IMPLEMENTATION OF ISOFIX AND LATCH EQUIPED AUTOMOTIVE CHILD RESTRAINT SYSTEMS IN AN AIRCRAFT ENVIRONMENT

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ABSTRACT

The increasing trend towards fractional aircraft ownership has seen a rise in the number of babies and children being transported on corporate and private aircraft. Occupant protection policies for children younger than 2 years on aircraft are inconsistent with all other national policies on safe transportation. Children younger than 2 years are not required to be restrained or secured on aircraft during takeoff, landing, and conditions of turbulence. The National Transportation Safety Board 2005-2006 Most Wanted Transportation Safety Improvements state that all occupants should be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children should be restrained in an approved child restraint system appropriate to their height and weight.

Current Federal Aviation Administration recommendations for child restraints are based on Federal Motor Vehicle Safety Standards and typically involve the use of child safety seats restrained by aircraft lap belts. Newer automotive restraint standards use the vehicle structure to restrain the child safety seat. These standards differ between North America (LATCH) and Rest of the World (ISOFIX). Development and testing to determine the optimum means of child restraint and a solution that works in both North America and Rest of the World is needed.

Based on the results from the dynamic sled tests conducted, in this study there is sufficient data to conclude that the ISOFIX and LATCH system can solve the interface issues found in the past between the CRSs and aircraft seats. Both the ISOFIX and the LATCH attachment methods offer similar level of safety for the 12 month and 3 YOLD occupants.

While this study provides an overview of the viability of the ISOFIX and LATCH system, additional research needs to follow in order to develop aerospace standards and recommendations.

INTRODUCTION

The increasing trend toward fractional aircraft ownership has seen a rise in the number of babies and children being transported on corporate and private aircraft. Occupant protection policies for children younger than two years of age on aircraft are inconsistent with all other national policies on safe transportation. Children younger than two years old are not required to be restrained or secured on aircraft during takeoff, landing, and/or conditions of turbulence. In the National Transportation Safety Board (NTSB) 2005-2006 Most Wanted Transportation Safety Improvements [1], NTSB states that all occupants should be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children should be restrained in an approved child restraint system appropriate to their height and weight.

A child restraint system (CRS) provides specialized protection for small occupants whose body structures are still immature and growing. Child restraint designs vary with the size of the child, the direction the child faces, the type of internal restraining system, and the method of installation. Current Federal Aviation Administration (FAA) recommendations for child restraints are based on Federal Motor Vehicle Safety Standards (FMVSS) and typically involve the use of child safety seats restrained by aircraft lap belts. Newer automotive restraint standards use the vehicle structure to restrain the child safety seat. These standards differ between North America (Lower Anchors and Tethers for Children or LATCH) and the rest of the world (International Organization for Standardization FIX or ISOFIX). Development and testing to determine the optimum child restraint and a solution that works with both the ISOFIX and LATCH system is needed.

CRS-AIRCRAFT SEAT INTERFACE ISSUES

According to NIAR CRS fitting studies and previous research conducted by van Gowdy & DeWeese [2], interface issues were found using conventional aircraft restraint systems to anchor the CRS.

The most common type of CRS/Aircraft seat interface issues are:

- Interference with the lap belt latching mechanism
- Insufficient belt webbing length
- Two-point aerospace belt geometry issues

- Lack of adjustment features for aerospace 2-point belts
- CRS dimensional compatibility with aircraft seat structure

Figure 1. Typical Aerospace/CRS Interface Issues.

The dimensions shown in table 1 and 2 were taken for typical CRS and Part 23 (General Aviation) and 25 (Business Jet) seats.

Table 1.

Typical child restraint dimensions

Seat Type	Height (inches)	Width (inches)	Depth (inches)
Convertible – 1	26.8	17.7	16.3
Convertible – 2	24.2	18.9	17.7
Booster	26.4	16.5	13
Infant	18.1	10.2	21.3

Table 2.

Typical aircraft seat dimensions

Seat Configuration	Width Between Arm Rests (inches)	Width of Seat Cushion (inches)	Depth of Seat Cushion (inches)
1	17.5	19.5	21
2	18.5	20.5	21
3	18.5	20.5	21
4	16.5	20.5	21
5	18	22	21
6		19	19
7		18.5	19
8		19.5	19
9		19.5	19
10		18.5	22.6
11		20	22
AVG	17.9	19.8	20.5
MIN	16.5	18.5	19
MAX	18.5	22	22.6

The Lower Anchors and Tethers for Children (LATCH) and the ISOFIX System are designed to make installation of child safety seats easier by requiring child safety seats to be installed without using the vehicle's/aircraft seat belt system.

LATCH System

According to FMVSS 213 [3]; as of September 1st 2002, two rear seating positions on all cars, minivans and light trucks are equipped with lower child safety seat anchorage points located between a vehicle's seat cushion and seat back. New child safety seats have two attachments which will connect to the vehicle's lower anchorage attachment points. In addition, all new vehicles have top anchor points that connect to a child safety seat's top tether strap. Together, the lower anchors and upper tethers make up the LATCH system [4].

Figure 2. LATCH Equipped Seat.

ISOFIX System

The International Organization for Standardization FIX constitutes a standardized quick rigid connection system for CRS. This rigid interface between the CRS and motor vehicle permits proper installation in all cases, regardless of the vehicle's seat belt system. The child restraint system is attached to vehicle anchorages by means of two rigid attachments at the bottom of the CRS [5].

It should be noted that for the aircraft seat tested, the upper tether was not used in order to reduce the complexity of the aircraft installation, and to asses whether or not this feature is necessary to prevent large ATD excursions and CRS rotation in the aircraft environment.

Anchorage System Specifications

Per FMVSS 225 [6] and ISO 13216-1 [5], anchorages shall be 6 mm + 1 mm in diameter transverse horizontal round bars with a minimum effective length of 25 mm. The transverse spacing of the bars shall be 280 mm, center to center. They shall be supported to extend from the adjacent vehicle or seat structure so they are readily accessible. Note that the general dimensions are compatible with both the ISOFIX and the LATCH standards.

Figure 3. ISOFIX Equipped Seat.

DYNAMIC SLED TESTS EVALUATIONS

In 1982, the Department of Transportation (DOT) had two standards for CRS. CRS for use in motor vehicles were required to be certified as complying with the requirements of FMVSS No. 213. CRS for use in aircraft were required to be certified as complying with the requirements of FAA's Technical Standard Order (TSO) C100. In 1983 it was proposed that NHTSA would be the sole agency responsible for administering the new FMVSS No. 213, which would be applicable to both CRS designed for use in motor vehicles and CRS designed for use in aircraft (Title 49 of the Code of Federal Regulations (49 CFR) part 571, § 213) [7].

For a CRS to be approved to be used on aircraft, it must meet the dynamic sled test requirements, and an inversion test (simulate turbulence condition) as specified in FMVSS 213 and ECE R44. As shown in figure 7, automotive pulses exhibit higher decelerations and changes of velocity than those specified in aircraft interior regulations described in FAR 23/25.562.

A series of sled tests without upper tether were conducted at the National Institute for Aviation Research Crash Dynamics Laboratory in order to evaluate the dynamic performance of child restraint systems when subjected to Parts 23 and 25.562 emergency landing conditions.

Description of Aircraft Passenger Seat Test Articles

Two types of aircraft seats were used for testing. A rigid seat was used to study occupant behavior and interface loads with the CRS, and a modified (ISOFIX attachments) part 25 business-jet seat was used to evaluate the implementation and performance of the ISOFIX interface on a production aircraft seat.

Description of Child Restraint Seat Test Articles

The following child restraint devices were provided for evaluation:

- Rear Facing Infant Seat: These seats are designed to be installed facing the rear. They are recommended for infants, from birth to at least age one and weighing less than 20 pounds. These seats have an integrated five-point restraint system. The seats used in these tests were fitted with either an ISOFIX base or a LATCH interface (see figure 4).

- Forward Facing Convertible Seat: Children over one year old and weighing at least 20 pounds may ride in a front-facing child safety seat. The maximum recommended occupant weight for these CRSs is 40 pounds. These seats have an integrated five-point restraint system. The seats used in these tests were fitted with either an ISOFIX base or a LATCH interface (see figure 4).

Figure 4. Convertible and Infant Seat.

Anthropomorphic Test Dummies

Two types of child ATDs were utilized in these tests:

- CRABI 12-Month: This ATD was developed to evaluate a small child restraint system in automotive crash environments, in all directions of impact, with or without air bag interaction [8]. The ATD weighs 22 pounds (10 kg), has a seating height of 18.9 inches (0.48 m), and a stature of 29.4 inches (0.75 m). The instrumentation used for testing is summarized in table 3.
- 3 YOLD Hybrid III: This ATD was developed by SAE and NHTSA to evaluate child restraint systems and airbag aggressiveness (out-of-position) in automotive crash environments. It weighs 34.5 pounds (15.6 kg), and has a seating height of 21.5 inches (0.55 m) and a stature of 37.2 inches (0.94 m) [8].

Table 3.

ATD instrumentation

Instrumentation	CRABI	3YOLD
Head Accelerometer	√	√
Upper-Neck Load Cell	√	√
Thorax Accelerometer	√	√
Lumbar Spine Load Cell	√	√
Pelvis Accelerometer	√	√

Dynamic Sled Pulse Definition

Tests with the rigid seat were conducted per FAR 23.562 Emergency Landing Conditions [9]:

- For the first test, the change in velocity may not be less than 31 feet per second. The seat/restraint system must be oriented in its nominal position with respect to the airplane and with the horizontal plane of the airplane pitched up 60 degrees, with no yaw, relative to the impact vector. For the seat/restraint systems, peak deceleration must occur in not more than 0.06 second after impact and must reach a minimum of 15 g.

- For the second test, the change in velocity may not be less than 42 feet per second. The seat/restraint system must be oriented in its nominal position with respect to the airplane and with no 10 degree yaw and no pitch relative to the impact vector. For the seat/restraint systems, peak deceleration must occur in not more than 0.06 second after impact and must reach a minimum of 21 g.

Figure 5. Type I Test setup with PART 25 Aircraft Seat.

Tests with the FAR 25 aircraft seat were conducted per FAR 25.562 Emergency Landing Conditions [9]:

- For the first test, the change in downward vertical velocity may not be less than 35 feet per second, with the airplanes longitudinal axis canted downward 30 degrees with respect to the horizontal plane and with the wings level. Peak floor deceleration must occur in not more than 0.08 second after impact and must reach a minimum of 14 g.

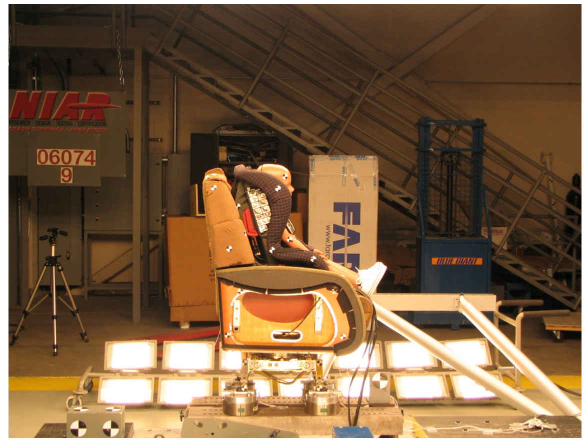

Figure 6. Type II Test setup with PART 25 Aircraft Seat.

- For the second test, the change in forward longitudinal velocity may not be less than 44 feet per second, with the airplanes longitudinal axis horizontal (no 10 degree yaw). Peak floor deceleration must occur in not more than 0.09 second after impact and must reach a minimum of 16 g. Where floor rails or floor fittings are used to attach the seating devices to the test fixture, the rails or fittings are not misaligned (no 10 degree pitch and no 10 degree roll).

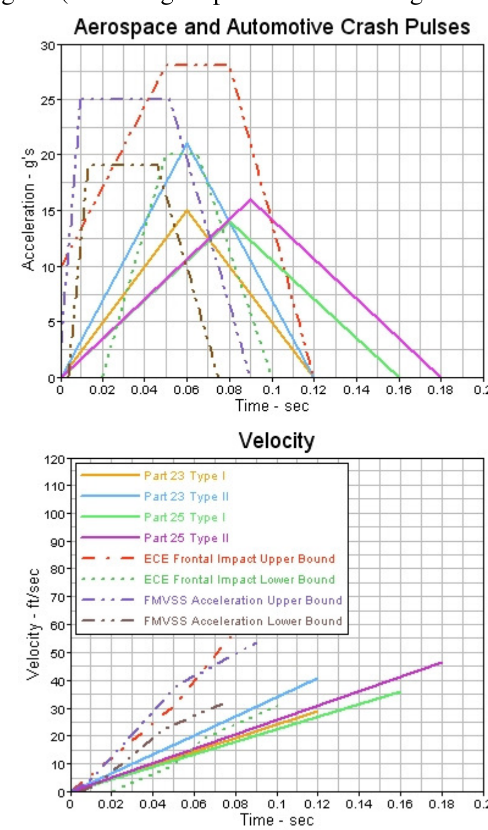

Figure 7. Automotive vs. Aerospace Crash Pulses.

Evaluation Criteria

The following factors extracted from FMVSS 213, ECE R44, FAR 23.562, and FAR 25.562 were applied to evaluate the dynamic performance of the child restraints.

Table 4.

Evaluation criteria

Criteria/Regulation	ECE R44	FMVSS 213	FAR 23 and 25 *
HIC 36	NA	1000	1000
Chest Z + Acc 3 ms	30 g's	NA	NA
Chest Res Acc 3 ms	55 g's	60 g's	NA
Lumbar Force Z	NA	NA	1500 lbf
Head Excursion	21.65 / 23.6 in	28.34 in	NA
Knee Excursion	NA	36.02 in	NA
* This value corresponds to a 50th percentile occupant, further research is required to find the appropriate scaling factor for children			

12-Month-Old FAR 23.562 Rigid Seat Type I Dynamic Performance Comparison: ISOFIX vs. LATCH

As shown in the following figures in this section and in table 5, the dynamic performance of the 12-month-old CRS with either the ISOFIX or LATCH attachment is very similar. Forty three milliseconds into the crash event, there is a slight difference in the CRS horizontal acceleration due to the flexible construction of the LATCH system. This instantaneous increase in acceleration level induces a small increase in head-x acceleration, neck moments and seat pan reaction forces.

Table 5.

Summary injury values type I test 12 month

	TYPE I				
	ISOFIX	**LATCH**			
Test No.	06074-4	06074-5			
Pulse	Part 23.562	Part 23.562			
Seat Type	Rigid	Rigid	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	120	86	NA	1000	
Chest Z + Acc 3 ms	0.7	2.2	30	NA	g
Chest Res Acc 3 ms	31	31	55	60	g
Lumbar Force Z	-76	-72	NA	NA	lbf
Seat Excursion	25.86	28.32	NA	NA	in
Knee Excursion	NA	NA	NA	NA	in

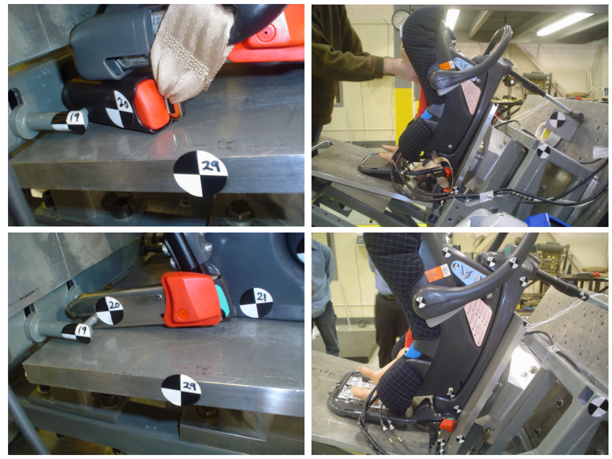

Figure 8. LATCH and ISOFIX Configurations.

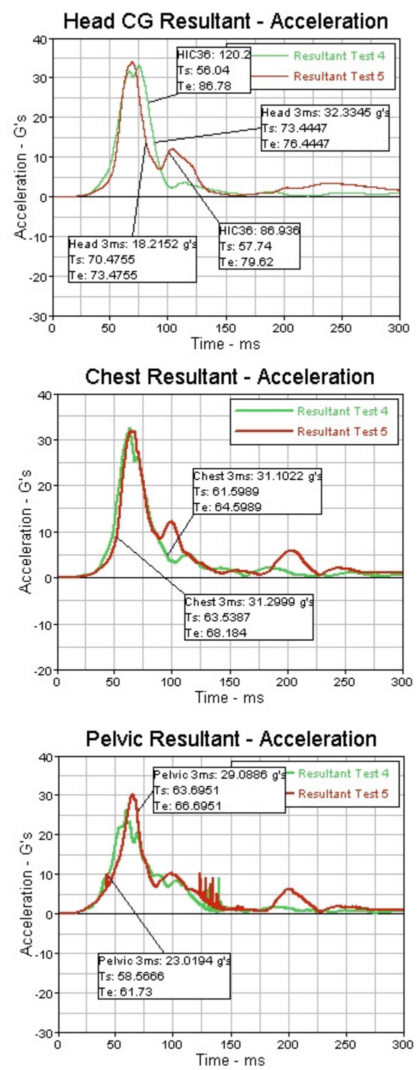

Figure 9. Head, Chest, and Pelvis Acceleration.

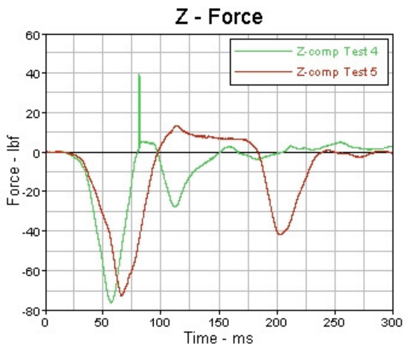

Figure 10. Lumbar Load.

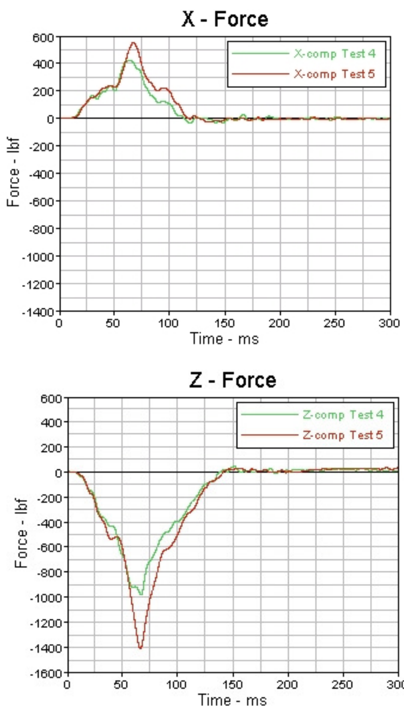

Figure 11. Seat Pan Reaction Forces

12-Month-Old FAR 23.562 Rigid Seat Type II Dynamic Performance Comparison: ISOFIX vs. LATCH

The dynamic performance of the 12-month-old CRS with ISOFIX or LATCH attachment is very similar. Thirty milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration due to the flexible construction of the LATCH system. This instantaneous increase in acceleration level induces a small increase in head, torso, and pelvis accelerations, neck moments, and seat pan reaction forces.

Table 6.
Summary injury values type II test 12 month

	TYPE II				
	ISOFIX	LATCH			
Test No.	06074-3	06074-12			
Pulse	Part 23.562	Part 23.562			
Seat Type	Rigid	Rigid	ECE R44	FMVSS 213	Unit
HIC 36	233	340	NA	1000	
Chest Z + Acc 3 ms	26	29	30	NA	g
Chest Res Acc 3 ms	33	40	55	60	g
Lumbar Force Z	-5	-14	NA	NA	lbf
Seat Excursion	27.57	31.37	NA	NA	in
Knee Excursion	NA	NA	NA	NA	in

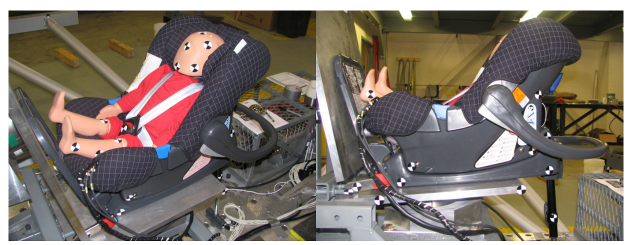

Figure 12. Infant Seat Type I Test.

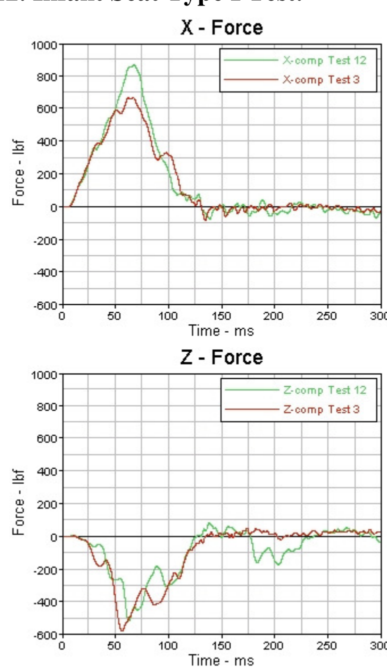

Figure 13. Seat Pan Reaction Forces.

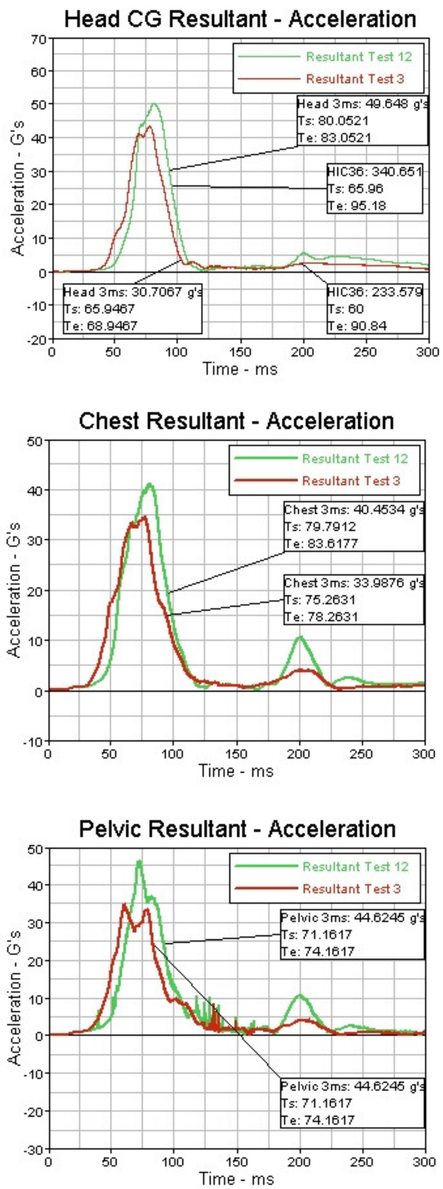

Figure 14. Head, Chest, and Pelvis Acceleration.

Three-Year-Old FAR 23.562 Rigid Seat Type I Dynamic Performance Comparison: ISOFIX vs. LATCH

As shown in the following figures in this section and in table 7 the dynamic performance of the 3 YOLD CRS with ISOFIX or LATCH attachment is very similar. Sixty five milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration (see figure 17) due to the flexible construction of the LATCH system. This instantaneous increase in CRS acceleration level induces a small increase in occupant head, torso, and pelvis accelerations.

Table 7.
Summary injury values type I test 3 YOLD

	TYPE I				
	ISOFIX	**LATCH**			
Test No.	06074-8	06074-6			
Pulse	Part 23.562	Part 23.562			
Seat Type	RIGID	RIGID	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	71	93	NA	1000	
Chest Z + Acc 3 ms	3	4	30	NA	g
Chest Res Acc 3 ms	36	41	55	60	g
Lumbar Force Z	-654	-716	NA	NA	lbf
Head Excursion	10.8	17.84	23.6	28.34	in

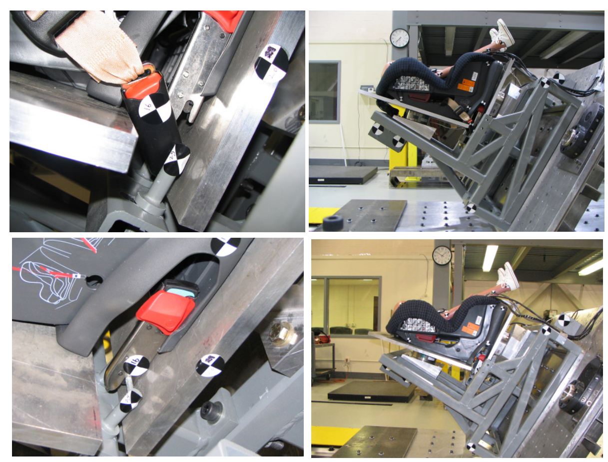

Figure 15. Three YOLD ISOFIX and LATCH Setup.

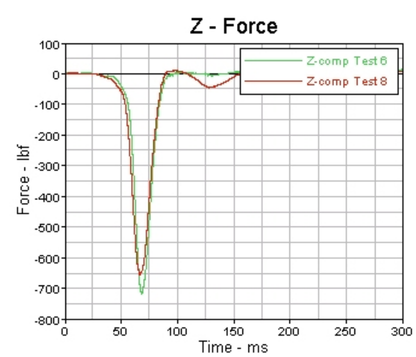

Figure 16. Lumbar Load.

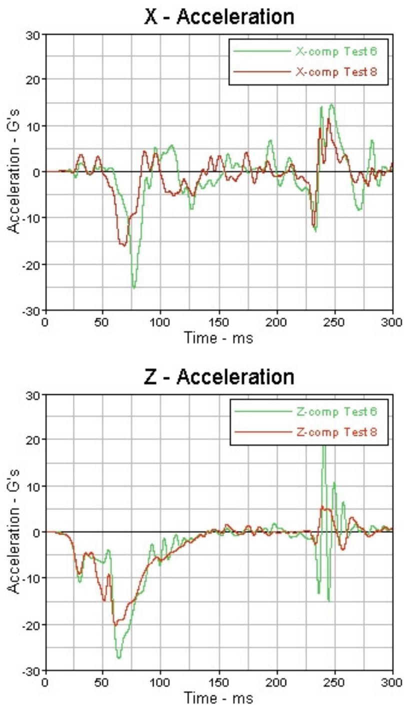

Figure 17. CRS Accelerometers.

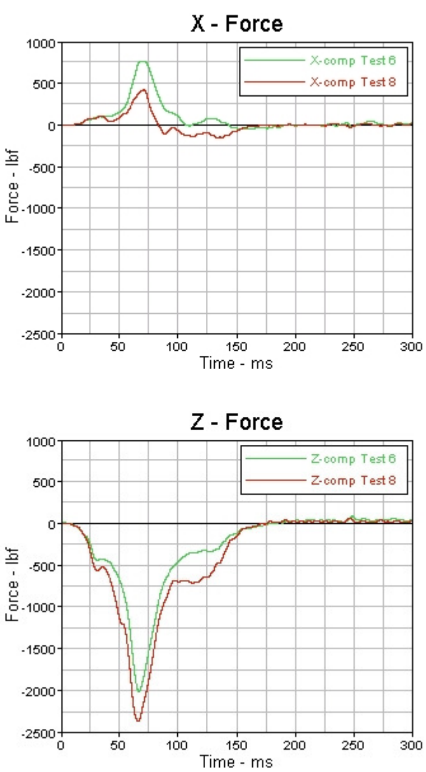

Figure 18. Seatpan Reaction Forces.

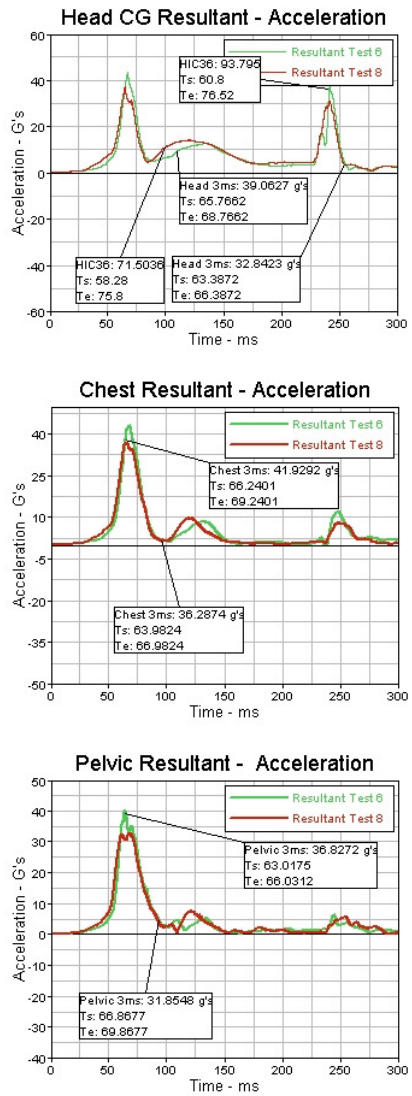

Figure 19. Head, Torso, and Pelvis Resultant Acceleration.

<u>Three-Year-Old FAR 23.562 Rigid Seat Type II Dynamic Performance Comparison: ISOFIX vs. LATCH</u>

As shown in the following figures in this section and in table 8, the dynamic performance of the 3 YOLD CRS with ISOFIX or LATCH attachment is very similar. Fifty five milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration, which induces a small increase in occupant, torso, and pelvis accelerations (see figures 21 and 22).

Figure 20. Three YOLD Type II Test Configuration.

Table 8

Summary injury values type II Test 3 YOLD

	TYPE II				
	ISOFIX	**LATCH**			
Test No.	06074-16	06074-11			
Pulse	Part 23.562	Part 23.562			
Seat Type	RIGID	RIGID	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	221	NA	NA	1000	
Chest Z + Acc 3 ms	7	8	30	NA	g
Chest Res Acc 3 ms	32	36	55	60	g
Lumbar Force Z	NA	NA	NA	NA	lbf
Head Excursion	10.75	15.01	23.6	28.34	in

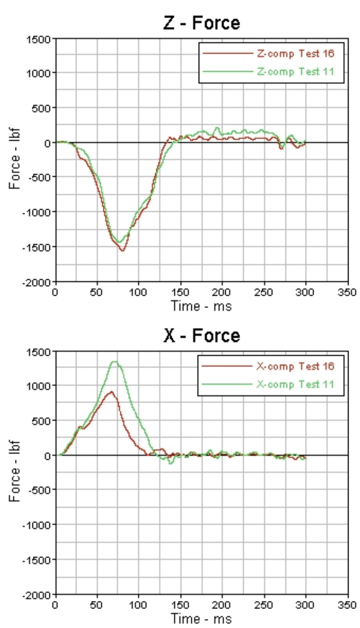

Figure 21. Seatpan Reaction Forces.

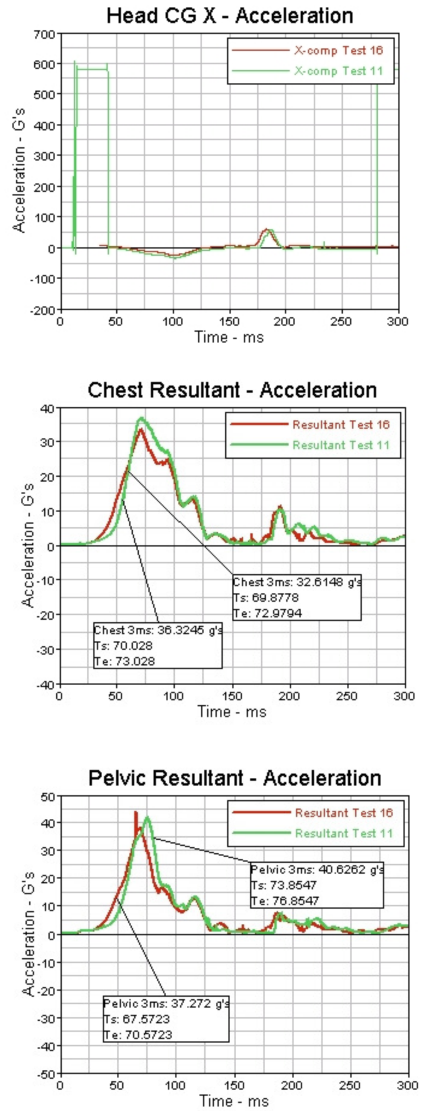

Figure 22. Head, Torso, and Pelvis Resultant Acceleration.

Three-Year-Old FAR 23.562 Type I Dynamic Performance Comparison: Aircraft Seat

The ISOFIX system provided a stable interface for the CRS. This test meets all FMVSS 213 and ECE R44 criteria. According to the video data, the CRS did not have any interaction problems with the aircraft seat cushion during the crash event. This test shows that, for this aircraft installation, it is not necessary to use the upper tether to prevent large CRS rotations or large head excursions. Further work is required to quantify lumbar load values on occupants other than at the 50th percentile. Even though the -458 lbf lumbar load is less than the -1500 lbf specified in the FARs for the 50th percentile, a proper scaling factor needs to be defined in the future for the 12-month-old, 3 YOLD, and 6 YOLD occupants.

Table 9.

Summary Injury Values 3 YOLD Type I Test

	VALUE	FMVSS 213	ECE R44	FAR 23 AND 25	Units
HIC 36	70	1000	NA	1000	
Chests Acc 3 ms Z +	9.81	NA	30	NA	g
Chest Acc 3ms RES	28	60	55	NA	g
Lumbar Force Z	-458	NA	NA	1500	lbf
Head Excursion	17.6	28.34	23.6	NA	in
Knee Excursion	NA	NA	NA	NA	in

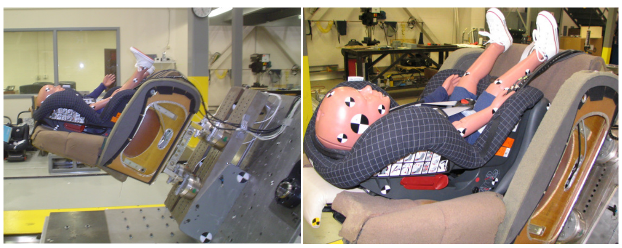

Figure 23. Three YOLD Test Setup.

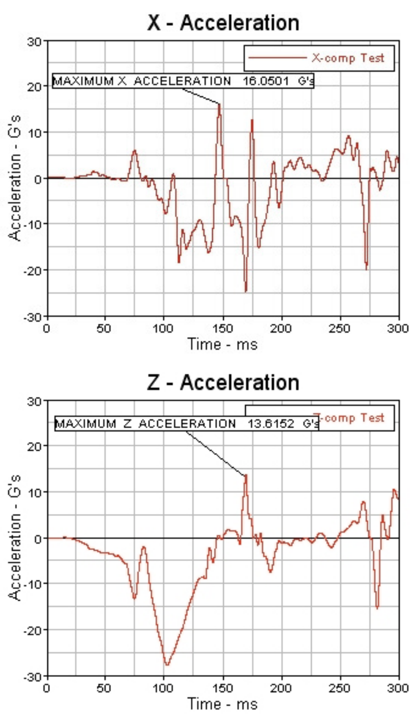

Figure 24. CRS Accelerations.

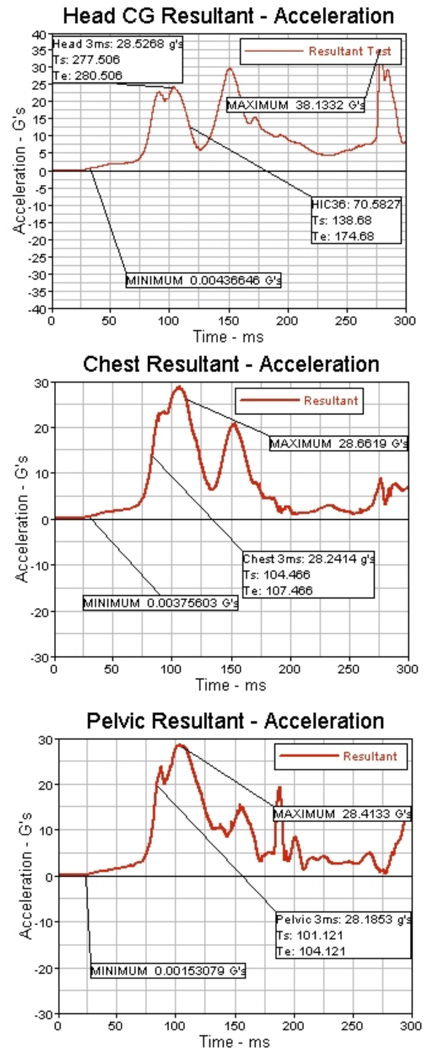

Figure 25. Head, Torso, and Pelvis Resultant Acceleration.

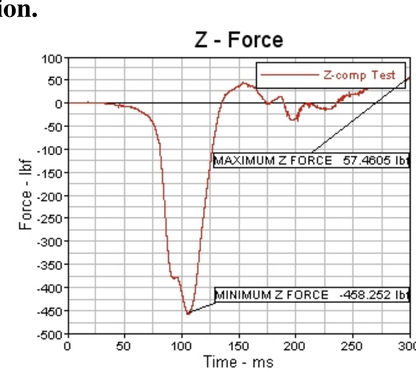

Figure 26. Lumbar Load.

<u>Three-Year-Old FAR 23.562 Type II ISOFIX System Dynamic Performance: Aircraft Seat</u>

The ISOFIX system provided a stable interface for the CRS. This test meets all FMVSS 213 and ECE R44 criteria. Note that no upper tether was used for the test in order to reduce the aircraft installation.

Table 10.

Summary injury values 3 YOLD Type II

	VALUE	FMVSS 213	ECE R44	FAR 23 AND 25	Units
HIC 36	435	1000	NA	1000	
Chests Acc 3 ms Z +	9.8	NA	30	NA	g
Chest 3ms RES	25	60	55	NA	g
Lumbar Force Z	-59	NA	NA	1500	lbf
Head Excursion	23.32	28.34	23.6	NA	in
Knee Excursion	23.2	36.02	NA	NA	in

Figure 27. 3YOLD Test Setup.

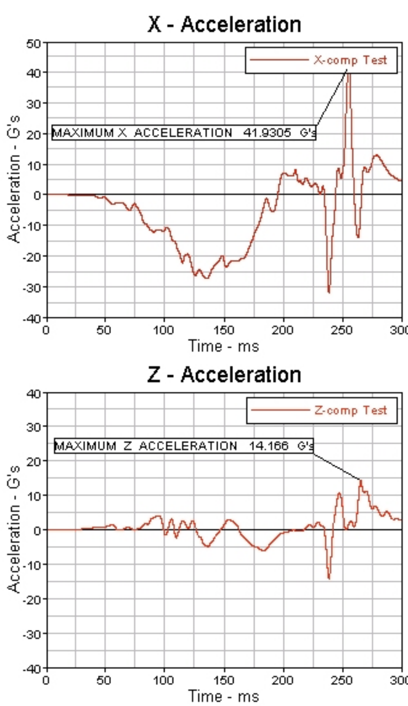

Figure 28. CRS Acceleration.

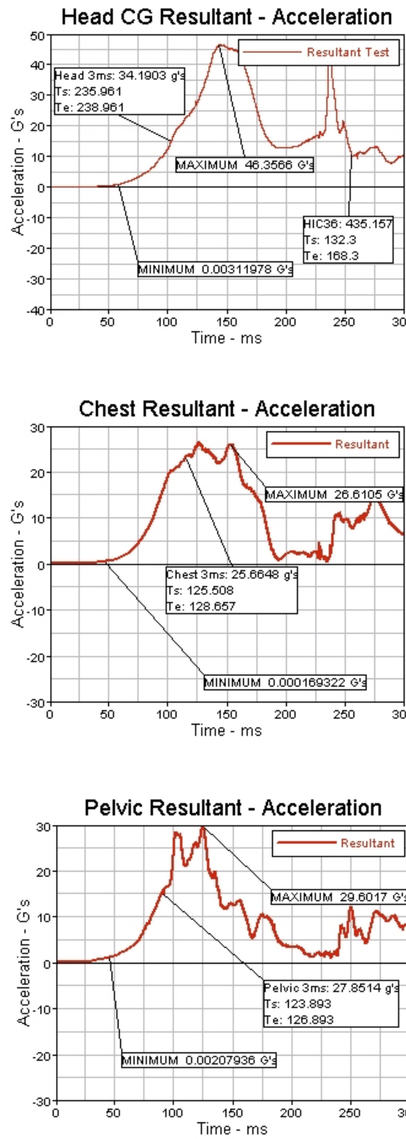

Figure 29. Head, Torso, and Pelvis Acceleration.

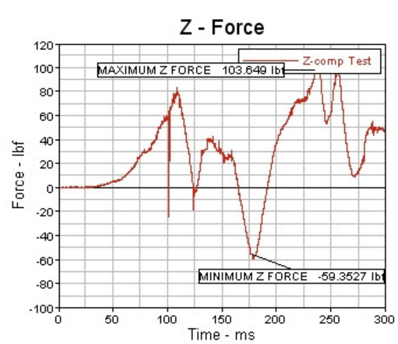

Figure 30. Lumbar Load.

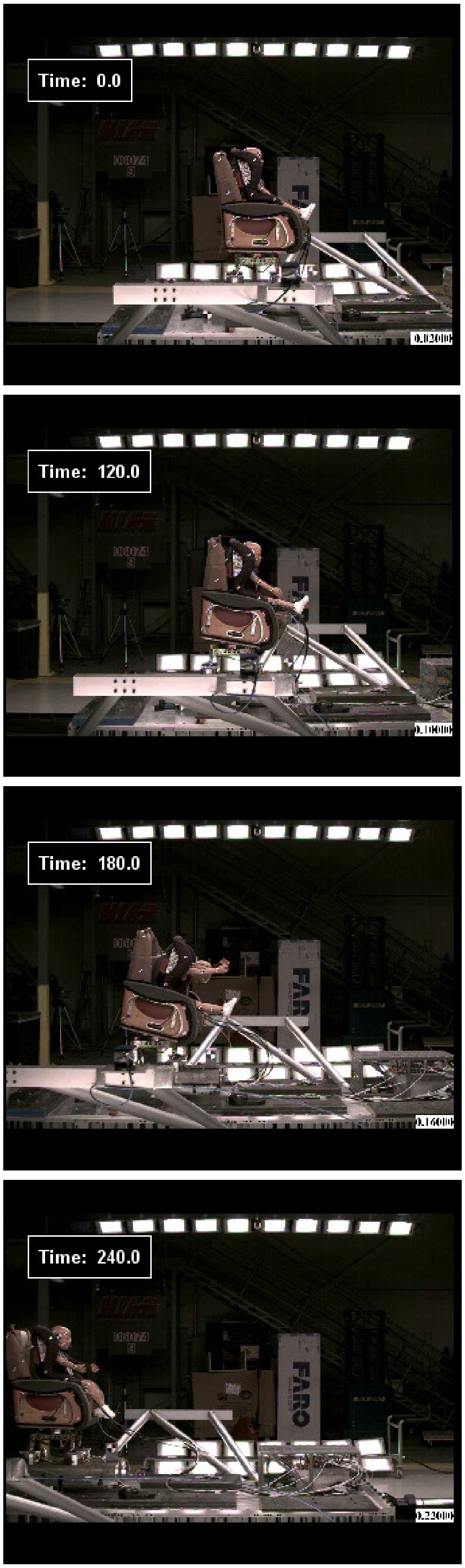

Figure 31. Three YOLD Kinematics.

CONCLUSIONS AND FUTURE RESEARCH

Based on the results from the dynamic sled tests conducted in this study, there is sufficient data to conclude that the ISOFIX and LATCH systems can solve the interface issues found in the past between the CRS and aircraft seats due to aircraft seatbelt incompatibilities. If aircraft seats in the future would be equipped with rigid anchors, the new CRS systems will provide the appropriate level of safety, and issues such as the large CRS excursions found in the past when the CRSs were secured by the aircraft two point belt system will be eliminated.

While this study provides an overview of the viability of the ISOFIX and LATCH systems, the following additional research needs to occur in order to develop aerospace standards and recommendations:

a) Additional dynamic and static testing with production Part 23 and 25 aircraft seats in order to address the following issues:

- Implementation of ISOFIX/LATCH anchor points in various Part 23/ 25 aircraft seat structure
- Effect of seat back break-over features found in current commercial aircraft seats
- Effect of different aircraft seat cushion materials in CRS performance
- The interaction with other occupants sitting in the row behind the CRS
- CRS/aircraft seat dimensional compatibility studies

b) Studies involving the application of FAR 25.561, 23.561, 25.785, and 23.785 inertial requirements on aircraft CRS attachments or the definition of new static requirements for the seat anchors.

c) Evaluation of CRS products of various manufacturers

d) Definition of a retrofit procedure to implement fixed anchorages on current aircraft seats, and the effect on their current certification status

e) Study the impact of requiring the usage of CRS on commercial aircraft operations and passengers, from both economic and ergonomic points of view

f) Definition of dynamic test criteria for CRS used in aircraft seats

g) Definition of lumbar load injury criteria to evaluate CRS performance

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