

An Assessment of Inflatable Seatbelt Interaction and Compatibility with Rear-Facing-Only Child Restraint Systems

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ABSTRACT

Ford Motor Company introduced the inflatable seatbelt system in 2011 and the system is now available in the second row of several Ford and Lincoln models. An important consideration is the interaction of the inflatable seatbelt system with child restraint systems (CRS). A comprehensive series of frontal impact sled tests, using a standardized test method, was conducted to compare the performance of rear-facing-only CRS installed using an inflatable seatbelt to the same CRS installed using a standard seatbelt. CRS models from several manufacturers in the North American market were tested both with and without their bases. CRABI 12 month old or Hybrid III 3 year old anthropomorphic test devices (ATD) were restrained in the CRS. The assessment included the ability to achieve a satisfactory installation with the inflatable seatbelt, comparisons of ATD and CRS kinematics, CRS system integrity, and comparisons of ATD responses. In all cases, acceptable installations of the CRS were achieved with the inflatable seatbelt system. When installed with the base, there was a statistically significant reduction in HIC36 for the ATDs restrained using the inflatable seatbelt compared to those installed using the standard seatbelt. The differences in peak resultant chest accelerations for the two seatbelt systems were not statistically significant and minor differences were noted in CRS and ATD kinematics. When installed without the base, HIC36 and peak resultant chest acceleration did not have statistically significant differences and kinematics were comparable. No system integrity issues were identified in CRS installed using inflatable seatbelts for either the installations with or without the base.

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INTRODUCTION

Ford Motor Company introduced an inflatable seatbelt system in 2011. The potential benefits of this system at reducing injury in dynamic events for some occupants have previously been shown by Sundararajan et al. [1]. A study by Rouhana et al. evaluated the injury risk to both in position and out of position children and small occupants from the static deployment of the inflatable seatbelt system showed the risk to be low. Given that the inflatable seatbelt system is available in the second row outboard seating positions, another consideration is its interaction with child restraint systems (CRS) when it is used to install a CRS.

Rear-facing child seats have been shown to be highly effective at protecting young children [3]. When used properly, CRS reduce fatal injuries by 71 percent for children less than 1 year old in passenger cars [4]. One type of CRS installed in a rear-facing configuration is rear-facing-only CRS. Rear-facing-only CRS typically consist of a convenience base which is intended to remain installed in a vehicle while a removable carrier with integrated harness restrains the child. This type of seat is a popular choice for infants given the convenience of the removable carrier. Older children are also able to use many of the currently available rear-facing-only CRS with many models having a weight limit of 35 pounds. This follows the American

Academy of Pediatrics guidance to keep children rear facing until, at a minimum, 2 years or until a child has outgrown either the weight or height limit of the CRS [5]. While the performance of CRS installed using LATCH or a lap belt is regulated by FMVSS 213, the performance with new safety system technologies such as the inflatable seatbelt are not typically studied [6]. Durbin et al, identified the need for further research to identify specific testing procedures in evaluating dynamic performance of rear row occupants and restraint systems such as the inflatable safety belt and cited specifically the consideration of use and performance with CRS [7]. This study assessed the interaction of inflatable seatbelts with rear-facing-only CRS when the inflatable seatbelt system is used to install the CRS.

The rear-facing-only CRS has unique considerations when evaluating the interaction with inflatable seatbelts. First, the effect of the inflation of the inflatable seatbelt on the system integrity of the CRS and the integrity of the attachment of the carrier to the base was of interest. Secondly, the compatibility of inflatable seatbelts with lock-offs included in many rear-facing-only CRS was another area of interest. Finally, compatibility of inflatable seatbelts with carrier without base installations was studied.

METHOD

A comprehensive series of frontal impact sled tests was completed on rear-facing-only CRS installed with an inflatable seatbelt simultaneously with a CRS installed with a standard seatbelt. Duplicate test benches were designed to incorporate either an inflatable seatbelt system or a standard seatbelt system. Test bench construction was similar to the proposed update to the FMVSS 213 frontal test bench as it is described in the 2015 Docket in terms of dimensions and material properties [8]. Though the benches were interchangeable and either seatbelt system could be installed on either test bench, for purposes of this study, the inflatable seatbelt system was always run on the right bench and the standard seatbelt system was always run on the left bench. The relationships between the inflatable seatbelt system and the standard seatbelt system anchorage points relative to the seating reference point in the production vehicle were maintained in the anchorage locations used in the test environment. Supplemental fixtures designed to interface with the test bench were used to position the shoulder belt retractor, D-ring, buckle, and lap belt retractor or floor anchor. Duplicate test benches and fixtures allowed the inflatable seatbelt system CRS installation to be run simultaneously with the standard seatbelt system CRS installation as shown in Figure 1.

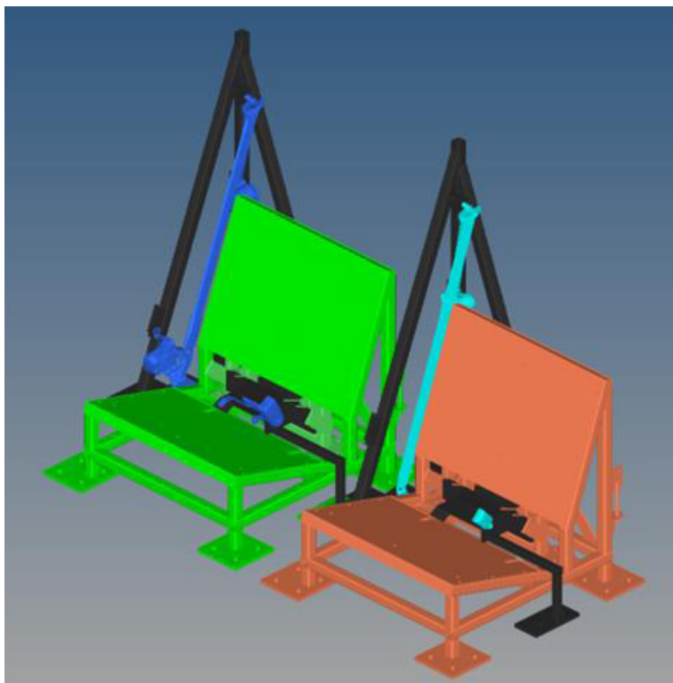


Figure 1. Test configuration with test benches (green/orange), retractor and buckle fixtures (black), and seatbelt systems (dark blue - inflatable seatbelt, light blue - standard seatbelt)

Installations of CRS and ATDs were performed by certified Child Passenger Safety (CPS) technicians following CRS manufacturer's owner manual instructions and CPS guidelines [9]. Specific pre-test seatbelt loads were not targeted nor measured during installation. Rather, the CPS guideline of checking that there is no more than 25 mm of side-to-side or front-to-back movement when the CRS is pulled at or near the seatbelt path was followed. A three dimensional positioning system (Aicon 3D Systems, Braunschweig, Germany) was used to ensure predetermined points on the CRS and ATD were

positioned in approximately the same positions relative to the restraint system used for the installation for the two seatbelt systems within a tolerance of 15 mm. A representative or representatives from each CRS manufacturer were present for all their respective tests. Representatives participated in the installation process and provided input on routing methods, adjustments, and positioning.

The inflatable seatbelt system and the standard seatbelt system were representative of the production system for the second row passenger right hand seating position in the 2011 Ford Explorer. The system has a pillar mounted shoulder belt retractor with a D-ring. The inflatable seatbelt system is fully described by Sundararajan et al. [1]. The inflatable seatbelt system consists of a shoulder portion containing a tubular belt within which an inflatable component (bag) is folded and packaged. The tubular portion of the shoulder belt transitions into standard seatbelt webbing, which is then wound onto a spool in a force-limiting retractor. The force-limiting level is approximately 5.25 kN. The lap belt is made of standard seatbelt webbing and is wound on a spool in a separate, non-force limiting retractor. The lap belt retractor is a switchable retractor which can be switched from an emergency locking retractor (ELR) to an automatic locking retractor (ALR). The ELR mode is used for adult occupants as it only locks in certain situations such as a sudden stop or quick extraction of seatbelt webbing. The ALR mode is used for CRS installations and is activated by extracting all the webbing from the retractor. Since the locking of CRS is accomplished by the switchable lap belt retractor, the shoulder belt retractor does not have this functionality. The shoulder belt retractor is an ELR only.

During inflation, gas is released from the inflator into the buckle, bypassing several mechanical seals to inflate the bag within the tubular webbing via the buckle and latch plate. Specialized stitching forms a seam in the tubular webbing allowing the bag to fully deploy to approximately 150 mm in diameter within 25 ms. Additionally, the bag uses a one piece woven construction and is coated with nylon to minimize porosity. The inflated pressure of the deployed bag is less than 20 psi and of ambient temperature due to the cold gas inflator. Unlike traditional airbags, any venting occurs through the mechanical seals in the buckle and latch plate when the bag is loaded. Inflation of the inflatable seatbelt was initiated 13 ms after the initiation of the pulse. Inflation of the inflatable seatbelt is tied to the front row seatbelt pretensioner deployment time in the production vehicle. The shoulder portion of the belt and lap belt attach to the sewn-on latch plate, thus there is no transfer of webbing between the lap belt and the shoulder belt.

The standard seatbelt system consists of a switchable shoulder belt retractor which can be switched from an ELR to an ALR. Unlike the shoulder belt retractor in the inflatable seatbelt system, the retractor in the standard seatbelt system does not have force limiting. The system has standard seatbelt webbing, a sliding latch plate, and a strap mounted buckle.

CRS from 12 different CRS manufacturers including Chicco, Evenflo, gb, Graco, Hauck, Peg Perego, SimpleParenting, UPPAbaby, Urbini, and others were tested. A total of 18 tests using 13 unique rear facing only models were run. Some CRS models were tested both with and without the base and others were tested either with the base or without the base. CRS carriers and bases were not reused in testing; a new CRS was used in each test. Either a 12 month old CRABI or a HIII 3 year old ATD was used. The selection of the ATD was based on CRS manufacturer recommendation. A summary of manufactures, models, and configurations tested is shown in Table 1.

Table 1. Summary of manufacturers, models, and configurations tested.

Test	Manufacturer	Model	ATD	Configuration
1	A	CRS 1	CRABI 12 MO	Carrier with Base
2	A	CRS 1	CRABI 12 MO	Without Base
3	B	CRS 2	CRABI 12 MO	Carrier with Base
4	C	CRS 3	CRABI 12 MO	Carrier with Base
5	C	CRS 3	CRABI 12 MO	Carrier with Base
6	C	CRS 3	CRABI 12 MO	Carrier with Base
7	D	CRS 4	CRABI 12 MO	Carrier with Base
8	D	CRS 4	CRABI 12 MO	Without Base
9	E	CRS 5	CRABI 12 MO	Carrier with Base
10	E	CRS 5	CRABI 12 MO	Without Base
11	E	CRS 6	CRABI 12 MO	Without Base
12	F	CRS 7	CRABI 12 MO	Carrier with Base
13	G	CRS 8	CRABI 12 MO	Carrier with Base
14	H	CRS 9	CRABI 12 MO	Carrier with Base
15	I	CRS 10	HIII 3 YO	Carrier with Base
16	J	CRS 11	HIII 3 YO	Carrier with Base
17	K	CRS 12	HIII 3 YO	Carrier with Base
18	L	CRS 13	HIII 3 YO	Carrier with Base

The average of the FMVSS 213 pulse corridor was used resulting in a change in velocity of approximately 30 mph. The pulse average and variability relative to the corridor are shown in Figure 2. ATD head and chest longitudinal, lateral, and vertical accelerations were collected. Consistent with FMVSS 213, no other ATD instrumentation data was collected. Seatbelt load cells were positioned near the shoulder belt retractor, near the D-ring, and near the floor anchor or lap belt retractor for both seatbelt systems. SAE J211 filtering practices were followed [10]. Head and chest accelerations were used to calculate HIC36 and peak resultant chest acceleration, respectively. Post test video reviews were completed to exclude any peak values occurring during the rebound phase.

High speed video cameras were used at a sample rate of 1 kHz. Cameras were positioned on the side, front, and rear of the CRS along with a combined view of the D-ring and shoulder belt retractor. Since both seatbelt systems represented a passenger side configuration, the front and rear views had the same perspective for the two seatbelt systems. The side view cameras were positioned on the outside of the sled which resulted in a difference in camera perspective. The camera was positioned on the retractor/D-ring side for the inflatable seatbelt system while the camera was positioned on the buckle/latch plate side for the standard seatbelt system as shown in Figures 3 and 4.

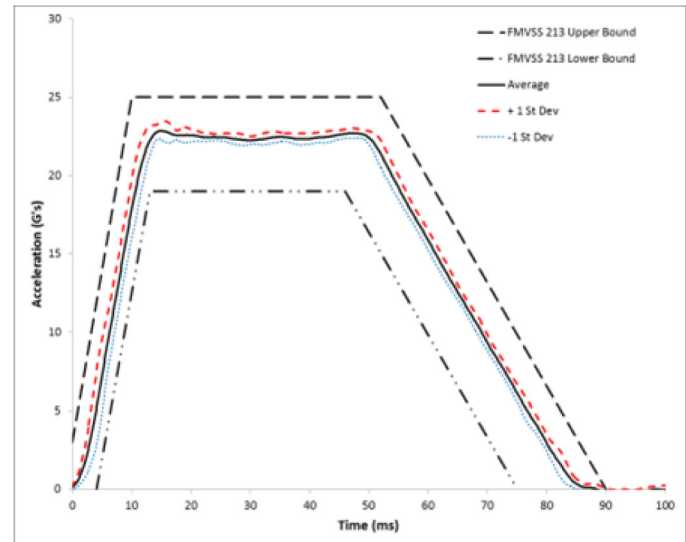


Figure 2. Target pulse

A post test review of CRS tested with both the inflatable seatbelt and the standard seatbelt was performed to identify any potential CRS system integrity issues and any abnormalities. FMVSS 213 includes system integrity requirements which cover four areas; structural integrity, adjustment position, exposed openings, and seating surface angle. The structural integrity portion does not allow complete separation of any load bearing structural element or partial separation which creates surfaces with small radii or protrusions larger than a certain size. Though not limited to the items included in the FMVSS 213 System Integrity requirement, it was used as a general guide for the post test review [11]. The seatbelt webbing, inflatable seatbelt cushion, and all seatbelt hardware were reviewed post test as well for any abnormalities.

Tests were conducted only to compare CRS performance when installed using the two different seatbelt systems. The results do not reflect performance to FMVSS 213 compliance testing, which uses a different standard vehicle seat and seatbelt system.

Twelve different rear-facing-only CRS installed on their bases were tested with the inflatable seatbelt system. One CRS model was tested with three different seatbelt routings relative to the lock-off for a total of 14 tests. The same model CRS installed using the standard seatbelt system was run simultaneously on the second test bench. Example installations are shown in Figure 3 for both the standard seatbelt and the inflatable seatbelt. The typical base installation has a single seatbelt path through which a lap and shoulder seatbelt are routed together from the retractor side of the base to the buckle side. This seatbelt path places the inflatable portion of the inflatable seatbelt directly between the installed base and the carrier which locks in place above it. Upon inflation, the inflatable seatbelt will apply upward force on the carrier. In all but one CRS carrier with base installation, the inflatable portion of the inflatable seatbelt was positioned between the base and the carrier. The one exception was a base which has slots on its seatbelt path allowing the lap belt to be placed in the base belt path and the shoulder belt to remain outside the interface between the base and carrier.



Figure 3. Carrier with base installations; left- standard seatbelt right-inflatable seatbelt installation

Four rear-facing-only CRS carrier without base tests were run with the inflatable seatbelt system. These installations typically consist of the lap belt routing under two tabs or slots in the carrier or in the rotatable carrier handle, one on each side of the carrier. Example installations are shown in Figure 4. Since the locking mechanism for the inflatable seatbelt system is in the lap belt retractor, these installations are similar to a lap belt only installation. The inflatable shoulder belt lies slack against the vehicle seat back between the D-ring and the buckle making its interaction with the carrier minimal.



Figure 4. Carrier without base installations; left- standard seatbelt right-inflatable seatbelt installation

An alternative installation method for rear-facing-only carrier without base configurations called the “European Routing” was of particular interest. In this seatbelt routing, the lap belt path is the same as a typical installation, but the shoulder belt is routed around the back of the carrier as shown in Figure 5. This installation method would put the inflatable portion of the inflatable seatbelt system in direct contact with the carrier. While a few CRS manufacturers do recommend that this routing be used when sufficient seatbelt webbing is available, none of the CRS in this study were able to be installed with this routing due to the lack of sufficient length of the shoulder belt in the inflatable seatbelt system.



Figure 5. European seatbelt routing

Statistical Analysis

Paired t-test analysis was completed to test for statistically significant differences between the occupant response values of HIC36 and peak resultant chest acceleration for the ATD restrained in the CRS installed with the inflatable seatbelt and the ATD restrained in the CRS installed using the standard seatbelt. A resulting P value of <0.05 was considered statistically significant. The analysis was completed for the carrier with base CRS separately from carrier without base CRS due to the fundamental differences in CRS installation belt paths. Twelve month old CRABI and HIII 3 year old ATD were combined for this analysis.

RESULTS

A summary of HIC36 and resultant peak chest acceleration ATD responses for both seatbelt systems are shown in Table 2.

Table 2. Summary of occupant responses

Test Number	Occupant	Seat Type	Seatbelt System	HIC36	Resultant Peak Chest Accel (G)
1	12 MO	Carrier with Base	Standard	1151	56.3
			Inflatable	987	54.9
2	12 MO	Without Base	Standard	439	49.4
			Inflatable	478	48.9
3	12 MO	Carrier with Base	Standard	780	52.4
			Inflatable	706	52.2
4	12 MO	Carrier with Base	Standard	739	50.3
			Inflatable	860	50.8
5	12 MO	Carrier with Base	Standard	995	53.7
			Inflatable	664	55.2
6	12 MO	Carrier with Base	Standard	940	50.9
			Inflatable	651	50.6
7	12 MO	Carrier with Base	Standard	882	52.3
			Inflatable	824	51.8
8	12 MO	Without Base	Standard	376	46.0
			Inflatable	488	50.5
9	12 MO	Carrier with Base	Standard	809	52.5
			Inflatable	762	52.4
10	12 MO	Without Base	Standard	344	40.7
			Inflatable	363	42.2
11	12 MO	Without Base	Standard	288	44.8
			Inflatable	236	42.7
12	12 MO	Carrier with Base	Standard	591	56.3
			Inflatable	654	56.3
13	12 MO	Carrier with Base	Standard	857	55.3
			Inflatable	801	47.6
14	12 MO	Carrier with Base	Standard	767	53.7
			Inflatable	666	57.7
15	3 YO	Carrier with Base	Standard	636	49.1
			Inflatable	691	49.2
16	3 YO	Carrier with Base	Standard	780	57.0
			Inflatable	601	51.7
17	3 YO	Carrier with Base	Standard	945	63.1
			Inflatable	738	58.7
18	3 YO	Carrier with Base	Standard	537	51.6
			Inflatable	498	54.2

Carrier With Base

Occupant Responses

Figure 6 shows the difference in HIC36 values for the inflatable seatbelt system compared to the standard seatbelt. Of the 14 tests, 11 had a lower HIC36 value in CRS installed using inflatable seatbelts compared to the CRS installed using the standard seatbelt. The 3 tests which resulted in an increase in HIC36 with the inflatable seatbelt had responses below the limit set in FMVSS 213. The difference in