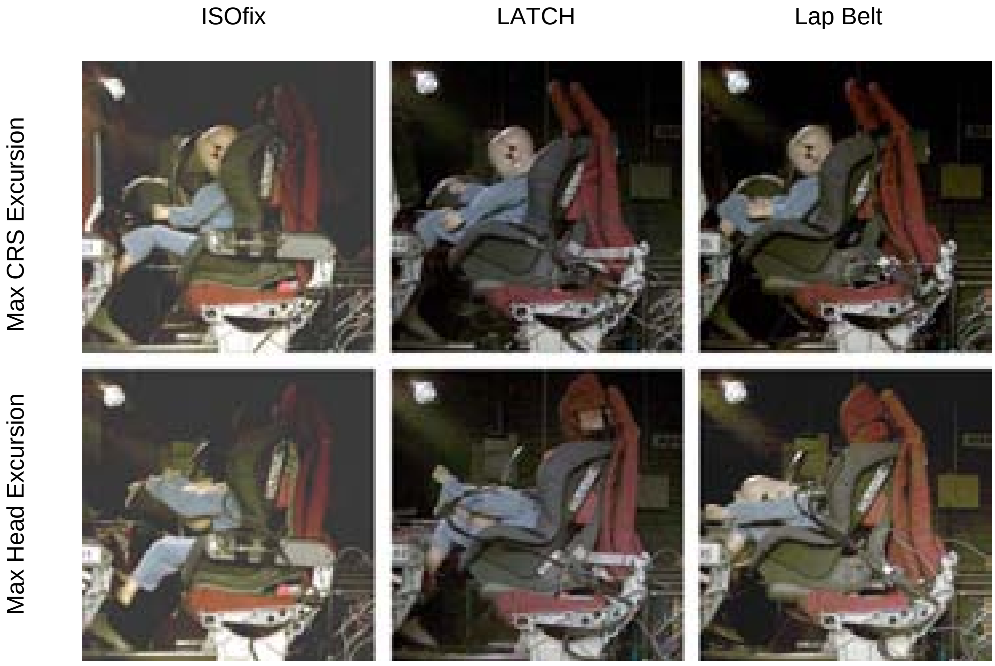

Figure 10 - Maximum CRS and Head excursions/impacts for the same CRS attached by ISOfix, LATCH and Lap belt methods respectively

Probably the most interesting property to be highlighted by this research is that for an infant or child in a CRS, their overall injury levels reduced if an adult sat behind them. For all except one injury measure for one case, the equivalent injury score measured with a rear adult occupant was reduced by between 8.5% and 73%. Part of this phenomena can be associated with the more flexible attachment method used (in-seat Lower Anchorage) when testing with aft adult occupants. However, it would also seem the impact from behind by the adult striking the seat back, both via knees/shins on the Lower Anchorage and head on the seat back, would push the CRS forward around the time peak accelerations were developing in the child leading to reduced injury levels.

This would seem to imply that adult injury should increase if sat behind a CRS. The research showed a mixed result, principally due to the limited number of cases tested. Whilst Head injury increased by between 5% and 54% for equivalent configurations, neck and femur injury in general showed a reduction in injury. However, one would anticipate that as the head of the adult occupant is imparting the energy to the seat back and the CRS, this is a truer measure of the overall injury changing effect. With the limited number of tests conducted, this aspect needs more assessment.

Whilst adult head injury may increase slightly with a CRS mounted to the seat in front, neck injury was shown to be high and beyond recognised limits for virtually all cases. Being designed for injury measurement associated with airbags in cars, whether the limits defined by FMVSS 208 are appropriate is beyond the scope of this research. However, it has highlighted that maybe neck injury needs to be assessed with the installation of child restraint systems.

Additionally, whilst femur loads were all well below limits required for aircraft seat certification, loads measured and video evidence suggest that Tibia fore/aft bending moments may be generated in excess of tolerable limits by structures that may be needed for Lower Anchorages.

For the 3 year old ATD seated in its own seat in an unbraced position, head injury was excessive, even higher than the baseline adult test. The lap belt did stay on the pelvis but this was with the ATD positioned in an upright, straight-legged posture. In reality, this seating position is uncomfortable for a person of any age and in practice leads to slumping where submarining may become an issue.

For the Supplementary loop belt, most of the applicable injury mechanisms could not be measured. When crushing forces are applied, head compression, chest deflection, and abdominal compression are measures that would be useful in assessing injury. However, these measures are not available for child ATDs. Injury mechanisms available, such as head acceleration, and neck force and moments, indicate that excessive head and neck trauma may have occurred. Chest injury was also high. However, video evidence subjectively indicates a far worse injury score than that given by conventional measures. The video shows severe interactions, particularly crushing injuries, between the child, seat back, and adult, who weighs 7 times more than the 18 month old child.

Figure 11 - Adult and 18 month old Infant Interaction

Figure 12 - Adult and 9 month old Infant interaction

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. Anti-rotation devices do not seem to be required for most CRS, though anti-rebound devices are recommended for rearward facing CRS.

4. Advisory material should be written containing technical guidelines regarding modifications to aircraft interiors with respect to lower anchorages and top tethers. Particularly this advisory material should detail minimum strength, deformation, and configurations requirements.

5. In the interests of infant and child safety in aircraft, CASA would encourage the revision of Australian Standard AS/NZS 1754 to require ISOfix and/or LATCH attachment methods for all future child restraints in Australia. Additionally, it is recommended AS/NZS 1754 include an optional aviation component defining dimensional, seat attachment, and accident performance criteria.

6. Further research should investigate:

    a. Whether there is the potential for neck injury to exceed recognised limits in adults seated behind CRS and whether they are worse than for current aircraft seat certification.

    b. Whether there is the potential for tibia bending fractures in adults seated behind Lower Anchorage installations.

    c. Effects of seat pitch, CRS installation stiffness, occupant size, and seat structural variations on CRS performance and occupant injury levels, especially in adults seated behind, should be investigated for standards development knowledge.

7. 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)*
HIC	Head Injury Criterion
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. 09/01

Autoliv Test No.: D1-3225

Test Purpose: To assess the dynamic performance of automotive ISOfix type child restraints in an airline seat modified with Lower Anchorages and to gather data on loads generated in the Lower Anchorages. This is a similar test to CASA 06/01 to give a baseline for the different sled facility being used and more rigid sled mounted Lower Anchorage modification.

Test configuration: Two ECE-R44 ISOfix child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat. They were attached to an instrumented, sled mounted, Lower Anchorage structure attached directly to the test sled frame, positioned behind the seat protruding through the seat bite in a position representative of where seat mounted Lower Anchorages would be. The ISOfix child restraints were installed in accordance with the manufacturer's instructions with the ISOfix attachment method. 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 removed. 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: The required test pulse was exceeded. A peak acceleration of 21.1g @ 62ms 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 Forward Rotation†	Peak Lower Anchorage Loads (L, R)
Britax Cosy-Tot (RF) – P3/4	-	-	-	-	3.76 kN 4.33 kN
Britax Duo Plus (FF) – P3	89.3g (68.9g)	528	45.7g (40.7g)	20º	4.92 kN 5.03 kN

* 3ms clip values included in brackets.

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

Description of results:

Britax Cosy-Tot ISOfix (RF) – P3/4: Movement and rotation of the CRS was minimal and rebound was well controlled. The ATD did not protrude past the leading edge of the CRS at any time.

Britax Duo Plus ISOfix (FF) – P3: The ATD was well restrained. No head or knee contact occurred and only foot contact with the seat back pocket. 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. Rebound motion of the CRS was minimal.

Lower Anchorage – No deformation was observed in the Lower Anchorage bars.

Figure 13 - Configuration tested - ISOfix

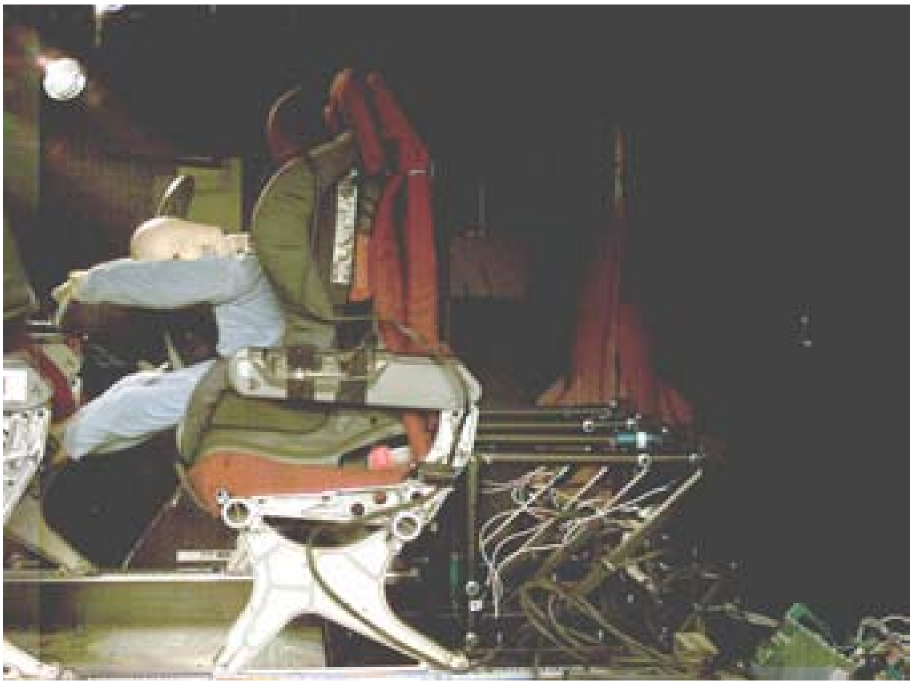

Figure 14 – Point of Maximum head extension (Duo Plus) @ 90ms

Figure 15 - Post Test

Figure 16 – Post Test

A1.2 CASA Test No. 09/02

Autoliv Test No.: D1-3226

Test Purpose: To assess the dynamic performance of automotive LATCH type child restraints in an airline seat modified with Lower Anchorages and to gather data on loads generated in the Lower Anchorages.

Test configuration: Two copies of an AS/NZS 1754 child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat. They were attached to an instrumented, sled mounted, Lower Anchorage structure attached directly to the test sled frame, positioned behind the seat protruding through the seat bite in a position representative of where seat mounted Lower Anchorages would be. The child restraints were installed with loose LATCH straps routed, for the forward facing CRS through the alternate belt path, and for the rearward facing CRS through the standard belt path. The forward facing restraint was adjusted to the recline position because it would not stay in the upright position when the LATCH Strap was tensioned. The top tether straps were not used and were securely tied away. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: IGC Gosafe 'Boulevard' Convertible restraint, rearward facing mode for 0kg – 9kg children.

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

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

TNO P3 child ATD (15kg) – Forward Facing

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: The required test pulse was exceeded. A peak acceleration of 20.9g @ 52ms 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 Forward Rotation†	Peak Lower Anchorage Loads (L, R)
IGC Gosafe (RF) – P3/4	-	-	-	-	3.08 kN 3.20 kN
IGC Gosafe (FF) – P3	138.6g (104.5g)	1028	42.7g (39.6g)	6º	3.48 kN 4.16 kN

* 3ms clip values included in brackets.

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

Description of results: IGC Gosafe (RF) – P3/4: There was minimal movement and rotation of the CRS and rebound was controlled. The ATD head protruded minimally past the leading edge of the CRS at the point of maximum excursion.

IGC Gosafe (FF) – P3: Whilst the CRS did translate, it did not travel far enough to fall or pivot off the seat base with the LATCH attachment method. Additionally there is very little rotation, during both translation and rebound. However, due to the distance travelled by the CRS on the seat base, engagement of the ATDs feet into the seat in front allowed the knees to ride up into the ATD head arc, resulting in a head strike.

Lower Anchorage – No deformation was observed in the Lower Anchorage bars.

Figure 17 - Configuration tested - LATCH

Figure 18 - Configuration tested - LATCH

Figure 19 - LATCH configuration for forward facing CRS

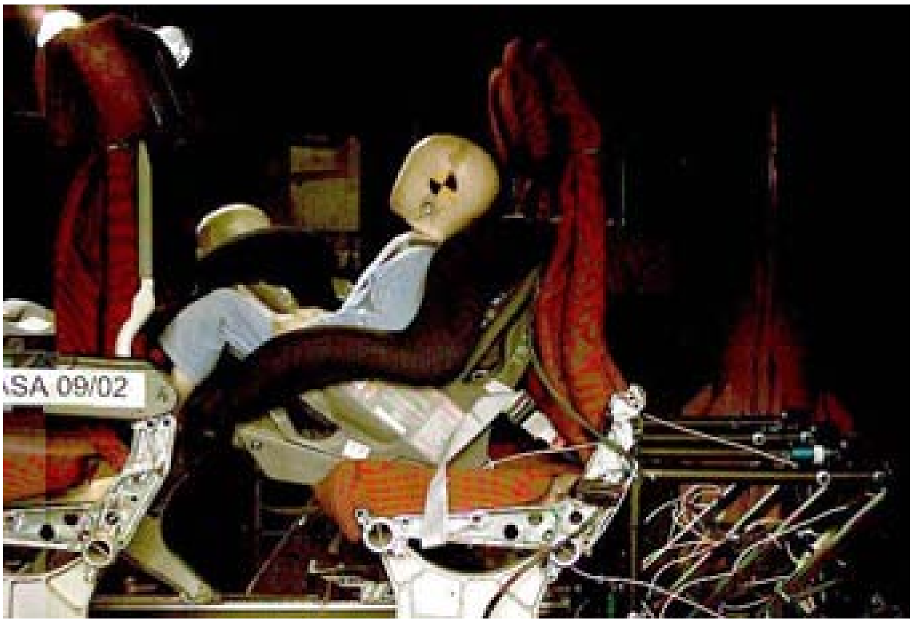

Figure 20 – P3 Foot engagement @ 60 ms - Note high knee position due to reclined CRS

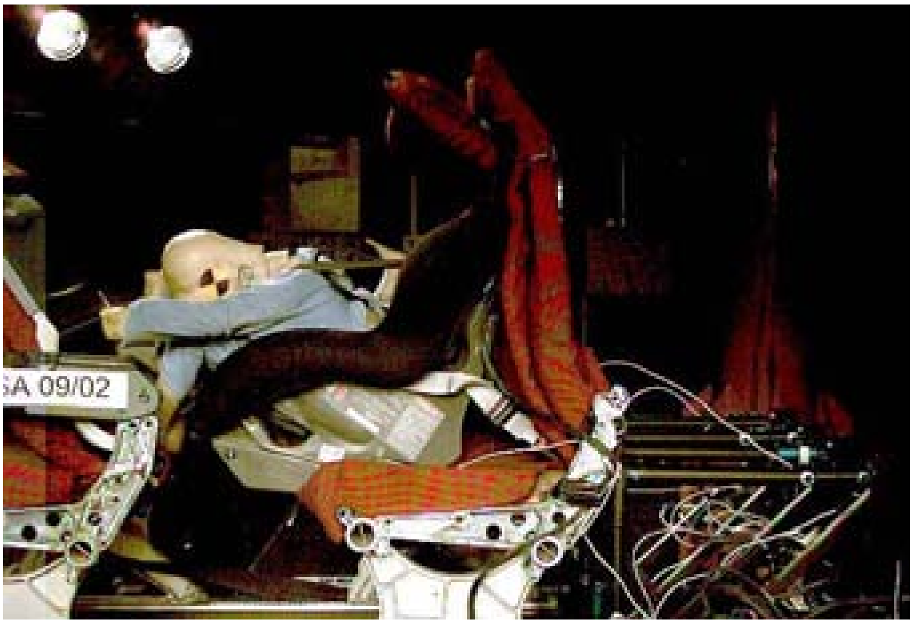

Figure 21 - P3 Maximum Head Excursion and Head strike on knees @ 103ms

Figure 22 - Post Test, note CRS rotation and bunching of LATCH strap

A1.3 CASA Test No. 09/03

Autoliv Test No.: D1-3227

Test Purpose: To assess the dynamic performance of automotive LATCH type child restraints in an airline seat modified with Lower Anchorages and to gather data on loads generated in the Lower Anchorages.

Test configuration: Two copies of an AS/NZS 1754 child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat. They were attached to an instrumented, sled mounted, Lower Anchorage structure attached directly to the test sled frame, positioned behind the seat protruding through the seat bite in a position representative of where seat mounted Lower Anchorages would be. The child restraints were installed with loose LATCH straps routed through the belt path. The forward facing restraint was adjusted to the upright position. The top tether straps were not used and were securely tied away. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: Safe-n-Sound 7000 Series Convertible restraint, rearward facing mode for 0kg – 12kg children.

Safe-n-Sound 7000 Series Convertible restraint, forward facing mode for 9kg – 18kg children.

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

TNO P3 child ATD (15kg) – Forward Facing

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: The required test pulse was exceeded. A peak acceleration of 21.1g @ 58ms 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 Forward Rotation†	Peak Lower Anchorage Loads (L, R)
Safe-n-Sound (RF) – P3/4	-	-	-	-	3.57 kN 3.26 kN
Safe-n-Sound (FF) – P3	132.6g (88.3g)	1269	47.8g (39.8g)	6º	3.92 kN 3.92 kN

* 3ms clip values included in brackets.

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

Description of results: Safe-n-Sound (RF) – P3/4: There was minimal movement and rotation of the CRS and rebound was well controlled. The ATD head did not protruded past the leading edge of the CRS at any time.

Safe-n-Sound (FF) – P3: Whilst the CRS did translate, it did not travel far enough to fall or pivot off the seat base with the LATCH attachment method. Additionally, there was very little rotation during the translation but rebounded substantially. The base of the CRS showed signs of stress due to bending loads over the seat forward cross tube. Again, due to the distance travelled by the CRS on the seat base, engagement of the ATDs feet in the seat back in front caused a head strike at 107 ms. This head strike was on the femur due to the knees being maintained in place rather than rising to meet the head in the case of the IGC Gosafe CRS. This can probably be attributed to the Safe-n-sound being tested in the upright position compared to the IGC Gosafe's reclined position.

Lower Anchorage – No deformation was observed in the Lower Anchorage bars.

Figure 23- Configuration tested - LATCH

Figure 24- Configuration tested - LATCH

Figure 25 - LATCH configuration for forward facing CRS

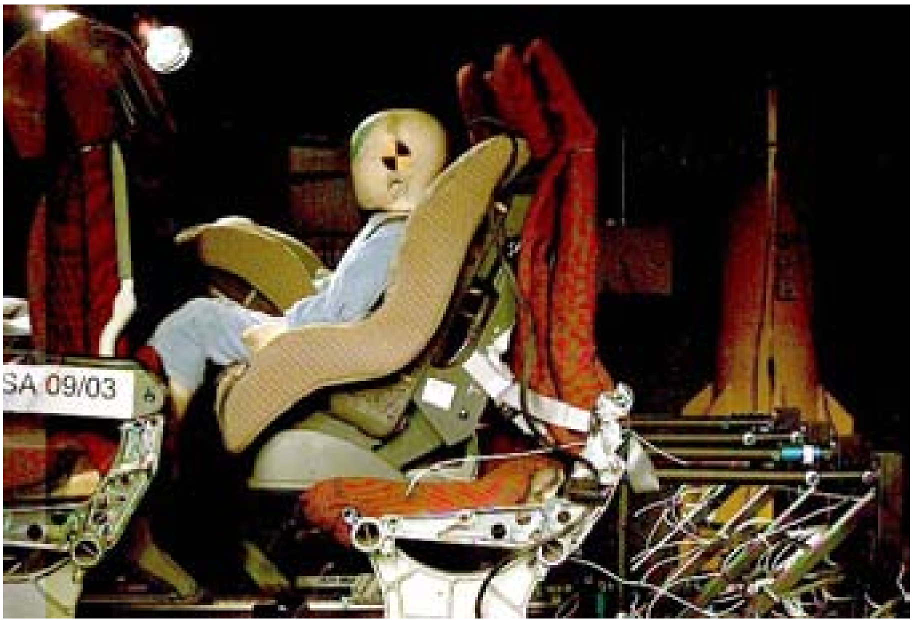

Figure 26 - P3 Foot engagement @ 60 ms

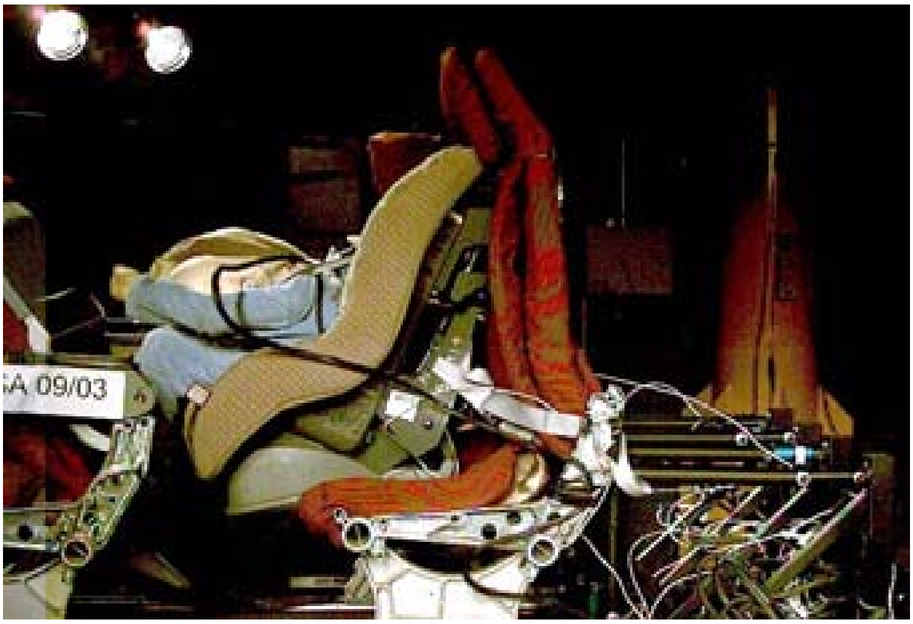

Figure 27 - P3 Maximum Head Excursion and Head strike on thighs @ 107ms

Figure 28 - Post Test, note CRS rotation

A1.4 CASA Test No. 09/04

Autoliv Test No.: D1-3229

Test Purpose: To assess the dynamic performance of automotive LATCH type child restraints in an airline seat modified with Lower Anchorages and to gather data on loads generated in the Lower Anchorages.

Test configuration: Two ECE-R44 child restraints, one forward facing and one rearward facing capsule, mounted onto an aviation airline economy class passenger seat. They were attached to an instrumented, sled mounted, Lower Anchorage structure attached directly to the test sled frame, positioned behind the seat protruding through the seat bite in a position representative of where seat mounted Lower Anchorages would be. The child restraints were installed with loose LATCH straps routed through the belt path. The forward facing restraint was adjusted to the upright position. The rear facing capsule was installed without the separate base plate. The top tether straps were not installed. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: Britax ‘Cosy-Tot’ rearward facing restraint for Birth – 13kg children. Note: the Britax ISOfix base was not used.

Britax ‘Duo Plus’ forward facing restraint for 9kg – 18kg children.

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

TNO P3 child ATD (15kg) – Forward Facing

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: The required test pulse was not quite met. A peak acceleration of 21.4g @ 59ms achieving a total velocity change of 43.9 ft/s (48.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS Forward Rotation†	Peak Lower Anchorage Loads (L, R)
Britax Cosy-Tot (RF) – P3/4	-	-	-	-	3.61 kN 3.24 kN
Britax Duo Plus (FF) – P3	64.6g (60.4g)	557	87.1g (47.6g)	4º	5.08 kN 4.91 kN

* 3ms clip values included in brackets.

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

Description of results: Britax Cosy-Tot (RF) – P3/4: There was a small installation issue in that the latch strap adjusters positioned themselves underneath the belt guide when tensioned. This was only a minor inconvenience and did not affect release of the CRS after the test. During the test, there was minimal movement and rotation of the CRS but the rebound was excessive and only protected the infant ATD because the carry handle was set vertically relative to the capsule. The ATDs head did not protrude past the leading edge of the CRS during the impact phase but did extend to make contact with the seat back during the rebound. This was due to the capsule not being installed with the base plate which contained an anti-rebound bar. The capsule was mounted in accordance with the installation instruction for aircraft installation of the USA version of the CRS with the exception that it was installed using a loose LATCH strap instead of the aircraft lap belt.

Britax 'Duo-Plus (FF) – P3: With the LATCH attachment method, whilst the CRS does translate, it remained well placed on the aircraft seat throughout the impact. This smaller translation when compared to other LATCH installed CRS still allowed feet engagement into the seat in front resulting in a head strike on the femur. Additionally there is very little rotation during translation but during the rebound rotated and resulted in a significant head strike near the top edge of the CRS.

Lower Anchorage – The Lower Anchorage loops were bent upwards at 8º and 12º.

Figure 29 - Configuration tested - LATCH

Figure 30- LATCH configuration for forward facing CRS

Figure 31- LATCH configuration for rearward facing CRS - Note adjuster positioned under guide

Figure 32 - P3 Maximum Head Excursion and Head strike on thighs @ 107ms

Figure 33 - P3 2nd Head strike on headrest @ 273ms

Figure 34 - P3/4 Head strike on seat back @ 267ms

Figure 35 - Post Test - note CRS rotation

Figure 36 - Lower Anchorage post-test - Note upward bend to the 6mm loop

A1.5 CASA Test No. 09/05

Autoliv Test No.: D1-3230

Test Purpose: To assess the dynamic performance of automotive conventional child restraints in an airline seat using aircraft lap belts for restraint.

Test configuration: Two ECE-R44 child restraints, one forward facing and one rearward facing capsule, mounted onto an aviation airline economy class passenger seat. They were attached to the aircraft seat via the seat's lap belt in a conventional manner. The lap belt was instrumented with a webbing transducer. The forward facing restraint was adjusted to the upright position. The rearward facing restraint was not installed with the base plate. The top tether straps were not installed. Another airline economy class passenger seat was mounted in front at 30 inches pitch.

Child Restraints: Britax 'Cosy-Tot' rearward facing restraint for Birth – 13kg children. Note: the Britax ISOfix base was not used.

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

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

TNO P3 child ATD (15kg) – Forward Facing

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: The required test pulse was not quite met. A peak acceleration of 21.1g @ 58ms achieving a total velocity change of 43.9 ft/s (48.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Max. CRS Forward Rotation[†]	Peak Lower Anchorage Loads (L, R)
Britax Cosy-Tot (RF) – P3/4	-	-	-	-	1.91 kN
Britax Duo Plus (FF) – P3	74.5g (67.9g)	475	44.1g (43.5g)	7º	6.45 kN

* 3ms clip values included in brackets.

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

Description of results: Britax Cosy-Tot (RF) – P3/4: There was minimal movement and rotation of the CRS but the rebound was excessive and similar in performance to the same CRS installed with the LATCH method. The infant ATD was protected because the carry handle was set vertically relative to the capsule. The capsule was seen to (elastically) deform visibly at the point of (rebound) impact. The ATDs head did not protrude past the leading edge of the CRS during the impact phase but did extend to make contact with the seat back during the rebound. This was due to the capsule not being installed with the base plate which contained an anti rebound bar. The capsule was mounted in accordance with the installation instruction for aircraft installation of the USA version of the CRS.

Britax 'Duo-Plus (FF) – P3: With the lap belt attachment method, whilst the CRS does translate, it remained placed on the aircraft seat throughout the impact. The feet engaged into the seat in front resulting in a head strike on the femur. Additionally there is very little rotation during translation but during the rebound rotated slightly and resulted in a not insignificant head strike near the top edge of the CRS.

Seat Belts – No damage was observed to the aircraft Seat Belts.

Figure 37 - Configuration tested - Lap Belt

Figure 38- Lap Belt configuration for forward facing CRS

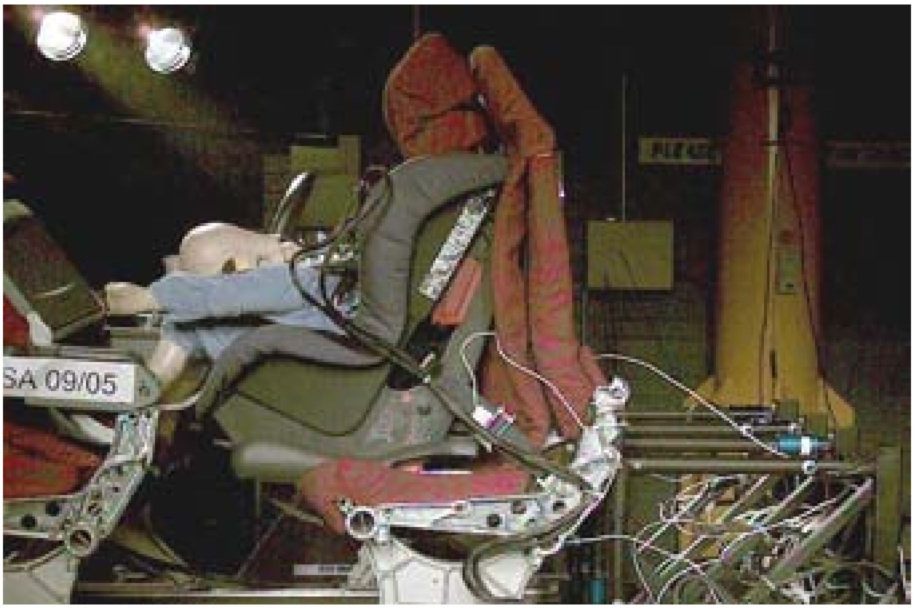

Figure 39 - P3 Maximum Head Excursion and Head strike on thighs @ 107ms

Figure 40 - P3 2nd Head strike on headrest @ 289ms

Figure 41 - P3/4 Head strike on seat back @ 333ms

Figure 42 - Post Test - note CRS rotation

A1.6 CASA Test No. 09/06

Autoliv Test No.: D1-3231

Test Purpose: To assess the injury levels to occupants when an adult is seated behind an automotive ISOfix type child restraint in an airline seat modified with Lower Anchorages. This is a similar test to CASA 06/02 to give a baseline for the different sled facility being used and more rigid sled mounted Lower Anchorage modification.

Test configuration: Two ECE-R44 ISOfix child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat. They were attached to Lower Anchorage structure attached to the airline seat. The ISOfix child restraints were installed in accordance with the manufacturer's instructions with the ISOfix attachment method. 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 removed. A second row of airline economy class passenger seating was mounted behind at 30 inches pitch and sat two Hybrid III 50% Male 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: The required test pulse was not quite met. A peak acceleration of 21.8g @ 43ms achieving a total velocity change of 43.9 ft/s (48.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. CRS Forward Rotation†	Max. Chest Acceleration*	Max Femur Compression	Neck Injury
Britax Cosy-Tot (RF) – P3/4	-	-	-	-	-	
Adult ATD (seated behind 'Cosy-Tot')	112.6g (106.6g)	1513	-	-	2.45, 3.37 kN (550, 758 lb_f)	1.07
Britax Duo Plus (FF) – P3	49.8g (46.0g)	344	34º	53.9g (40.9g)	-	
Adult ATD (seated behind 'Duo Plus')	122.6g (109.7g)	1651	-	-	1.89, 2.30 kN (425, 517 lb_f)	1.44

* 3ms clip values included in brackets.

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

Description of results:

Britax Cosy-Tot ISOfix (RF) – P3/4: The ATD was ejected from the CRS. At approximately 25ms, the harness tangs were seen to pull from the buckle. There was no damage to the CRS harness or buckle. Pre test photographic evidence suggests the buckle release was accidently activated at some point in the installation process and not noticed. The CRS remained attached to the Lower Anchorage and aircraft seat.

Adult ATD (RHS, seated behind 'Cosy-Tot): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. The severe neck rotation seen in other testing was not repeated for this case[1]. Femur compression was well within limits despite the lower legs inflicting severe bending loads on the Lower Anchorage structure and leaving witness marks on the seat rear crossmember. Seat back breakover was only slightly reduced. Neck injury exceeded recognised limits slightly.

Britax Duo Plus ISOfix (FF) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled with very similar motion to Test 09/01.

Adult ATD (LHS, seated behind 'Duo-Plus'): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. The severe neck rotation seen in other testing was not repeated for this case, but did exceed recognised limits[1]. Femur compression was well within limits despite the lower legs inflicting severe bending loads on the Lower Anchorage structure and leaving one witness mark on the seat rear crossmember. Seat back breakover was greatly reduced, being restricted to a forward rotation of approximately 12º forward of vertical. This caused the ATD to impact the tray table much higher than that for the ATD on the RHS. See Figure 46 and Figure 48

Lower Anchorage – The tube structure mounted across the back of the aircraft seat spreaders was deformed in a W pattern consistent with pressure applied from behind by the lower legs of the Adult ATDs. However, there were indications that the crossmember also yielded due to loads developed from the CRS. No deformation was observed in the Lower Anchorage 6mm bar loops.

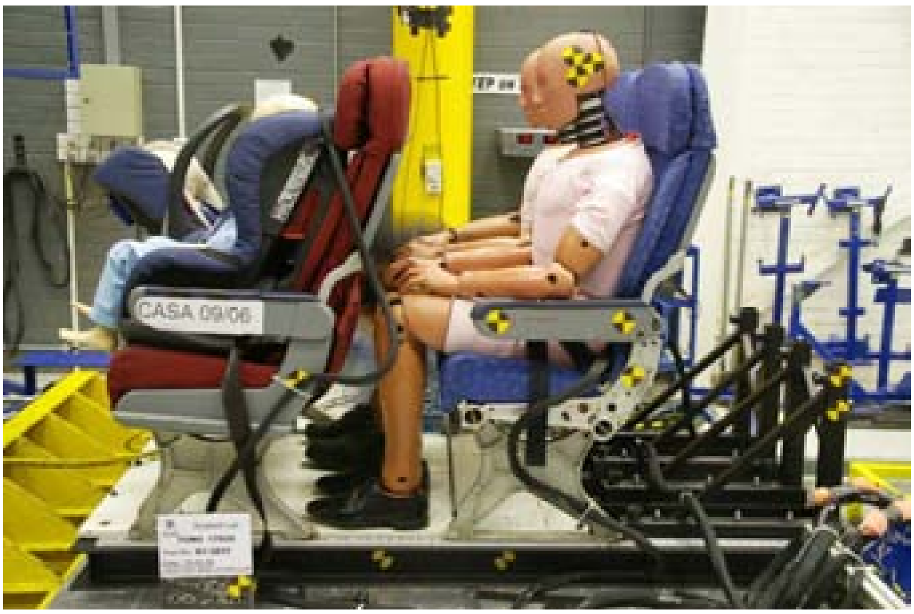

Figure 43 - Configuration tested - ISOfix with 50th percentile rear occupants

Figure 44 - Configuration tested - ISOfix with 50th percentile rear occupants

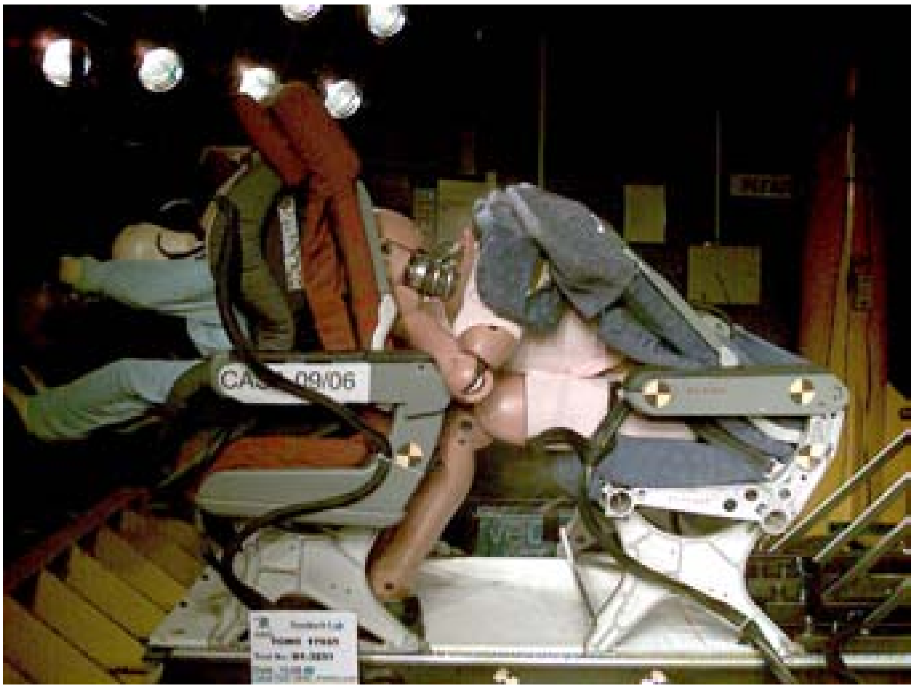

Figure 45 - Maximum seat back breakover @ 103ms

Figure 46 - Comparative head impact placement on seat backs due to ISOfix CRS

Figure 47 - Post Test - Note ejected infant ATD has been moved

Figure 48 - Seat back damage - LHS tray table, RHS tray table, LHS Adult ATD head witness mark - Note the different vertical placement of witness marks on tray tables.

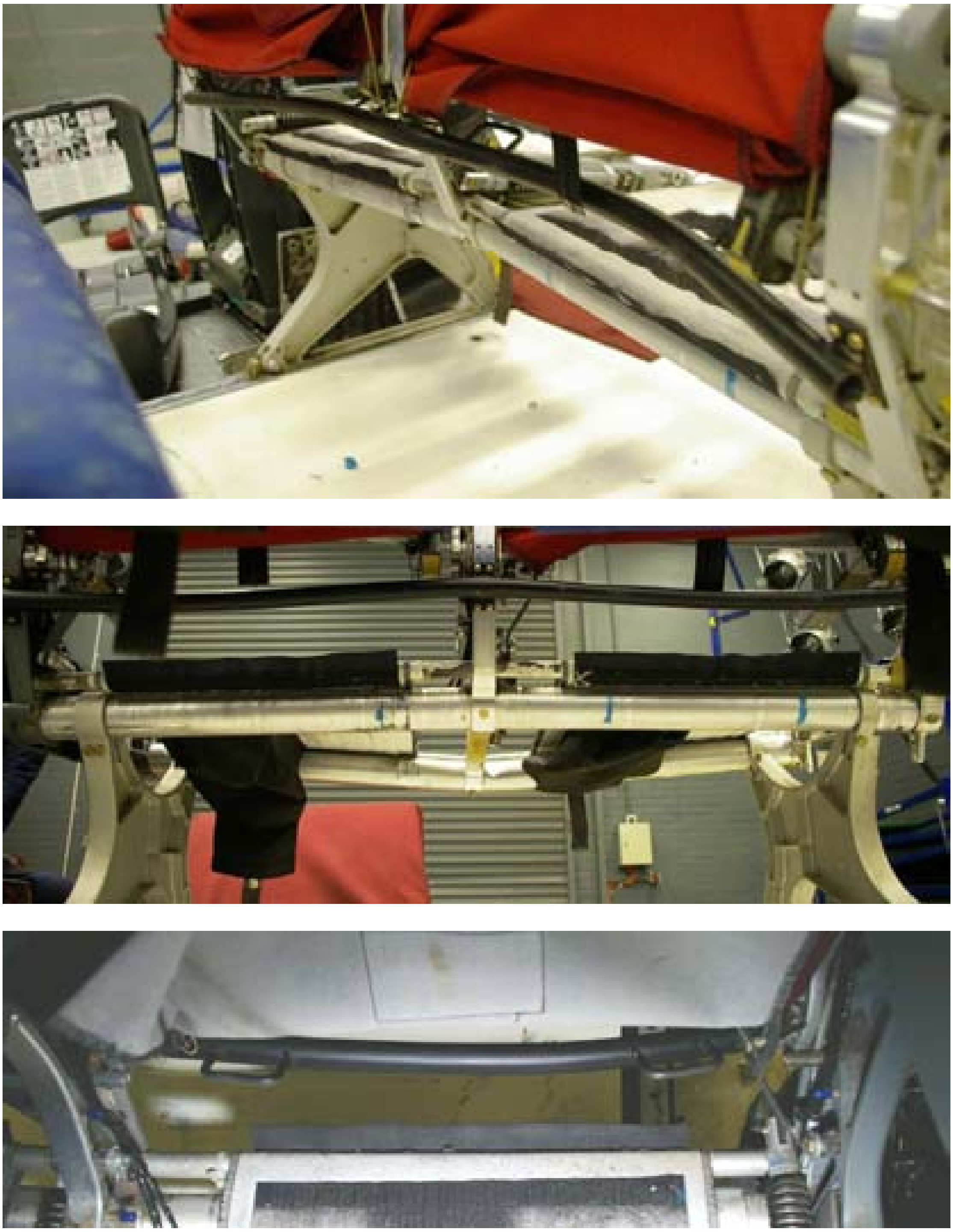

Figure 49 - Lower Anchorage deformation

A1.7 CASA Test No. 09/07

Autoliv Test No.: D1-3234

Test Purpose: To assess the injury levels to occupants when an adult is seated behind an automotive ISOfix type child restraint in an airline seat modified with Lower Anchorages. This test is designed to assess injury variation with rear occupant size.

Test configuration: Two ECE-R44 ISOfix child restraints, both forward facing mounted onto an aviation airline economy class passenger seat. They were attached to Lower Anchorage structure attached to the airline seat. The ISOfix child restraints were installed in accordance with the manufacturer's instructions with the ISOfix attachment method. The restraints were adjusted to the upright position. The optional top tether strap was not installed. A second row of airline economy class passenger seating was mounted behind at 30 inches pitch and sat one Hybrid III 5% Female ATD and one Hybrid III 95% Male ATD.

Child Restraints: 2 x Britax 'Duo-Plus' ISOfix forward facing restraint for 9kg – 18kg children.

ATDs: 2 x TNO P3 child ATD (15kg) – Britax 'Duo-Plus' ISOfix.

Hybrid III 5^{th} percentile female ATD.

Hybrid III 95^{th} percentile male ATD.

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: The required test pulse was exceeded. A peak acceleration of 21.3g @ 42ms achieving a total velocity change of 44.4 ft/s (48.7 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. CRS Forward Rotation†	Max. Chest Acceleration*	Max Femur Compression	Neck Injury
Britax Duo Plus (FF) – P3	66.4g (55.9g)	365	-	42.7g (40.9g)	-	
95% Adult ATD (seated behind right 'Duo Plus')	189.6g (178.5g)	3659	-	-	2.89, 3.35 kN (649, 752 lb_f)	1.42
Britax Duo Plus (FF) – P3	54.2g (52.3g)	374	9º	43.4g (38.7g)	-	
5% Adult ATD (seated behind left 'Duo Plus')	148.6g (110.2g)	1626	-	-	0.50, 0.52 kN (113, 117 lb_f)	0.58

* 3ms clip values included in brackets.

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

Description of results: Britax Duo Plus ISOfix (FF) (RHS) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled with very similar motion to Test 09/01. One ISOfix link was slightly bent due to the distortion of the Lower Anchorage.

Adult 95% Male ATD (RHS, seated behind 'Duo-Plus'): The ATD remained restrained but suffered a high HIC score that exceeded normal limits by a very large margin. Femur compression was well within limits despite the lower legs inflicting severe bending loads on the Lower Anchorage structure and leaving one witness mark on the seat rear crossmember. Seat back breakover was greatly reduced, being restricted to a forward rotation of approximately 12º forward of vertical.

Britax Duo Plus ISOfix (FF) (LHS) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled with very similar motion to Test 09/01.

Adult 5% female ATD (LHS, seated behind 'Duo-Plus'): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. The femurs were mostly in tension with a small momentary compression when the lower leg glanced the seat aft crossmember. Seat back breakover was greatly reduced, being restricted to a forward rotation of approximately 12º forward of vertical.

Lower Anchorage – The tube structure mounted across the back of the aircraft seat spreaders was deformed in a W pattern. As the 5th percentile female did not make contact with the Lower Anchorage, some bending was induced by the CRS itself. No deformation was observed in the Lower Anchorage 6mm bar loops.

Figure 50 - Configuration tested - ISOfix with 5th percentile female and 95th percentile male rear occupants

Figure 51 - Configuration tested - ISOfix with 5th percentile female and 95th percentile male rear occupants

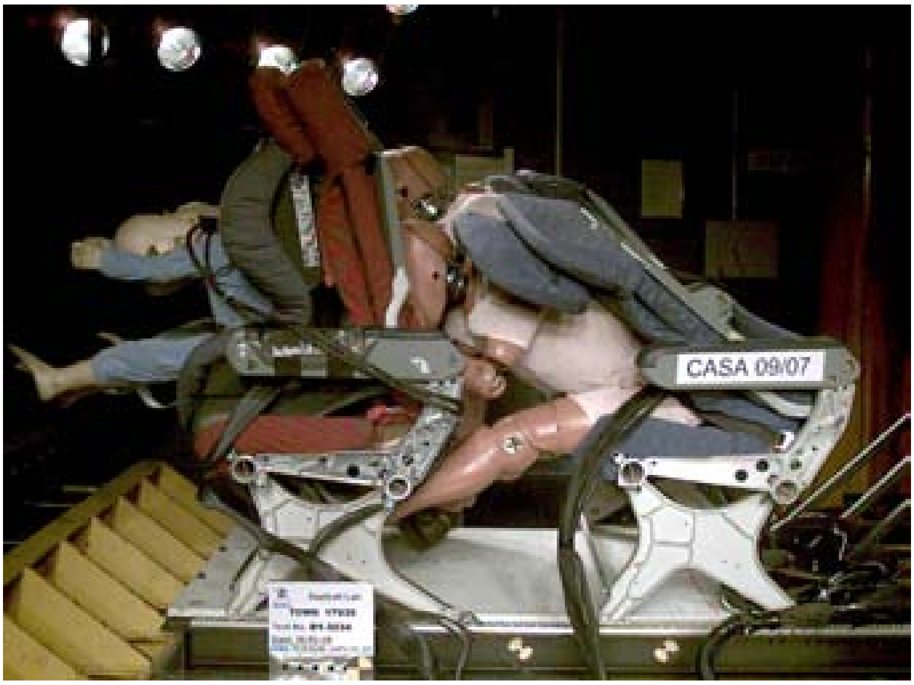

Figure 52 - Maximum seat back breakover @ 101ms

Figure 53 - Relative head strike placements @ 105ms

Figure 54 - Post Test

Figure 55 - Relative head strike placement

Figure 56 - RHS Lower Anchorage

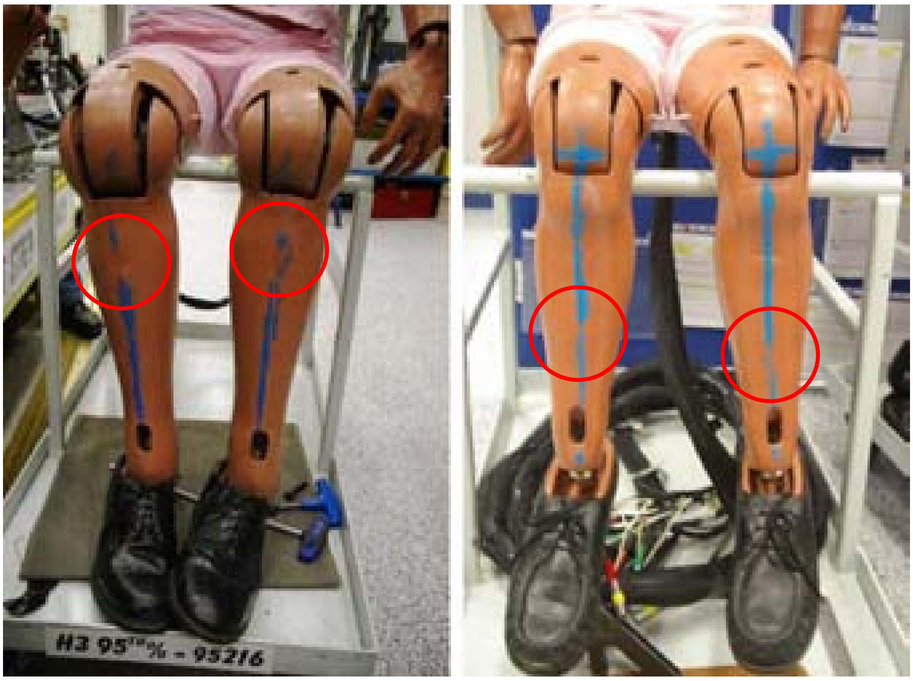

Figure 57 - Lower Leg witness marks from Lower Anchorage, 95% male | 5% female

Figure 58 - Post test - Bent ISOfix link of the CRS mounted in front of the 95^{th}% male

A1.8 CASA Test No. 09/08

Autoliv Test No.: D1-3232

Test Purpose: To assess the injury levels to occupants when an adult is seated behind an automotive child restraint in an airline seat. This is a similar test to CASA 09/06 but the CRS are installed using aircraft Lap Belts.

Test configuration: Two ECE-R44 child restraints, one forward facing and one rearward facing, mounted onto an aviation airline economy class passenger seat. They were attached using the airline seat lap belt. The child restraints were installed in accordance with the manufacturer's instructions with the lap belt attachment method. The forward facing restraint was adjusted to the upright position. The optional top tether strap was not installed. The rear facing capsule was installed without the separate base plate. A second row of airline economy class passenger seating was mounted behind at 30 inches pitch and sat two Hybrid III 50% Male ATDs seated.

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 (50^{th} 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: The required test pulse was not quite met. A peak acceleration of 21.5g @ 43ms achieving a total velocity change of 43.9 ft/s (48.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. CRS Forward Rotation†	Max. Chest Acceleration*	Max Femur Compression	Neck Injury
Britax Cosy-Tot (RF) – P3/4	-	-	-	-	-	-
Adult ATD (seated behind 'Cosy-Tot')	115.6g (95.3g)	1377	-	-	1.21, 2.12 kN (271, 476 lb_f)	1.02
Britax Duo Plus (FF) – P3	53.2g (50.8g)	261	18º	47.6g (40.2g)	-	-
Adult ATD (seated behind 'Duo Plus')	142.4g (126.2g)	1714	-	-	1.71, 1.61 kN (384, 362 lb_f)	1.21

* 3ms clip values included in brackets.

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

Description of results:

Britax Cosy-Tot ISOfix (RF) – P3/4: There was minimal movement and rotation of the CRS but the rebound was substantial. The ATDs head did not protrude past the leading edge of the CRS. The CRS rotated during the rebound and this was due to the capsule not being mounted in the base. The capsule was mounted in accordance with the installation instruction for aircraft installation of the USA version of the CRS.

Adult ATD (RHS, seated behind ‘Cosy-Tot): The ATD remained restrained but suffered a HIC score that exceeded normal limits. Femur compression was well within limits despite the lower legs creasing the seat rear crossmember. Seat back breakover was only slightly reduced.

Britax Duo Plus ISOfix (FF) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled with very similar motion to Test 09/05.

Adult ATD (LHS, seated behind ‘Duo-Plus): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. Femur compression was well within limits despite the lower legs marking the seat rear crossmember. Seat back breakover was greatly reduced, being restricted to a forward rotation of approximately 16º forward of vertical.

Aircraft seat – On removal of the rear seat, both the front and rear crossmembers fractured in the centre spreader fitting. It is assumed that the structural failure had initiated during the impact and was completed when the sled components were being disassembled. This failure can be attributed to the seat being used in multiple tests.

Figure 59 - Configuration Tested - lap belt restrained CRS

Figure 60 - Post Test

Figure 61 - Seat crossmember witness marks and damage

Figure 62 - Post test seat crossmember fracture (Adult ATD)

A1.9 CASA Test No. 09/09

Autoliv Test No.:	D1-3233
Test Purpose:	To assess the injury levels to occupants when an adult is seated behind an automotive LATCH type child restraint in an airline seat modified with Lower Anchorages. This is a similar test to CASA 09/06 but the CRS are installed using aircraft loose LATCH straps.
Test configuration:	An AS/NZS 1754 and an ECE-R44 child restraint, both forward facing, mounted onto an aviation airline economy class passenger seat. They were attached to Lower Anchorage structure attached to the airline seat. The child restraints were installed with loose LATCH straps routed through the belt path. The restraints were adjusted to the upright position. The top tether straps were not installed. A second row of airline economy class passenger seating was mounted behind at 30 inches pitch and sat two Hybrid III 50% Male ATDs.
Child Restraints:	Safe-n-Sound 7000 Series Convertible restraint, forward facing mode for 9kg – 18kg children. Britax 'Duo-Plus' ISOfix forward facing restraint for 9kg – 18kg children.
ATDs:	2 x TNO P3 child ATD (15kg) 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:	The required test pulse was not quite met. A peak acceleration of 21.7g @ 41ms achieving a total velocity change of 43.9 ft/s (48.2 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. CRS Forward Rotation†	Max. Chest Acceleration*	Max Femur Compression	Neck Injury
Safe-n-Sound (FF) – P3	72.4g (68.5g)	339	-	36.0g (33.6g)	-	-
Adult ATD (seated behind 'Safe-n-Sound')	151.5g (119.7g)	1468	-	-	1.49, 2.25 kN (335, 507 lb_f)	0.76
Britax Duo Plus (FF) – P3	43.4g (39.7g)	230	15º	36.7g (32.9g)	-	-
Adult ATD (seated behind 'Duo Plus')	169.1g (135.0g)	2025	-	-	2.19, 2.03 kN (492, 457 lb_f)	1.08

* 3ms clip values included in brackets.

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

Description of results: Safe-n-Sound (FF) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled though more excessive than the Duo-Plus. The seat base plate fractured (see photo below) though this did not affect the child ATD.

Adult ATD (RHS, seated behind Safe-n-Sound): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. The severe neck rotation seen in other testing was not repeated for this case and was the only case where the neck injury was within recognised limits[1]. Femur compression was well within limits despite the lower legs inflicting severe bending loads on the Lower Anchorage structure and leaving witness marks on the seat rear crossmember. Seat back breakover was slightly more than for the other side.

Britax Duo Plus ISOfix (FF) – P3: The ATD was well restrained and remained attached to the aircraft seat. Motion of the ATD and CRS was well controlled with very similar motion to Test 09/04.

Adult ATD (LHS, seated behind 'Duo-Plus): The ATD remained restrained but suffered a high HIC score that exceeded normal limits. The severe neck rotation seen in other testing was not repeated for this case[1]. Femur compression was well within limits despite the lower legs inflicting severe bending loads on the Lower Anchorage structure and leaving witness marks on the seat rear crossmember. Seat back breakover was greatly reduced, being restricted to a forward rotation of approximately 8º forward of vertical.

Lower Anchorage – The tube structure mounted across the back of the aircraft seat spreaders was deformed in a W pattern consistent with pressure applied from behind by the lower legs of the Adult ATDs. No deformation was observed in the Lower Anchorage 6mm bar loops.

Figure 63 - Configuration Tested - LATCH restrained CRS

Figure 64 - Post Test

Figure 65 - RHS CRS Fractured Seat Base

A1.10 CASA Test No. 09/10

Autoliv Test No.:	D1-3235
Test Purpose:	Assessment of the injury to a lap belt restrained 3 year old to provide a baseline comparison to the various CRS restrained child ATDs. Additionally, to assess injury to an adult and a lap held, supplementary loop belt restrained 9 month old to provide a comparison to various CRS restrained infant ATDs.
Test configuration:	One 3 year old and one 50% male adult ATD in each seating position restrained by the aircraft lap belt. The adult ATD nursing a 9 month old ATD attached to the adult by a 'Supplementary Loop Belt'. A second row of airline economy class passenger seating was mounted in front at 30 inches pitch.
Child Restraints:	Aircraft Lap Belt Supplementary Loop Belt
ATDs:	TNO P3 child ATD (15kg) – Aircraft Lap Belt TNO P3/4 child ATD (9kg) – Supplemental Loop Belt Standard Hybrid III ATDs (50^{th} 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:	The required test pulse was exceeded. A peak acceleration of 21.6g @ 58ms achieving a total velocity change of 44.4 ft/s (48.7 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Chest Deflection‡	Max Femur Compression	Neck Injury
Supplementary Loop Belt - P3/4		-			-	-
Adult ATD (nursing P3/4)	65.1g (62.3g)	464	52.5g (46.4g)	34.6mm	1.57, 2.12 kN (353, 475 lb_f)	0.87
Lap Belt – P3	121.7g (100.2g)	1601	56.9g (48.7g)		-	-

* 3ms clip values included in brackets.

‡ FMVSS 208 lists the maximum chest deflection to be 76mm.

Description of results: Supplementary Loop Belt – P3/4: With a high and forward initial position on the lap of the Adult ATD with straight legs, the Infant ATD struck the seat back in front early in the impact, feet first. The legs were driven into the seat in front, with the head arcing into the seat back tray table, and then sliding down. To a limited extent, at this point an aft impact was applied by the chin of the nursing Adult ATD before sliding to the right of the Infant ATD head. During the downward slide, severe distortion and bunching of the ATD skin in the area of the face occurred along with the face breaking the lateral aluminium brace of the tray table. The motion is then stopped when the infant is squashed between the adult torso, legs, and seat back, followed by the rebound. The Infant ATD remained attached to the seat by the serial lap belt and supplemental loop belt assembly. However, post test the supplemental loop belt was found to be around the ATDs abdomen.

Adult ATD nursing P3/4: The infant was seated on the Adult ATD with the pre-test position such that the infant ATD's head was just below the ATDs chin. During the initial portion of the impact, the chin made contact with the Infant's head initiating a slight neck extension in the adult head until a slight misalignment allowed the head to rotate to the left ultimately generating a peak upper neck torsional moment of 30.7 Nm. No head strike occurred on the surrounding structure principally because of the Infant, though reasonably constant contact was maintained with the infant's head throughout the deceleration. Normal extension for the adult was not obtained because of the forced inflection over the infant resulting in a severe but acceptable chest displacement.

P3: The ATD was restrained and remained attached to the aircraft seat. During the initial impact and torso rotation, the right hand caught on the seat squab, the arm locked driving the limb into the squab. This had the effect of stopping the shoulder just forward of the hip inducing a rolling and yawing moment. This resulted in the head striking the left lower leg inducing the high HIC value, though this action probably stopped the head from rotating far enough between the legs to strike the leading edge of the seat squab shrouding the forward seat crossmember.

Figure 66 - Configuration tested – Baseline configurations for 9 month and 3 year old occupants

Figure 67 – Configuration tested

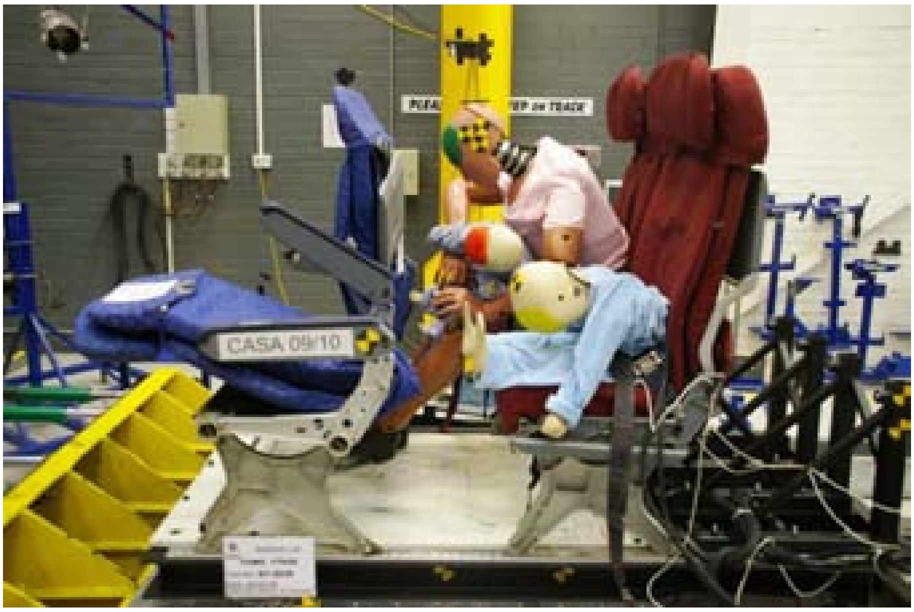

Figure 68 - Post Test

Figure 69 - Post Test

Figure 70 - P3 Head Strike Paint Transfer

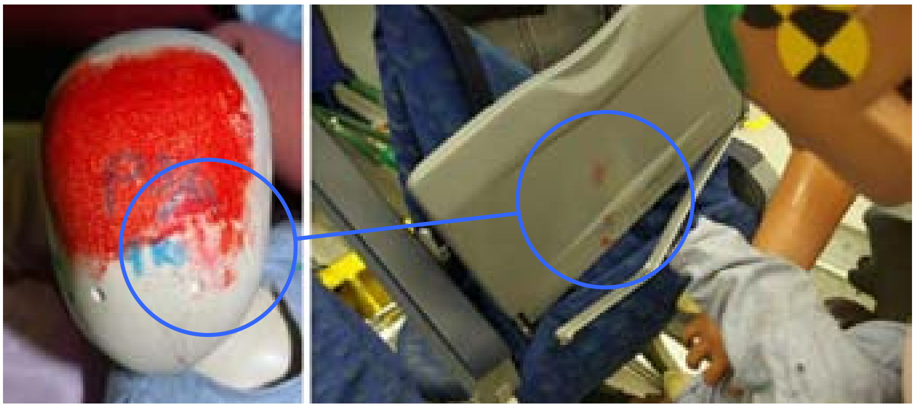

Figure 71 - P3/4 Head Strike Paint Transfer

Figure 72 - Adult to P3/4 Head Strike Paint Transfer

A1.11 CASA Test No. 09/11

Autoliv Test No.: D1-3336

Test Purpose: Assessment of the injury to a lap belt restrained adult with no CRS in front to provide a baseline comparison to the various adult injury cases with CRS mounted in front. Additionally, to assess injury to an adult and a lap held, supplementary loop belt restrained 18 month old to provide a comparison to various CRS restrained infant ATDs.

Test configuration: Two 50% male adult ATDs in each seating position restrained by the aircraft lap belt. One adult ATD nursing an 18 month old ATD attached to the adult by a 'Supplementary Loop Belt'. A second row of airline economy class passenger seating was mounted in front at 30 inches pitch.

Child Restraints: Supplementary Loop Belt

ATDs: TNO P1½ child ATD (11kg) – Supplemental Loop Belt

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: The required test pulse was exceeded. A peak acceleration of 22.1g @ 46ms achieving a total velocity change of 44.4 ft/s (48.7 km/h). The resulting peak acceleration and deflection values are tabled below.

	Max Head Acceleration*	HIC36	Max. Chest Acceleration*	Chest Displacement‡	Max Femur Compression	Neck Injury
Adult ATD	135.6g (109.5g)	1313	67.5g (65.4g)	6.2mm	2.53, 3.24 kN (569, 729 lb_f)	1.38
Supplementary Loop Belt – P1 ½	102.3g (89.1g)	1078	57.2g (54.5g)	-	-	0.40
Adult ATD (nursing P1 ½)	110.2g (89.8g)	711	73.4g (50.7g)	33.9mm	2.20, 2.66 kN (495, 599 lb_f)	1.21

* 3ms clip values included in brackets.

‡ FMVSS 208 lists the maximum chest deflection to be 76mm.

Description of results: Adult ATD: The ATD was restrained and remained attached to the aircraft seat. The head struck mid height on the tray table, slid down the table, bent and broke the aluminium lateral brace of the tray table. The upper shins left witness marks on the aft crossmember of the seat in front. The rear seat back broke on rebound.

Supplementary Loop Belt – P1½: With a high and forward initial position on the lap of the Adult ATD with straight legs, the Infant ATD struck the seat back in front early in the impact, feet first. The legs were driven into the seat in front, with the head arcing into the seat back tray table, and then sliding down. At the point of contact with the tray table, aft pressure was also applied by a large impact from the face of the nursing Adult ATD (see graph below at around 105ms). The motion is then stopped when the infant is squashed between the adult torso, legs, and seat back, followed by the rebound. The Infant ATD remained attached to the seat by the serial lap belt and supplemental loop belt assembly.

Adult ATD nursing P1½: The infant was seated on the Adult ATD with the pre test position such that the infant ATD's head was just ahead of the adult ATDs chin. During the initial portion of the impact, the nose made contact with the Infant's head. The Adult ATD head strike bore directly of the back of the Child ATD's head and stayed there until the rebound started, thus the Adult ATD head never made contact with the tray table. Chest compression occurred because of the child between the Adult's chest and legs.

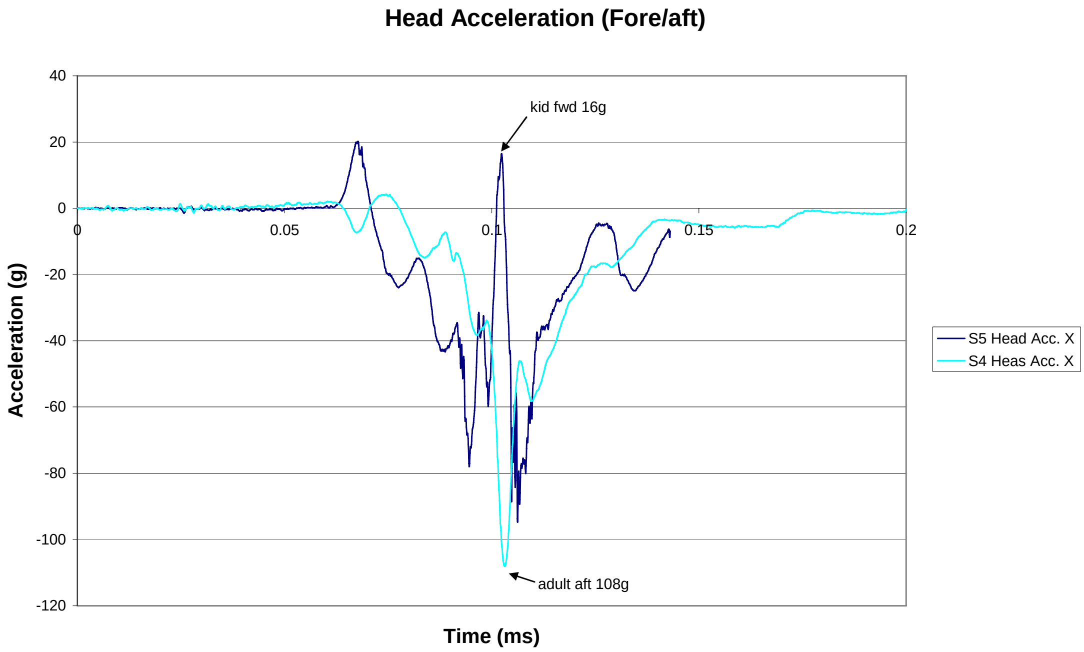

Figure 73 - Graph of fore/aft head acceleration

Figure 74 - Configuration Tested – Baseline configurations for 50 percentile male adult and 18 month old child occupants

Figure 75 - Configuration tested

Figure 76 - Configuration Tested - P1½

Figure 77 - Point of Peak Head Acceleration @ 103ms

Figure 78 - Post Test

Figure 79 - P1½ Post Test position

Figure 80 - Head Strike Witness marks - P1½ | 50% Adult ATD

Figure 81 - P1½ head strike witness mark

Figure 82 - Adult to P1½ Head Strike Paint Transfer, note adult forehead is clear of markings.

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)

Figure 83 - 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)]
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 or LATCH straps.

Figure 84 - Britax 'Cosy Tot' (mounted on the ISOfix base)

Figure 85 - 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)

Figure 86 - Safe-n-Sound 'Premier' Convertible (shown with top tether, which was not used for this series of tests).

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)

Figure 87 - IGC Gosafe 'Boulevard' Convertible (shown with top tether, which was not used for this series of tests).

A2.5 LATCH Strap

Manufacturer	Britax
Design Standard	FMVSS 213
Weight	430 g (15 oz)
Dimensions	Maximum 1400 mm (55 in) length

Figure 88 - LATCH strap

A2.6 Supplementary Loop Belt

Manufacturer	Air Safety Solutions/Autoliv
Design Standard	CASA CAO 108.42 (FAA TSO-C22f)
Weight	240 g (8.5 oz)

Figure 89 – Supplementary Loop Belt

Appendix 3 Lower Anchorage modification to airline seat

A3.1 Instrumented Lower Anchorage independent of airline seat

For the first five tests, an instrumented Lower Anchorage system was manufactured and mounted independent of the aircraft seat. The anchorage was mounted directly to the sled frame. This system provided the most rigid anchorage imaginable so that the loads generated would feasibly be the highest.

Each lower anchorage loop was welded to a tube that was designed to be a replaceable item, should it be deformed in a test. This sleeve was attached to a horizontally mounted tube connected to a Denton A-2121-D single axis load cell that was in turn bolted (pin jointed) to a sub-frame. To support this horizontal tube, a vertical tube was pin jointed to it and it in turn attached to another Denton A-2121-D load cell that was pin jointed to the sub-frame. This was replicated to make a right and left pair. Each sub-frame contained two triangulated and cross-braced mounts off which attachments the load cells were mounted. Two sub-frames were constructed, one for each place in the double airline seat and was bolted to the sled adapter frame used to mount the aircraft seats.

This setup effectively resolved the forces applied to the Lower Anchorage into vertical and horizontal components for each Lower Anchorage loop. The vertical force measured was corrected during the analysis for the gearing effect of the arrangement. All pin joints in the structure were arranged to minimise bending loads that may otherwise affect the load cell measurements.

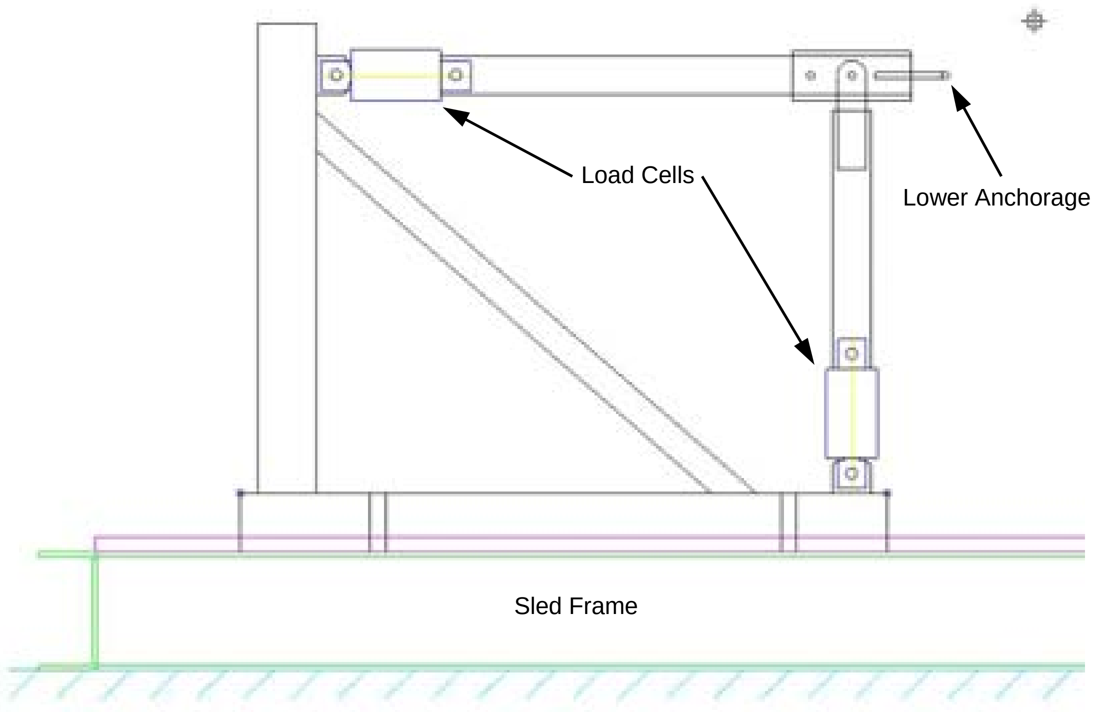

Figure 90 - Instrumented Lower Anchorage – side view

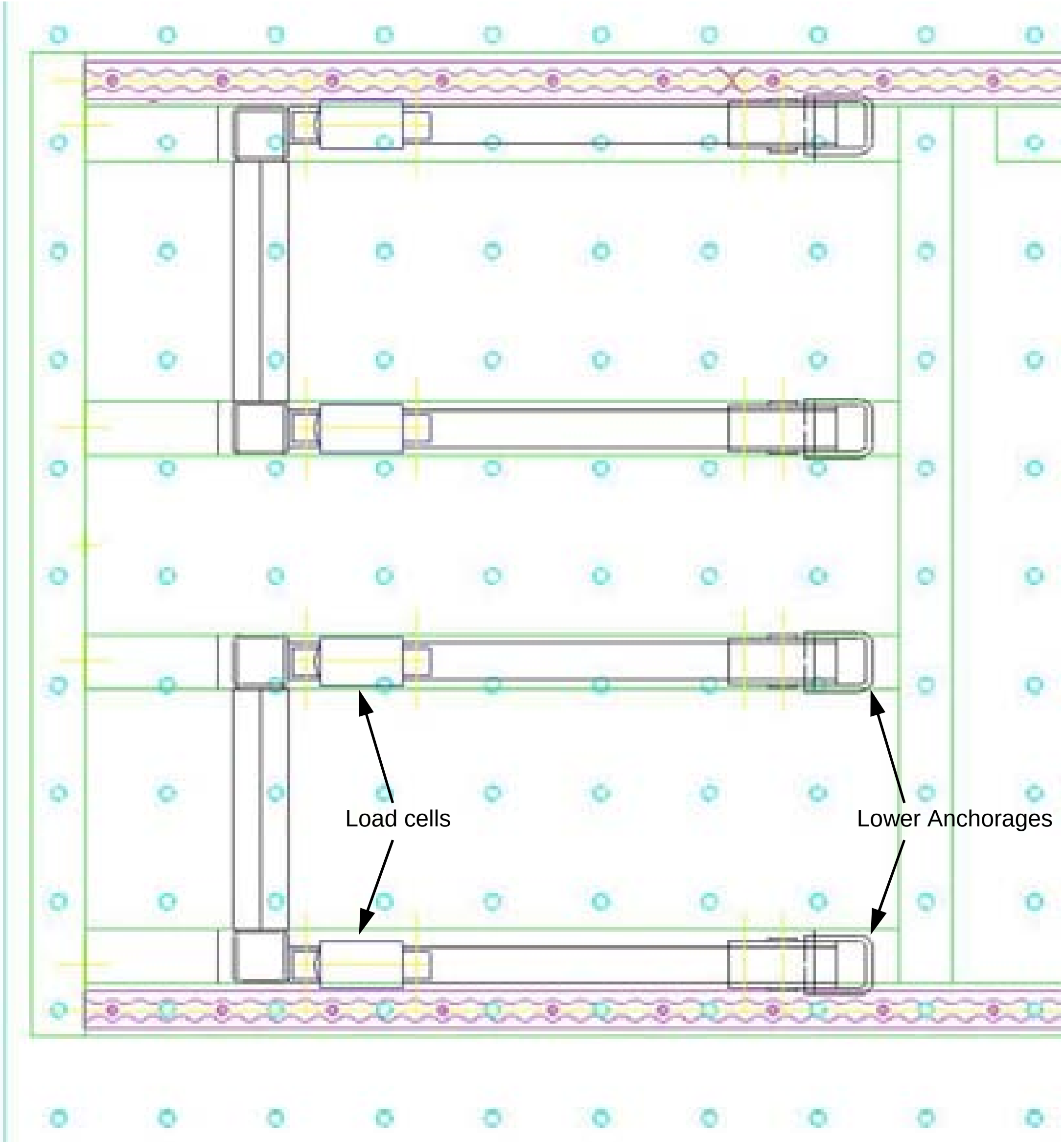

Figure 91 - Instrumented Lower Anchorage - plan view

Figure 92 - Instrumented Lower Anchorage arrangement

Figure 93 - Instrumented Lower Anchorage installed behind aircraft seat

Figure 94 - Lower Anchorage Loops protruding through seat bight.

A3.2 Lower Anchorage modification to airline seat

For the subsequent four tests, aircraft seats were modified to incorporate an integral lower anchorage system. This consisted of a Ø20x2mm mild steel tube strung across the rear of the seat spreaders. 3mm tags welded to the tube allowed it to be screwed to the seat spreaders with aviation grade 8/32 screws and nuts. AS1443/1214 Ø6mm round bar were formed into loops meeting the requirements of FMVSS 225 and were welded into the tube at 280mm spacings.

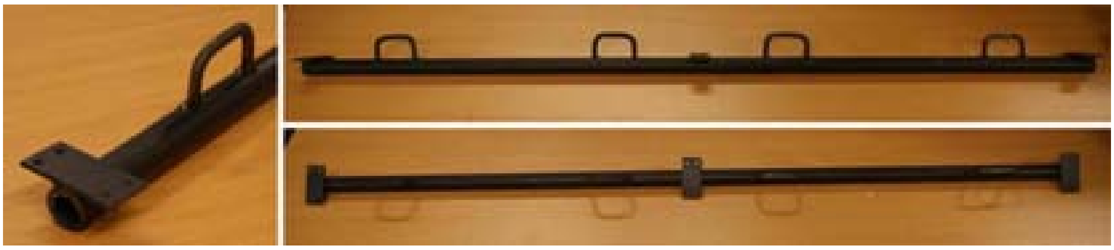

Figure 95 - Integrated Lower anchorage Assembly

Figure 96 - Integrated Lower Anchorage

Figure 97 - Integrated Lower Anchorage (post-test 09-06)