

**Testing of Passenger Airbags with
12-Month-Old Infant CRABI Dummy to
Assess Injury Risk to Restrained Infants**

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BACKGROUND

More than 3.3 million driver airbags and more than 600,000 passenger airbags with people occupying right front seats have inflated in crashes in the United States. Experts agree that these airbag deployments have resulted in a net safety benefit. Deaths in frontal crashes are reduced about 26 percent among drivers using seat belts and about 32 percent among those not using belts. Similarly, deaths in frontal crashes are reduced about 14 percent among right-front passengers using belts and about 23 percent among those not using belts. The National Highway Traffic Safety Administration (NHTSA) estimates that the combination of an airbag plus a lap/shoulder belt reduces the risk of moderate and serious head injury by 81 percent, compared with a 60 percent reduction for belts alone. Despite this effectiveness, deaths are about 34 percent higher than expected among child passengers younger than age 10 (Insurance Institute for Highway Safety (IIHS), 1999a).

Airbag injury risk to children would be essentially eliminated if all children were properly restrained in the rear seats of passenger vehicles. State legislatures have responded to concerns about airbags injuring children by considering laws that would require children to ride in rear seats. Delaware, Louisiana, and Rhode Island already have passed such laws (IIHS, 1999b). Massive public information campaigns, such as NHTSA's "Buckle Up America" and the National Safety Council's "Air Bag & Seat Belt Safety Campaign," have tried to encourage parents and others who transport children to put them in rear seats. A recent survey shows these campaigns have been effective and that fewer children were riding in the front seats of passenger airbag-equipped vehicles in 1997 than in 1996 (Cammisa and Ferguson, 1998). Still, the authors found that 44 percent of those surveyed in 1997 had sometimes transported children in front seats within the previous 6 months. According to the survey, children rode in front seats because they wanted to and not because of some necessity (e.g., not enough rear-seat capacity or so the child's health could be monitored by the driver). Parents' desires to let their children ride in front seats are reflected in the Delaware law, which would allow children to ride in the front seats of cars with passenger airbags designed to be safe for children.

The federal government has proposed safety regulations intended to mitigate airbag injury risk to children. These regulations involve tests with crash dummies that represent small children. IIHS has conducted similar tests with dummies representing 6-year-old children and 12-month-old infants. This report describes the test methods and results using the 12-month-old infant Child Restraint Airbag Interaction (CRABI) dummy restrained in the front passenger seat of various passenger vehicle models. Tests methods and results using the 6-year-old child Hybrid III dummy are described in a separate report (Powell and Zuby, 1999).

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TEST CONDITIONS

Static (noncrash) in-vehicle airbag deployment tests were conducted using four different passenger vehicle models and the 12-month-old infant CRABI dummy in three different seating positions.

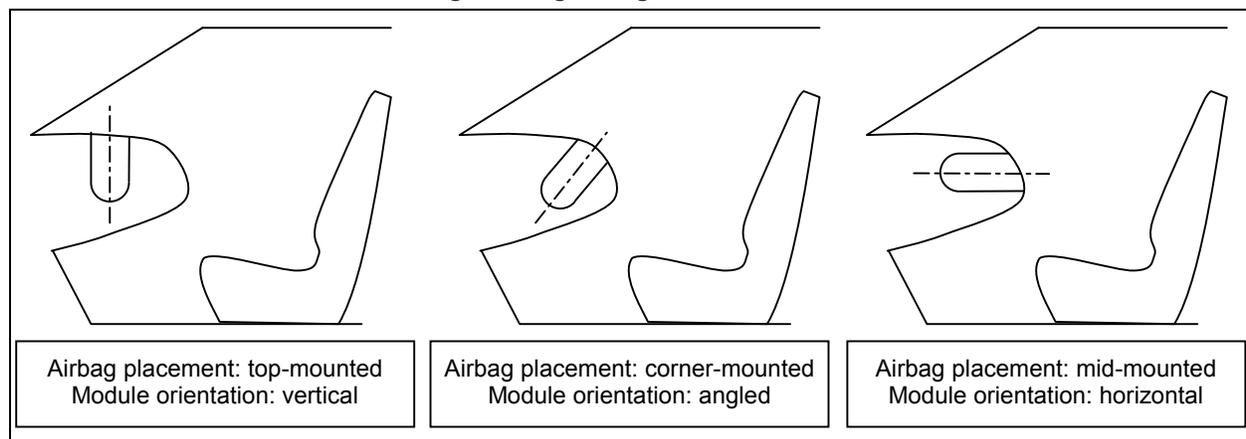
Vehicles/airbag configuration: The vehicle models tested were a 1990 Lincoln Town Car, 1996 Dodge Grand Caravan, 1996 Ford Taurus, and 1996 Volvo 850. These vehicles were chosen in part because they have different passenger airbag configurations (see Table 1).

Table 1
Passenger Airbag Configurations

Vehicle	Type of Door	Airbag Placement	Module Orientation
1990 Lincoln Town Car	Dual-flap, soft plastic door	Mid-mounted	Horizontal
1996 Dodge Grand Caravan	Dual-flap door, thin steel backing	Mid-mounted	Horizontal
1996 Ford Taurus	Tethered, unhinged single-flap door, rigid steel backing	Top-mounted	Angled
1996 Volvo 850	Tethered, hinged, hard plastic single-flap door	Corner-mounted	Angled

Airbag placement was defined as *top-mounted* if most of the airbag deployment opening was part of the top horizontal (or nearly horizontal) surface of the instrument panel, *corner-mounted* if the opening was nearly equally positioned between the top horizontal and vertical surfaces of the instrument panel, or *mid-mounted* if most of the opening was part of a vertical (or nearly vertical) surface of the instrument panel. Module orientation was defined as *vertical* if the orientation of the airbag module housing was closer to vertical than 45 degrees, *angled* if the orientation was nearly halfway between vertical or horizontal (i.e., at a 45-degree angle), or *horizontal* if the orientation was closer to horizontal than 45 degrees. Figure 1 illustrates three possible airbag placement/module orientation configurations. It should be noted that module orientation is not synonymous with deployment direction, which is necessarily three dimensional in all cases.

Figure 1
Passenger Airbag Configuration Nomenclature



Dummy positioning: For each vehicle, the passenger seat was positioned according to manufacturer’s compliance testing specifications for seat back angle, seat height, and seat pan angle. Three seating positions were used to place the CRABI dummy, secured in a forward-facing child restraint in the right front passenger seat, at different locations relative to the airbag: a worst case full-forward position, a 3/4-forward position, and a best case full-rearward position.

NHTSA (1982) conducted sled tests to evaluate the CRABI dummy’s design and observed that the neck shear forces and extension bending moments were higher in tests with a passenger airbag from a Lincoln Town Car than in tests without the airbag (Table 2). The neck bending moments measured in the airbag tests were much greater than the respective injury assessment reference value (IARV) for the CRABI dummy, compared with that measured in the no-airbag test, which was less than the IARV. The high extension moments seemed to result from the airbag expanding under the chin, forcing the neck rearward. This type of loading mechanism has been described as causing some of the fatal injuries to children in real-world crashes. The IIHS 3/4-forward tests were intended to place the dummy in a similar position as the dynamic test, and the 1990 Lincoln Town Car was included in the IIHS tests to determine whether the static test condition could reproduce the loading mechanism originally observed in the NHTSA tests.

Table 2
Injury Measurements – NHTSA Sled Tests with Lincoln Town Car Passenger Airbag and CRABI Dummy

	Peak Head Acceleration (g)	Neck A-P Shear Force (N)	Neck Extension (Nm)	Chest 3 ms Clip (g)
IARV	80*	None	25**	40**
With airbag (1st test)	51	912	36	65
With airbag (2nd test)	79	904	42	69
Without airbag	69	527	7	46

*NHTSA, 1996

**Critical values for calculation of neck injury criterion (N_{ij}) and combined thoracic index (CTI), which were proposed in the notice of proposed rulemaking to upgrade Federal Motor Vehicle Safety Standard 208 (Kleinberger et al., 1998).

High-speed videotape of the NHTSA sled tests was reviewed to determine the position of the CRABI dummy with respect to the airbag cover at various times during the tests. In the tests, the seat back of the standard test seat flexed forward, the child restraint slid and tipped forward, and the CRABI dummy’s head and shoulders moved forward relative to the restraint prior to airbag deployment. In the first test, the dummy’s face was approximately 52 cm from the airbag module cover at the time of deployment. By the time the airbag contacted the dummy’s face, it had moved within 45 cm of the cover.

The child restraint used in the NHTSA sled tests was a forward-facing Evenflo Scout, but a Century 2000 restraint was chosen for the IIHS tests because its smaller side bolsters provided a less obstructed view of the CRABI dummy for the high-speed cameras. The Century 2000 is a convertible child restraint that has a T-shield type of belt system. The restraint was configured in the upright

forward-facing position for all tests and installed in each vehicle according to the manufacturer instructions. The CRABI dummy was properly secured in the restraint. To simulate the position of the dummy relative to the child restraint observed in the NHTSA tests, two pieces of foam were inserted behind the dummy's shoulders after the T-bar straps of the restraint were tightened, forcing the dummy's torso forward against the straps.

Full- and 3/4-forward tests were conducted in the Dodge Grand Caravan, Ford Taurus, and Volvo 850, and 3/4-forward and full-rearward tests were conducted in the Lincoln Town Car. Table 3 lists for each test the pretest distance from the CRABI dummy's face to the airbag cover. After testing was completed, it was discovered that the dummy had been inadvertently mispositioned in the Volvo 850 3/4-forward test. In this test, with the vehicle seat in the desired position, the foam padding behind the dummy's shoulders pushed the dummy forward enough such that it was closer to the airbag module than in the Volvo 850 full-forward test.

Table 3
Pretest Distance from CRABI Dummy's Face to Airbag Cover

Vehicle	Full-Forward Position (cm)	3/4-Forward Position (cm)	Full-Rearward Position (cm)
1990 Lincoln Town Car	n/a	52	65
1996 Dodge Grand Caravan	44	48	n/a
1996 Ford Taurus	42	45	n/a
1996 Volvo 850	52	49	n/a

Dummy instrumentation: The CRABI dummy used in these tests simulates the size and weight of a 50th percentile 12-month-old infant. The monitored parameters for the tests consisted of four head accelerations (one along the anterior-posterior (A-P) axis, one along the lateral-medial (L-M) axis, and two along the inferior-superior (I-S) axis), six upper neck loads (A-P and L-M shear forces, axial force, A-P and L-M bending moments, and the twisting moment about the I-S axis), and three chest accelerations (A-P, L-M, and I-S).

Data were collected at 10,000 samples per second. Head accelerations and neck shear forces were filtered to Society of Automotive Engineers Channel Frequency Class (SAE CFC) 1000 (SAE, 1988). Neck bending moments were filtered to SAE CFC 600, and chest accelerations were filtered to SAE CFC 180.

Neck flexion/extension bending moments were measured on the CRABI dummy at a point 5.842 mm above the location of the occipital condyle. The flexion/extension moments therefore were translated to the occipital condyle location by including the moment (in Nm) induced by the A-P shear force (in N) as

$$\text{occipital } M_{A-P} = M_{A-P} + [0.005842(F_{A-P})].$$

Neck injury indices were calculated for four combinations of neck loading: tension-extension, tension-flexion, compression-extension, and compression-flexion. These indices were developed by NHTSA (Kleinberger et al., 1998) to evaluate the injury risk associated with axial loading and flexion/extension bending moments acting simultaneously on the neck.

The head rotational acceleration about the Y-axis was calculated using

$$\alpha = (A_{I-S2} - A_{I-S_{cg}}) / 0.07112,$$

where A_{I-S2} is the head I-S acceleration (in m/s^2) at a point on the midsagittal plane 0.07112 m away from the center of gravity and $A_{I-S_{cg}}$ is the I-S acceleration at the head's center of gravity.

High-speed photography was used to record the airbag deployments. Two cameras, one at 2,000 frames per second and the other at 500 frames per second, were positioned perpendicular to the longitudinal axis of the vehicle and facing directly into the occupant compartment. A real-time camera at 24 frames per second also was used.

RESULTS

Head injury measures: Table 4 summarizes the head injury measurements recorded during the airbag deployments and respective IARVs (Kleinberger et al., 1998; NHTSA, 1996). Both Dodge Grand Caravan tests produced high instantaneous head accelerations. High-speed film analysis showed that in all tests peak head accelerations occurred with initial face/airbag contact. All but one test (Ford Taurus 3/4-forward) produced head rotational accelerations that exceeded the IARV of 2500 rad/s^2 . The rotational acceleration data exhibited high-frequency oscillations, and the recorded peaks occurred during pulses of very short duration. It was unclear whether the short-duration rotational accelerations observed in these tests represented the same kind of loading on which the IARV was based, so a 3 ms clip calculation was performed to examine whether the somewhat sustained rotational accelerations also were at levels associated with injury. The 3 ms clip values exceeded the IARV for instantaneous rotational head acceleration in the full-forward tests in the Dodge Grand Caravan, Ford Taurus, and Volvo 850 and in the 3/4-forward test in the Lincoln Town Car.

Neck injury measures: Table 5 summarizes the neck injury measurements and respective IARVs (Kleinberger et al., 1998). Two tests produced neck injury measurements that exceeded the respective IARVs. In the Lincoln Town Car 3/4-forward test, the neck extension moment was nearly twice the IARV of 25 Nm. High-speed film analysis of this test showed that the lower portion of the deploying airbag caught on the dummy's right foot. The airbag was held briefly by the foot and then snapped rearward and struck the dummy under the chin, hyperextending the neck and causing the high

Table 4
Head Injury Measurements – CRABI Dummy and Century 2000 Forward-Facing Child Restraint

	1990 Lincoln Town Car		1996 Dodge Grand Caravan		1996 Ford Taurus		1996 Volvo 850		
	IARV	3/4- Forward	Full- Rearward	3/4- Forward	Full- Forward	3/4- Forward	Full- Forward	3/4- Forward	Full- Forward
		Peak head acceleration (g)	80*	76	30	82	109	19	50
3 ms clip head acceleration (g)	None	38	13	49	66	16	31	19	31
Head injury criterion (HIC) (36 ms interval limit)	660**	115	7	116	362	7	41	37	55
Peak head rotational acceleration (rad/s ²)	±2500*	6998	-5010	12085	13825	2043	-6430	8955	9675
3 ms clip head rotational acceleration (rad/s ²)	None	3037	646	922	3233	612	-2767	613	2830
Peak head rotational velocity (rad/s)	±37*	-37	-12	-14	-19	-34	-22	-12	-24

Sources: *NHTSA, 1996; **Kleinberger et al., 1998

Table 5
Neck Injury Measurements – CRABI Dummy and Century 2000 Forward-Facing Child Restraint

	1990 Lincoln Town Car		1996 Dodge Grand Caravan		1996 Ford Taurus		1996 Volvo 850		
	IARV	3/4- Forward	Full- Rearward	3/4- Forward	Full- Forward	3/4- Forward	Full- Forward	3/4- Forward	Full- Forward
		Peak shear force (N)							
A-P direction	None	763	-240	-534	-662	-161	-240	169	-221
L-M direction	None	152	-64	49	206	156	-64	-165	-206
Neck axial force (N)									
Tension	2200	1043	38	80	136	222	97	561	517
Compression	2200	460	352	762	1412	185	405	345	314
Neck bending (Nm)									
Flexion	85	1	12	25	50	7	16	7	8
Extension	25	47	0	1	1	2	0	6	7
Neck indices									
Tension-extension	1.00	1.87	0.02	0.04	0.06	0.10	0.04	0.37	0.35
Tension-flexion	1.00	0.47	0.15	0.03	0.59	0.15	0.19	0.25	0.24
Compression-extension	1.00	2.04	0.16	0.35	0.64	0.08	0.18	0.31	0.37
Compression-flexion	1.00	0.21	0.25	0.63	1.01	0.11	0.28	0.23	0.22
Neck twisting Moment (Nm)	None	5	1	-1	6	4	8	-5	-3

extension moment. This loading mechanism was similar to that observed in the NHTSA sled test. At the time the maximum bending moment was measured (57 ms), the dummy's head/neck was hyperextended, indicating the applicability of the extension bending moment criterion. The high extension moment contributed to tension-extension and compression-extension indices, which were approximately equal to 2.00. The Dodge Grand Caravan full-forward test produced a maximum neck flexion bending moment

that was more than half the IARV at about the same time compression forces also were more than half the IARV, so the compression-flexion index exceeded unity. In both Dodge Grand Caravan tests, high-speed film analysis showed that the airbag struck the dummy's chin, forcing the head to rotate downward and causing relatively high neck flexion moments, axial compression, and A-P shear forces.

Chest injury measures: Table 6 summarizes the chest injury measurements and respective IARVs (Kleinberger et al., 1998). Both Dodge Grand Caravan tests produced chest accelerations that exceeded limits proposed for new regulations governing future airbag designs.

Table 6
Chest Injury Measurements – CRABI Dummy and Century 2000 Forward-Facing Child Restraint

	Estimated IARV	1990 Lincoln Town Car		1996 Dodge Grand Caravan		1996 Ford Taurus		1996 Volvo 850	
		3/4-Forward	Full-Rearward	3/4-Forward	Full-Forward	3/4-Forward	Full-Forward	3/4-Forward	Full-Forward
Peak chest acceleration (g)	40	28	12	43	56	16	19	19	15
3 ms clip chest acceleration (g)	None	25	9	39	50	12	14	12	12

SUMMARY

These tests may indicate a risk of rotational acceleration head injuries. High peak rotational accelerations were recorded in all but one test (Ford Taurus 3/4-forward). However, many of the high rotational accelerations were of very short duration, so it is unclear that these tests represent the injury risks implied by comparing the recorded peaks with the respective IARVs. Only four tests (Lincoln Town Car 3/4-forward test and the full-forward tests of the Dodge Grand Caravan, Ford Taurus, and Volvo 850) produced 3 ms clip values that exceeded the head rotational acceleration IARV of 2500 rad/s². Some of the real-world cases involve small children (12-36 months old) who were facing passenger airbags and sustained closed head injuries like those associated, through animal testing, with high head rotational accelerations.

The neck compression-flexion index greater than 1.00, recorded in the Dodge Grand Caravan full-forward test, resulted from combined flexion bending and compression loading. In this test, the airbag struck the dummy's chin, forcing the neck to flex forward. Neither the flexion bending moment nor the compression force exceeded the respective IARV, but both were sufficiently large and occurred at the same time so that the index exceeded 1.00. Although excessive compression can cause injuries of the cervical spine and base of the skull, most of the head/neck injuries observed in the real-world cases of airbag-related injuries and deaths to children have been described as resulting from hyperextension and tension forces. Consequently, although this test demonstrates that airbags can generate injury forces, it may not represent the true risks to children seated near passenger airbags. The loading observed in the

Lincoln Town Car 3/4-forward test was more similar to the description of real-world injuries but, as noted earlier, the dummy's foot seemed to influence the airbag's deployment path. These two examples indicate that it is difficult to devise tests using dummies that realistically reflect the injury risks to children sitting near passenger airbags. Nevertheless, the tests clearly demonstrate that passenger airbags generate sufficient force to injure infants.

Both Dodge Grand Caravan tests produced chest accelerations that exceeded proposed limits, but chest injuries are not commonly noted in documented real-world cases involving forward-facing children injured or killed by airbags. Of 68 injury and fatal airbag cases involving forward-facing children under investigation by NHTSA, only 5 reportedly involved thoracic or abdominal injuries, and all but 1 were unrestrained children older than the 12-month-old infant the CRABI dummy represents.

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