FRONT CENTER AIRBAG INFLATION INDUCED INJURY EVALUATIONS AND RESULTS

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ABSTRACT

General Motors LLC and the Takata Corporation have worked together to bring to production an industry first technology, called the Front Center Airbag, which is being implemented on General Motors' 2013 Midsize Crossover Vehicles.

The Front Center Airbag is an airbag that mounts to the inboard side of the driver front seat. It has a tubular cushion structure and it deploys between the front seating positions in far side impacts, near side impacts and rollovers, with the cushion positioning itself adjacent the driver occupant's head and torso.

This new airbag technology, which is in a different location on the vehicle than other airbags and deploys in a different manner, needed a set of demonstration tests for assessing inflation induced injury potential. This paper discusses the test setup conditions and presents the test results.

Occupants in surrounding seating positions were considered when developing the test approaches. Several of these were based on the Recommended Procedures For Evaluating Occupant Injury Risk From Deploying Side Airbags, prepared by the Side Airbag Out-of-Position Injury Technical Working Group in July 2003 for outboard mounted seat airbags [1]. Additional evaluation modes were developed through a General Motors peer review process involving internal experts. Three driver arm interaction conditions were tested, along with a driver torso in close proximity to the airbag configuration. A passenger head on console condition and infants in rear facing child seats installed in the middle seating position of the second row were also evaluated.

An example test of each approach is presented, with graphics of the test event at different points in time, and with the anthropomorphic test device's maximum recorded injury values included.

The results presented for inflation induced injury testing of the Front Center Airbag indicate that this technology can meet inflation induced injury goals for the range of conditions evaluated.

This paper also includes a brief summary of the Front Center Airbag hardware design and in-position performance. A sister paper containing field data, a detailed hardware description, and a detailed in-position performance summary for far side impacts has been published at the 2013 SAE World Congress. [2]

INTRODUCTION – THE FRONT CENTER AIRBAG

The Front Center Airbag is an airbag that deploys from the inboard side of the driver's seat, as illustrated in the deployment sequence in Figure 1.

Figure 1. Front Center Airbag Deployment Sequence.

The Front Center Airbag is packaged in the side of the seat inside a pocket in the seat foam and mounts directly to the seat frame. When commanded, the airbag cushion deploys through the side trim of the seat similar to a conventional outboard seat mounted side impact airbag. The cushion is designed to initially deploy upward and forward and then to wrap around the driver occupant, providing head and torso coverage to that occupant.

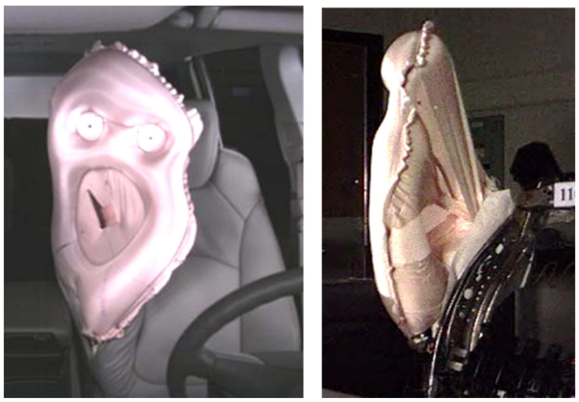


Figure 2. The Cushion Design.

The cushion is a unique shape when compared to other airbags. As shown in Figure 2, the cushion has a tubular structure that has a "figure 8" shape. A tube filled with pressurized gas becomes very rigid and is difficult to bend, so the tubular structure contributes to the cushion's lateral stiffness and resulting occupant restraint.

Two tethers are used in the cushion design to help curve it toward the driver occupant. One external tether routes from the top of the cushion to its seat anchoring location. A second, lower tether routes fore-aft on the cushion and passes through two slots in the uninflated lower region. Both tethers are shorter in length than the surrounding cushion panels and, as a result, curve the cushion toward the occupant when the cushion is under pressure. These two tethers also serve to add to the aforementioned lateral occupant restraint.

The deployment mechanization for the Front Center Airbag commands airbag deployment in near side impacts, far side impacts, and rollovers. The airbag is not deployed in frontal impacts or rear impacts so that it will be available for deployment if the vehicle is involved in a multiple impact event where a later side impact or rollover occurs.

IN-POSITION FAR SIDE IMPACT PERFORMANCE

The primary purpose of the Front Center Airbag is to provide restraint and cushioning when a front seated occupant is in a far side impact, where the impacting object is on the opposite lateral side of the vehicle from the occupant.

The Front Center Airbag was evaluated in far side impacts with both one and two front occupants present.

In-Position Demonstration Testing With A Seat Belted Single Front Occupant

A brief introduction to the Front Center Airbag's in-position performance is provided. If more detail is desired, the SAE paper written on Front Center Airbag in-position performance should be reviewed. [3]

Figure 3 shows occupant kinematics from two far side impact, 32 kph (20 mph) oblique pole sled tests run without and with a Front Center Airbag [4]. For these technology demonstration tests, a rigid sled test buck was propelled from the passenger side to simulate an oblique pole barrier impact.

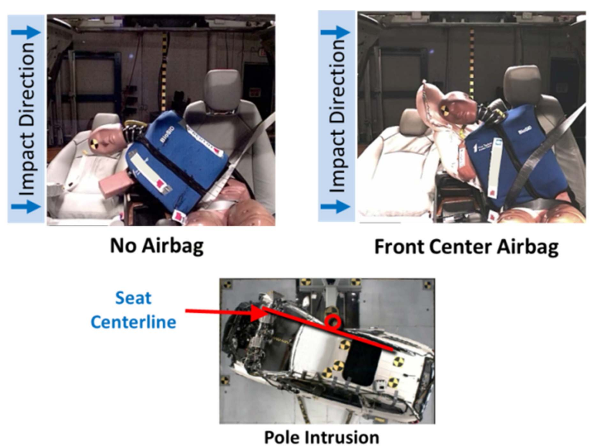


Figure 3. Single Occupant Oblique Pole Impact Without and With the Front Center Airbag.

In the sled test without the Front Center Airbag, the Anthropomorphic Test Device (ATD) pivots laterally over the center console. At maximum excursion, the top of the ATD's head is approximately at the centerline of the adjacent seating position. This is the approximate location of the pole penetration in the 32 kph (20 mph) oblique pole test condition, as can be seen in the overhead illustration of such a test at the bottom of Figure 3.

In the test with a single far side occupant and the Front Center Airbag, the Front Center Airbag acted as a restraint, reducing the ATD's lateral motion toward potential injury sources that would have been present in a full vehicle environment. In addition, the Front Center Airbag reduced occupant interaction with the center console and lowered rib deflections in the tested condition.

In-Position Demonstration Testing With Two Seat Belted Front Occupants

Figure 4 shows occupant kinematics from two far side impact oblique pole tests that were also run with and without a Front Center Airbag [5].

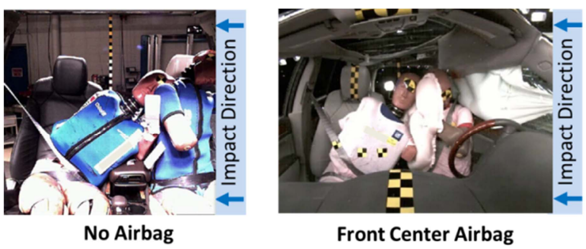


Figure 4. Two Occupant Oblique Pole Impact Without and With the Front Center Airbag.

In the demonstration test without a Front Center Airbag, conducted on a rigid sled buck, the passenger ATD's head contacts the driver ATD's shoulder region, after passing over the center console. A Head Injury Criteria (HIC) injury value of 3907 or 558 percent of the Injury Assessment Reference Value (IARV) was recorded for the passenger ATD.

The demonstration test conducted with the Front Center Airbag is shown on the right of Figure 4. In this full vehicle pole barrier test, both occupants are cushioned by the Front Center Airbag. For this test, the passenger ATD's HIC was reduced to 56 percent of the IARV and the Driver ATD's HIC was 22 percent of the IARV. For this condition with an adjacent occupant present, the Front Center Airbag acted as a cushioning element between the occupants. The passenger ATD's head did not make direct contact with the driver ATD, which reduced the magnitude of the passenger ATD's HIC value and the associated potential for head injury.

INFLATION INDUCED INJURY EVALUATIONS - METHODS AND DATA SOURCES

The Front Center Airbag is a very different restraint system from anything else in production. Because of this, several new inflation induced injury related demonstration test conditions were developed to assess the airbag's performance. Some of these conditions were based on the Recommended Procedures For Evaluating Occupant Injury Risk From Deploying Side Airbags, prepared by the Side Airbag Out-of-Position Injury Technical Working Group (TWG) for outboard mounted seat airbags [6]. Additional conditions were developed based on a General Motors internal peer review process, considering the inflation characteristics of the airbag and the potential occupant positions in close proximity to the deploying Front Center Airbag.

As a result of this work, several driver arm interaction conditions were developed for technology demonstration, along with a position where the driver torso is in close proximity to the airbag. Occupants in surrounding seating positions were also considered when developing the conditions. A position with the passenger head on the center console and a condition with infants in rear facing child seats installed in the middle seating position of the second row were included.

The setup procedures and example tests of each condition follow with images of the test events at different points in time. The anthropomorphic test device's maximum recorded injury values are also provided for each test.

ARM INTERACTION DEMONSTRATION TESTS WITH THE FRONT CENTER AIRBAG

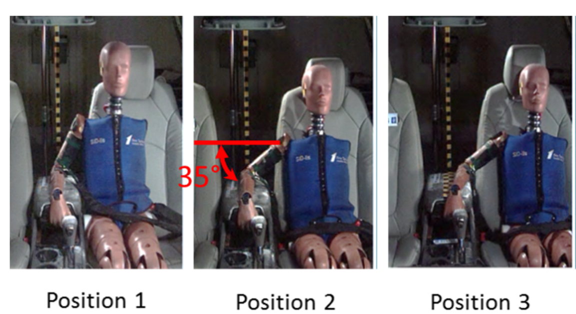


Figure 5. Arm Interaction Test Conditions.

Arm interaction was assessed in several Front Center Airbag demonstration test deployments. Three similar test conditions were developed to assess a range of arm and occupant positions using the existing Side Airbag Out-of Position Injury Technical Work Group (TWG) conditions as a basis [7]. The three positions, labeled Position 1, Position 2, and Position 3, are shown in Figure 5. A SID-IIs ATD with the enhanced instrumented arm was used, the seat was set at the design seat back angle as well as the mid-fore aft location, and the center console (adjustable in the vehicle-specific test environment), was positioned in the full forward position. The front passenger seat was set in a position to mirror the driver seat. Similar to the setup procedure found in the TWG conditions for outboard seat-mounted side airbags, the arm was positioned so that the rearward surface of the elbow was tangent to the forward edge of the seat bolster with the under-side of the arm resting on a horizontal surface, that being the center console for all three conditions.

In addition for these tests, the ATD's upper arm skin was rotated so that the inner surface and the slit in the arm skin typically adjacent the torso were positioned forward on the arm, as shown in Figure 6. Tape was placed over the slit in the arm skin, as shown in Figures 6 and 7, and around the elbow, as shown in Figure 7, to prevent the deploying airbag cushion from entering an arm region at a location without skin. In earlier testing, it was noted that the deploying cushion could enter these openings in the ATD's arm skin, so these measures were adopted to create a more biofidelic interaction with the ATD's arm.

Figure 6. Rotated Upper Arm Skin And Applied Tape.

Figure 7. Tape Applied To Upper Arm Skin And Elbow Region.

For Position 1, the ATD was located with the elbow centerline at the vehicle centerline and the torso against the center console. This condition follows the intent of the TWG 3.3.3.7 position [8] for the outboard seat mounted airbag as much as possible, with the ATD being positioned with the torso vertical in the front view. The TWG specified instrumented arm and associated performance criteria (130 Nm humerus / upper arm bending moment and 44 Nm ulna / forearm bending moment) were also utilized.

Vehicles can have different width center consoles, so it was decided that an elbow centerline position at the console centerline was a reasonable approach for the test condition. In addition, the test setup procedure allows the front seat to be raised or lowered to help the ATD achieve the elbow position at the console centerline. A small block can also be positioned under a portion of the ATD's buttocks to keep it from tipping laterally.

The hand was placed at the console centerline and the console mounted shifter was placed in the drive position. The set up procedure calls for the hand to be placed on the shifter if the shifter position matches the hand position. For the results shown, these positions did not match. The arm, hand and shifter were powdered on all surfaces (including touching surfaces) with baby powder prior to deployment to achieve representative / realistic frictional characteristics on the rubber ATD skin as is typical for tests in the referenced TWG procedure [9].

Finally, the ATD's shoulder construction played a role in the setup procedure as the amount of lateral arm rotation away from the ATD's torso is limited by the SID-IIs ATD's shoulder construction. In order to keep the arm away from its lateral travel stop on very tall or very wide center consoles, a criterion was added to limit the initial arm position to a location where the arm could still be rotated (abducted) an additional 5 degrees laterally away and more upward from the torso from its initial position on the center console. If this criterion cannot be achieved, the test procedure calls for the elbow position to be modified to be closer to the ATD, so as not to limit/prevent motion of the arm in the test.

At the time of this testing, both the Hybrid III and the SID-IIs ATDs were capable of using the enhanced instrumented arm. A picture of each shoulder construction follows.

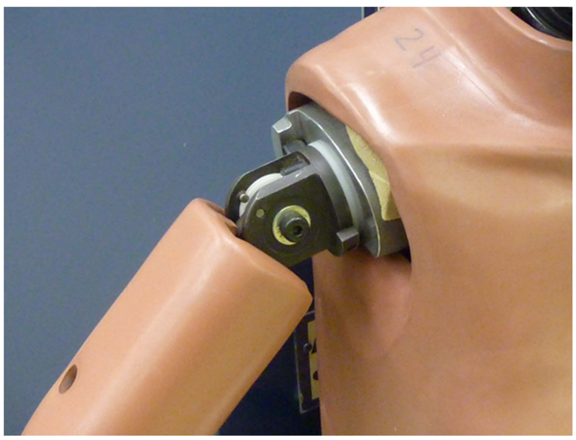


Figure 8. Hybrid III Shoulder Construction (Instrumented Arm Not Mounted In this Picture).

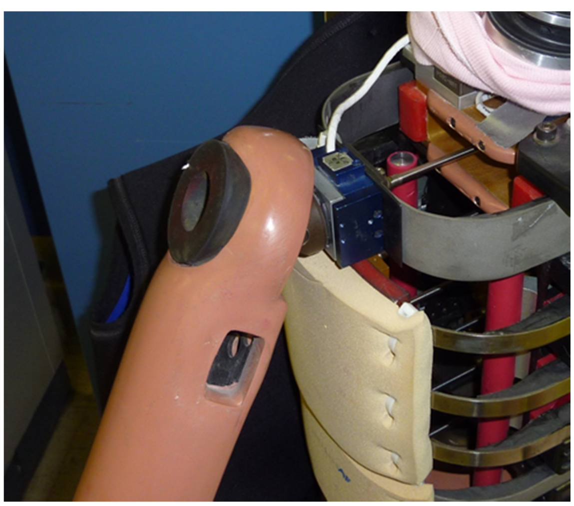


Figure 9. SID-IIs Shoulder Construction (Instrumented Arm Not Mounted In This Picture).

The Hybrid III has a more rigid shoulder construction. The clevis joint and rigid torso mounting do not enable significant forward arm motion once the upper arm is rotated laterally away from the ATD's torso. The SID-IIs ATD has a more compliant torso mounting via the upper metal torso ring structure and a less resistant joint torque, which together enable forward arm motion with respect to the torso when the upper arm is positioned laterally away from the torso in an abducted position. Because of this, the SID-IIS was selected for testing, as an actual occupant's arm can be pushed forward relative to the torso by the deploying cushion.

Position 2 uses the same setup guidance as Position 1 with the elbow centerline at the console centerline, with the exception that the torso is positioned outboard from the center console in order to obtain an upper arm angle 35 degrees from horizontal.

Position 3 uses the same ATD setup guidance as the first two positions, but the ATD is placed at the seat centerline and the elbow centerline is positioned in a more natural location. The seat height is adjusted to laterally position the elbow centerline approximately 40 mm inboard of the console's side wall. The hand is placed at the console centerline and is also positioned on the shifter if the shifter has a location under the hand when in the drive position.

Kinematics views showing the arm performance for these three demonstration test positions are shown in Figure 10. The maximum injury value recorded for the instrumented arm was 54 percent, which is lower than the TWG research value with significant margin. In Position 1, the maximum injury value of 23 percent of upper arm moment occurs when the arm is contacted by the cushion at 14 ms. The maximum injury value of 41 percent of lower arm moment in Position 2 occurs when the wrist contacts the back of the shifter and becomes constrained behind it at 73 ms. The maximum injury value of 54 percent of lower arm moment in Position 3 occurs when the elbow reaches full extension at 75 ms.

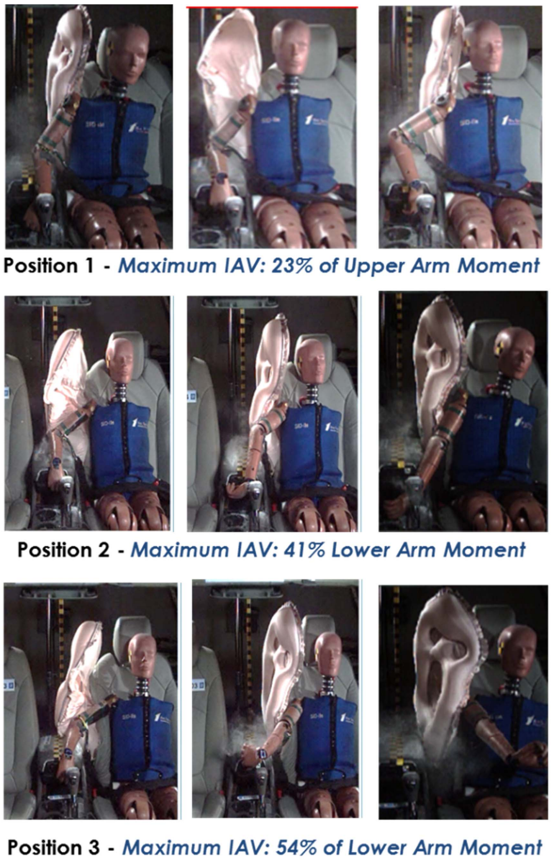


Figure 10. Arm Interaction Test Results.

OUT-OF-POSITION OCCUPANT DEMONSTRATION TESTS WITH THE FRONT CENTER AIRBAG

Two out-of-position test conditions were developed for front seat occupants to assess the Front Center Airbag's performance.

For the driver seat position Front Center Airbag demonstration test deployment, an outward facing SID-IIs ATD was positioned with its back touching the center console and the rearward arm horizontal, as shown in Figure 11. This position mirrors TWG position 3.3.3.6 [10] with the seat full rear full down, seat at the design back angle, and the center console bin also in a full rear position. The associated TWG performance criteria for the SID-IIs ATD were also utilized.

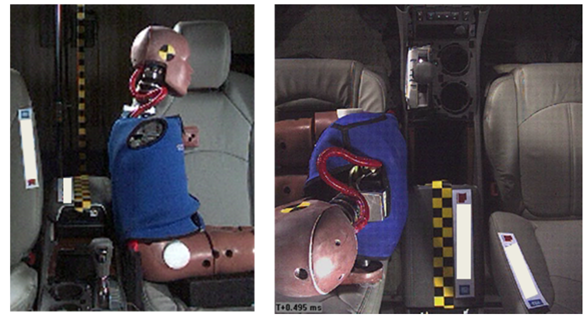


Figure 11. The Outward Facing ATD Test Condition.

The intention of the outboard seat mounted side airbag TWG 3.3.3.6. test is to maximize the head, neck and chest interactions by aligning the center of the top thoracic rib with the top edge of the seat-mounted airbag module. However, when adapting this procedure for the Front Center Airbag, it was not practical to raise the ATD to this level because this airbag package is significantly higher in the seat. In addition, the inflator nozzle is below the top of the module and better aligns with the ATD's rib cage when the ATD is not raised. For this test, the ATD was positioned with its back against the center console in an outboard-facing position, with its arm against the seatback at a 90 degree angle to its torso.

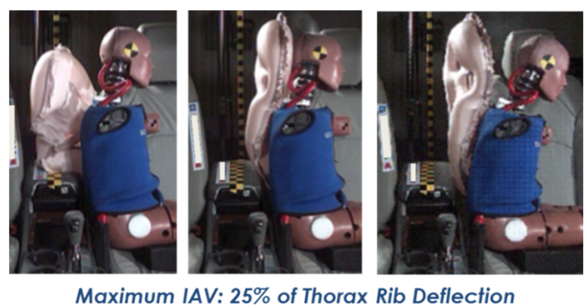


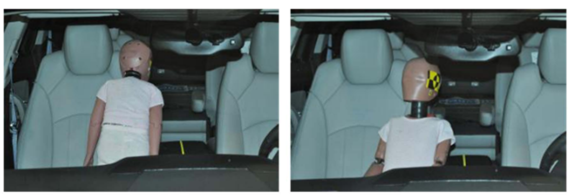
Figure 12. Outward Facing ATD Test Results.

Additional test procedure details are as follows: If needed, a block may be used under the ATD's thighs to help position its back against the console, but the presence of a block is not intended to raise the ATD. Like the TWG test, this test would typically be run with the seat in a full rear, full down position, but if the side door opening interferes with the ATD's legs, the seat can be moved forward the necessary amount to allow the legs to extend through the door opening. Finally, the back of the ATD's head is powdered before testing.

Figure 12 shows the test position and the corresponding demonstration test results which had a maximum injury value result of 25 percent of the IARV, recorded by the third thoracic rib at 17 ms when the cushion was expanding around the occupant and the lower tubular region was deflecting away from the seat bolster and the occupant torso.

For the passenger seat position, the TWG positions were adapted for this airbag application and were considered with passenger occupants. It was determined that there would not be significant airbag interaction with the ATD's head, neck, or torso. For reference, Figure 13 shows four of the adapted TWG positions.

Adapted TWG Position 3.3.3.3 With 3 Yr. Old ATD | *Adapted TWG Position 3.3.3.1 With 3 Yr. Old ATD*



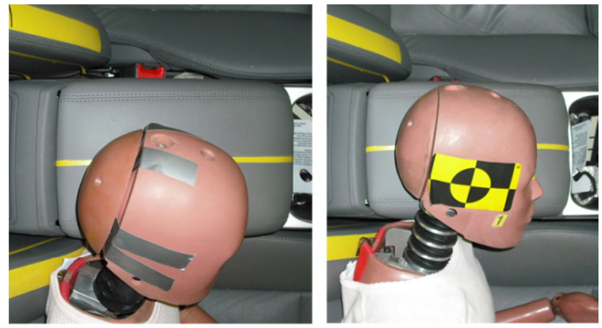
Adapted TWG Position 3.3.3.2 With 3 Yr. Old ATD | *Adapted TWG Position 3.3.3.5 With 6 Yr. Old ATD*

Figure 13. Adapted TWG Positions For The Passenger Seating Position

In addition, a test was devised to represent a sleeping occupant with the head resting on the console. Pictures of several different size children are shown in Figure 14 and the overhead views of the 6 year old and 10 year old ATDs are shown in Figure 15.

3 Yr. Old ATD Sized Child | *6 Yr. Old ATD Sized Child* | *10 Yr. Old ATD Sized Child*

Figure 14. Different Size Children With Their Head On The Console (Similar But Different Vehicle Environment).



6 Yr. Old ATD | *10 Yr. Old ATD*

Figure 15. Overhead Views Of The 6 Yr. Old And 10 Yr Old ATDs With Their Head On The Console (Similar But Different Vehicle Environment).

Based on these pictures, a 10 year old ATD was selected because this size occupant may be more likely to interact with the Front Center Airbag than a smaller occupant, as the head and neck extend further over the console.

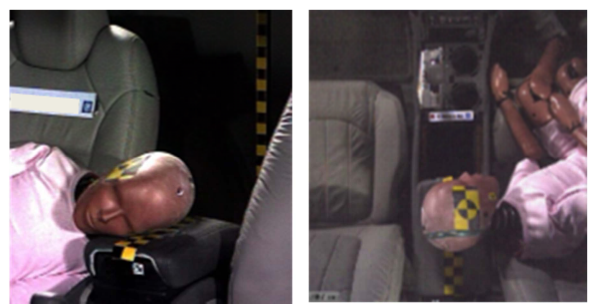
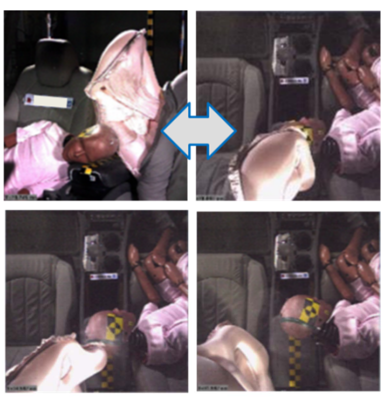


Figure 16. 10 Yr. Old ATD Head On Console Test Condition.

Figure 16 shows two views of the demonstration test position developed for the 10 year old ATD. The front seats are placed full rear at the design seat back angles and the driver seat is raised to a height that maximizes airbag interaction with the ATD's head. To maximize airbag interaction with the ATD, the driver seat is positioned at the lowest possible height adjustment where the bottom of the Front Center Airbag cushion deploys without significant console interaction. If there is cushion interaction with the console for the full range of vertical seat travel, the seat is positioned full up. Since the cushion shape tested had lateral interaction with the console during deployment at all seat heights, the test was run with the seat in the full up position.

The passenger seat that supports the ATD is set at the same height as the driver seat, when the passenger seat has vertical adjustment. If the console bin is adjustable, as in the cited example, it is set in the full rear position, or moved forward the minimum distance needed to support the ATD head for the test. This is done to limit the airbag escape paths and focus it on the ATD as much as possible.

The ATD is positioned with the left buttock on the seat and is tipped inboard so that the neck is positioned in a cross-vehicle orientation in the plan view. The left shoulder is touching the seat back and in some cases with wider consoles as shown in Figure 16, the side of the center console. If needed, a foam block can be placed under the left arm to support the ATD so the neck is not initially loaded and so both the head and left shoulder are in contact with the center console. The rearward, upper, top, and lower sides of the ATD's head are powdered prior to running the test. In order to prevent interference with the driver, in vehicles with laterally smaller consoles, the top of the ATD's head should not extend past the driver's side of the console top surface in the plan view into the driver's seating position.



Max. IAV: 17% of Upper Neck Bending Flexion

Figure 17. 10 Yr. Old ATD Head On Console Test Results.

Figure 17 shows the demonstration test results for this condition. The airbag cushion grazed the back of the head during deployment and the ATD's head moved forward about 100 mm in the test. The maximum injury value was 17 percent of the IARV for upper neck bending flexion at 41 ms, near the time when the cushion moved past the head.

Note that this head on console position can be viewed as an extreme condition, because a head positioned in this manner would tend to interfere with the location of the driver's inboard arm, which could affect the driver's use of the steering wheel.

REAR FACING CHILD RESTRAINT DEMONSTRATION TESTS WITH THE FRONT CENTER AIRBAG

Rear facing child restraints (RFCRs) were evaluated in demonstration test deployments with the child restraint installed in the second row center seating position. Prior to testing, more than 40 RFCRs were evaluated to determine the models and installation configurations that appeared to have the most potential for airbag interaction. The amount of padding, top tether storage location, top tether routing configuration, and adjustable handle positions were also considered when selecting the designs and conditions that were tested. For these tests, the front seat was positioned full rear and full down at the design seat back angle and the second row seat was moved full forward to maximize the potential for airbag interaction with the selected child restraints. This arrangement positioned the RFCRs in close proximity to the inboard side of the driver seat next to the Front Center Airbag module. In these tests, the front passenger seat was positioned full rear and full down at the design seat back angle (when enabled by the RFCRs) and also evaluated in a full forward position. The adjustable center console was positioned full rear to maximize airbag interaction with the child restraint unless this location interfered with the RFCRs.

The CRABI 12 ATD was used because its height results in a head position in closer proximity to the Front Center Airbag than that of the CRABI 6 ATD. However, the injury values were evaluated against the more stringent IARVs for the smaller 6 month old ATD. Tests were run with the ATD centered in the child restraint and with the ATD leaning toward the driver seat mounted Front Center Airbag. A 50th percentile Hybrid III Male ATD was added to the centerline of the driver seat to add ballast and assess airbag deployment kinematics and positioning. In addition, a Hybrid III 3 Year Old ATD was evaluated in this test series because some RFCRs can accommodate this size occupant. The top portion of Figure 21 illustrates a setup with the CRABI 12 ATD's head leaning toward the driver seat.

37 % Of Neck Twist, 3 % Of HIC Using 6 Month Old IARVs.

Figure 21. RFCR Test Condition With Infant Leaning And Passenger Seat Full Forward – Graco My Ride.

Table 1
Selected Belted ATD Second Row RFCR Tests

RFCR	ATD	Head Orient-ation	Pass. Seat Location	HIC	Max. Injury Value*
Graco My Ride	12 Month	Centered	Full Forward	0%	31%
Graco My Ride	12 Month	Leaning To Driver Side	Full Forward	3%	37%
Graco My Ride	12 Month	Leaning To Driver Side	Full Rear	3%	38%
Graco My Ride	3 Yr.	Leaning To Driver Side	Full Forward	0%	9%
Graco Snug Ride 30	12 Month	Centered	Full Forward	0%	16%
Graco Snug Ride 30	12 Month	Leaning To Driver Side	Full Rear	0%	12%
Graco Comfort Sport	12 Month	Centered	Full Forward	0%	10%
Cosco Comfy Carry	12 Month	Leaning To Driver Side	Full Forward	0%	14%
Britax Boule-vard	12 Month	Leaning To Driver Side	Full Forward	0%	4%
Top Tether Installed To Base Of Driver Seat					
Safety 1st Compl-ete Air 65	12 Month	Leaning To Driver Side	Full Forward	0	26%

Upper neck twist was the maximum injury value for all tests. The 6 month old ATD IARV for upper neck twist is 24 Nm.

The lower portions of Figure 21 show a deployment progression. The Front Center Airbag deployed forward and upward from its location inside the seat. While the airbag interaction resulted in some lateral motion of the child restraint in the example presented, the highest injury value measured was 37 percent of the IARV for upper neck twist (Mz moment). The peak response at 32 ms occurred as the child restraint moved laterally away from the driver seat, resulting in slight rotation of the ATD's head toward the driver side. Of all the tests conducted, the leaning CRABI 12, with the both driver and passenger seat located full rear, produced the highest response of 38 percent neck twist (The images for this test are not shown because the full rear passenger seat obscures the view of the deploying airbag.)

Table 1 indicates the maximum injury values recorded in a selection of the RFCR demonstration tests conducted. In addition, the following general observations could be made about this testing: a) the CRABI 12 ATD produced higher responses than the Hybrid III 3 Year Old ATD, b) there was little difference in CRABI 12 response when the passenger seat position was varied and also when the CRABI 12 seating orientation was varied. c) a top-tether attached from the RFCR to the base of the driver seat did not adversely affect the deployment of the airbag, d) there was no visible damage to any of the RFCRs or the deployed airbags, e) the RFCRs did not prevent the Front Center Airbag from getting into position, and f) the RFCRs did not direct the Front Center Airbag into the driver occupant.

CONCLUSIONS

The Front Center Airbag deploys forward from the inboard side of the driver seat and provides restraint to the driver in far side impacts by reducing this occupant's lateral motion across the vehicle toward potential intrusion, adjacent components, and the striking vehicle or object. The airbag can also provide cushioning between the driver and front passenger when present in side impacts and rollovers.

The General Motors and Takata team has spent significant engineering effort to minimize the inflation induced injury risk during Front Center Airbag deployment. As part of the development of this new technology, several out-of-position and arm interaction test conditions were conceived for technology demonstration. Some of these positions were based on existing TWG out-of-position test procedures [11] while others were developed independently. The conditions were developed with different size interior environments in mind and involve occupants in the seating positions that surround the Front Center Airbag. The Front Center Airbag has been developed and initially assessed using these conditions and has demonstrated performance that has met IARV goals with margin.

This Front Center Airbag technology is being implemented on the 2013 Buick Enclave, GMC Acadia, and Chevrolet Traverse.

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2. Thomas, S. D., Wiik, R. A., and Brown, J. E. 2013. "The Front Center Airbag." SAE 2013-01-1156
3. Ibid
4. Ibid, pgs 8, 9, 11.
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6. "Recommended Procedures For Evaluating Occupant Injury Risk From Deploying Side Airbags, prepared by the Side Airbag Out-of-Position Injury Technical Working Group, A joint project of Alliance, AIAM, AORC, and IIHS), Adrian K. Lund (IIHS), Chairman, First Revision – July 2003."
7. Ibid.
8. Ibid.
9. Ibid.
10. Ibid.
11. Ibid

DEFINITIONS / ABBREVIATIONS

ATD	Anthropomorphic Test Device
HIC	Head Injury Criteria
IARV	Injury Assessment Reference Value
IAV	Injury Assessment Value
kph	Kilometers per Hour
mm	Millimeters
Nm	Newton Meter
RFCR	Rear Facing Child Restraint
TWG	(Side Impact Out-of-Position Injury) Technology Work Group