INVESTIGATION OF HYBRID III FIFTH FEMALE DUMMY USE IN THE CARAVAN AIR BAG TEST ENVIRONMENT

Background

Review of a proposed SAE paper documenting LTV aggressivity tests conducted by NHTSA brought to light some questions regarding the Caravan passenger-side airbag and/or the biofidelity of the head-neck junction of the small female Hybrid III dummy. An oblique crash test (reference NHTSA Crash Test Datbase # 2915) in which a '97 Caravan impacted into a '97 Honda Accord resulted in an unusually high neck response for the passenger occupant of the Caravan - a small female dummy belted and seated normally in a full forward seating position (i.e. not in an OOP condition). Review of the high speed film of the event revealed that the cushion deployed under the chin of the dummy and as the cushion continued to pressurize, the head was projected upwards, extending the neck to an extreme degree.

At the time of the LTV aggressivity tests series, the 5th percentile female test dummy was still being developed. Because of this, the head skin used in the crash test was different from that specified in the Sep. '98 Notice of Proposed Rulemaking (NPRM) for FMVSS 208. Specifically, the NPRM head skin does not have openings under the chin and behind the jaw. The newer head skin, referred to as the TMJ head skin, was intended to reduce the possibility of the deploying airbag to become trapped under the chin during testing. (See Figures 1 and 2)

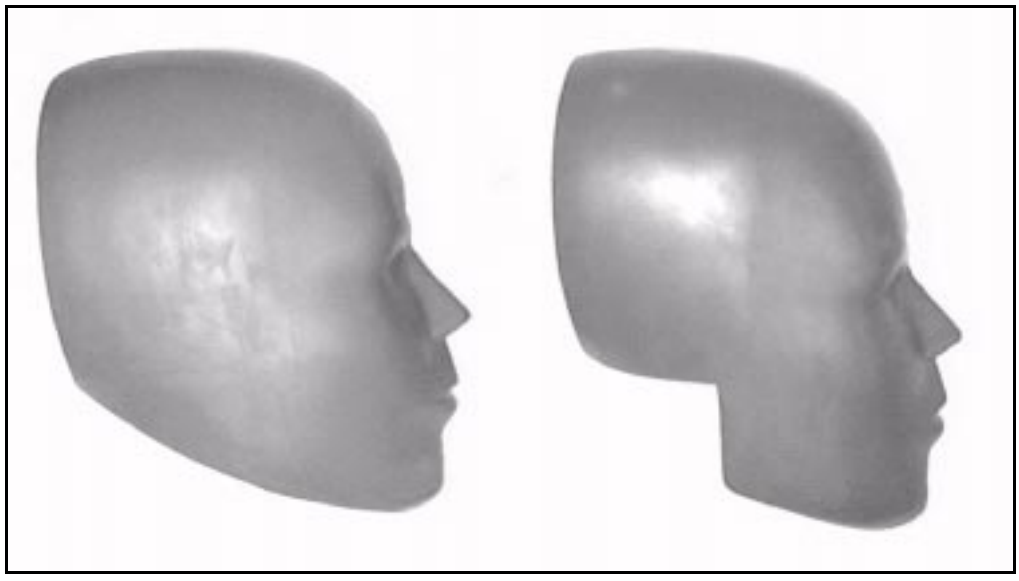


Figure 1. TMJ Head Skin (left) and Standard Head Skin.

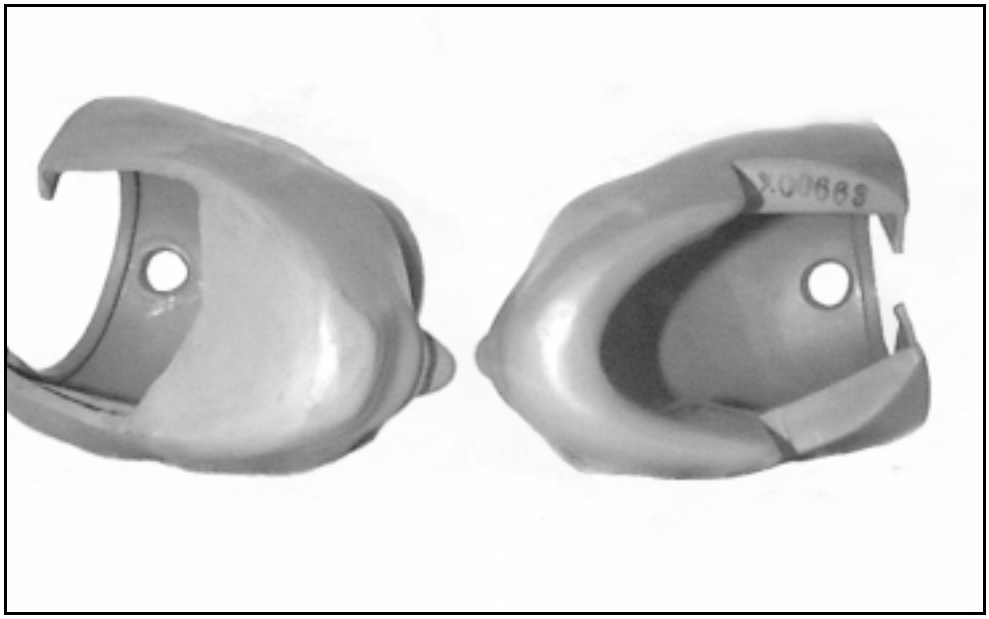


Fig. 2. TMJ Head Skin (left) and Standard Skin.

Replacement Airbags

VRTC removed the passenger airbag from the crashed Caravan vehicle so that replacement parts could be ordered for additional testing. Upon receipt of the replacement airbag, it was discovered that the replacement contained a different inflator than that contained in the original airbag (see Fig. 3).

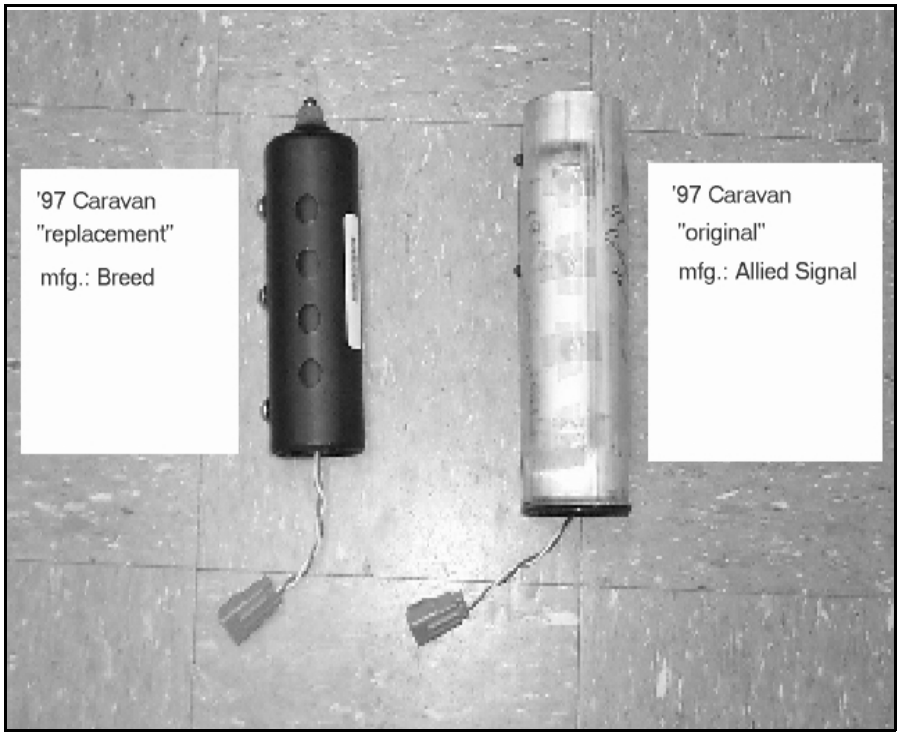


Fig. 3. Replacement (left) and original inflators.

A 60- liter closed tank test was then conducted with the replacement inflator. The results were compared to previous testing conducted at VRTC with original-vintage '97 Caravan passenger inflators. The results confirmed that there was a significant performance difference between the inflator used in the crash test (peak pressure of approximately 565 kPa with a rise rate slope of approximately 27 kPa/ms) and the one received in the replacement part (peak pressure of approximately 480 kPa with a rise rate slope of approximately 17 kPa/ms) (see Fig.4). VRTC concluded that this difference in inflator performance would translate into a restraint system performance difference, as well.

Based on this finding, VRTC determined that the most meaningful testing would be achieved by using airbags of the original vintage. However, this decision presented a potential problem in terms of availability of airbags. Purchases from three different Chrysler dealerships all resulted in airbags containing the replacement inflator. Initially, VRTC was able to locate only six original vintage airbags from an earlier research program. Later, VRTC was able to locate additional original airbags in the GSA fleet and replace them with the replacement airbag.

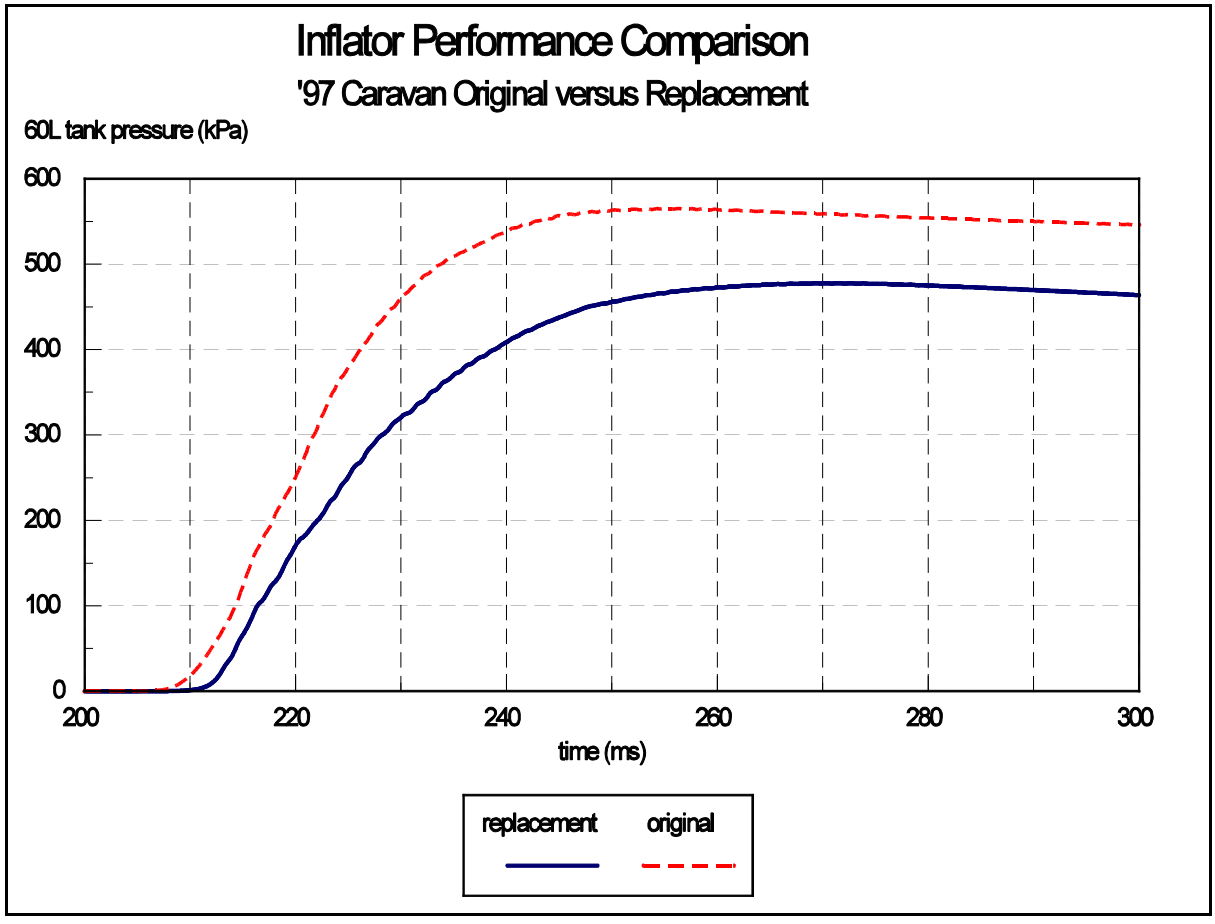


Fig. 4. Inflator Tank Test Results

Testing - Series 1

The sole purpose of the testing conducted by VRTC was to determine whether or not the high neck loading seen in NHTSA crash test #2915 was an artifact of the dummy, and if so, to determine what changes were needed to make the dummy more humanlike. VRTC attempted to replicate the dynamic crash event in a static test environment. To accomplish this, the dummy positioning would need to account for the forward displacement of the dummy which occurred in the dynamic test after impact and before contact with the airbag. Therefore, the dummy was placed in the passenger seat and propped forward with approximately 4" of foam. A typical set-up can be seen in Fig. 5.

Fig. 5. Typical Test Seating Position.

A total of 11 tests were conducted. A test matrix and some neck responses are contained in Table1. Following Table 1 is a brief summary for each test.

Table 1. Test Matrix and Results Summary

Test #	Airbag System	Head Skin	Neck Skin	Neck Responses				Head Resultant (g)	Chest Resultant (g)	Chest Deflection (mm)	Comments
				Fz (N)	Moc (Nm)	Nij	mode[6]				
04340100	original[1]	standard	n/a	6454	-195	4.8	NET	105	46	32	
04340101	original[1]	TMJ	n/a	2318	135	1.3	NFT	92	53	24	cushion rupture[4]
04340102	original[1]	TMJ	n/a	6391	-227[5]	4.7	NET	94	50	33	cushion rupture[4]
04340103	replacement[2]	TMJ	n/a	-1342	87	0.8	NFC	56	26	7	
04340104	original[1]	TMJ	SAE[3]	1199	126	0.9	NFT	114	51	26	
04340105	original[1]	TMJ	SAE[3]	2386	123	1.3	NFT	80	47	20	cushion rupture[4]
following test #105, the seat was raised approx. 2" to increase the likelihood of the airbag unfolding beneath the dummy's chin											
04340106	original[1]	TMJ	SAE[3]	4589	-188	4.1	NET	81	63	33	
04340107	original[1]	TMJ	contour	3896	66	1.5	NET	71	38	33	
04340108	original[1]	TMJ	contour	4443	-116	3.1	NET	92	34	32	severe cushion rupture
04340109	original[1]	TMJ	contour	5943	-150	4.1	NET	109	39	31	
04340110	original[1]	standard	n/a	5772	-222	4.6	NET	81	43	32	

footnotes:
1,2: The "original" airbag system was more aggressive than the "replacement" system.
3: The neck shield was previously recommended for use by the SAE. It is also commonly referred to as the "mouse pad" neck wrap.
4: See individual test summaries for descriptions of ruptures.
5: The signal for neck moment about the y-axis surpassed the full scale range of the load cell.
6. "Mode" refers to Nij mode: NET = extension-tension; NEC = extension-compression; NFT = flexion-tension; NFC = flexion-compression

Test #04340100

The first test was an attempt to replicate the results observed in the dynamic crash test. This test utilized the original airbag and the dummy contained the standard head skin and no neck wrap. The results indicated that the neck responses were quite similar to that observed in the oblique crash test (see Fig. 6 and 7). Note that the time shift between the two curves is due to the static versus dynamic nature of the two tests - the time shift is inconsequential. The magnitude and shapes of the curves are similar and this is significant. The Nij response for the static test was 4.8 while the Nij for the crash test was 4.4. Review of the high speed digital video also indicated very similar event kinematics: the inflating cushion deployed under the chin of the dummy resulting in the head being projected upward and severe neck extension. This result provided the confidence level needed to proceed with the testing.

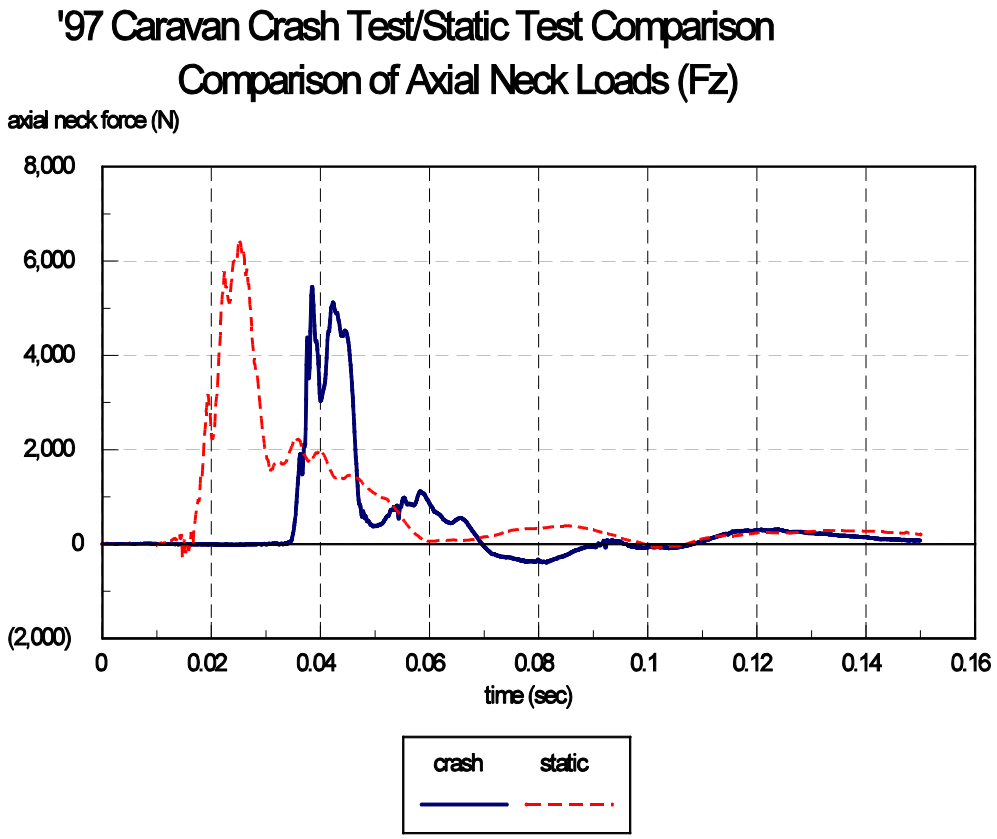


Fig. 6. Comparison of Axial Neck Loads in Crash Test and Static Replication Test

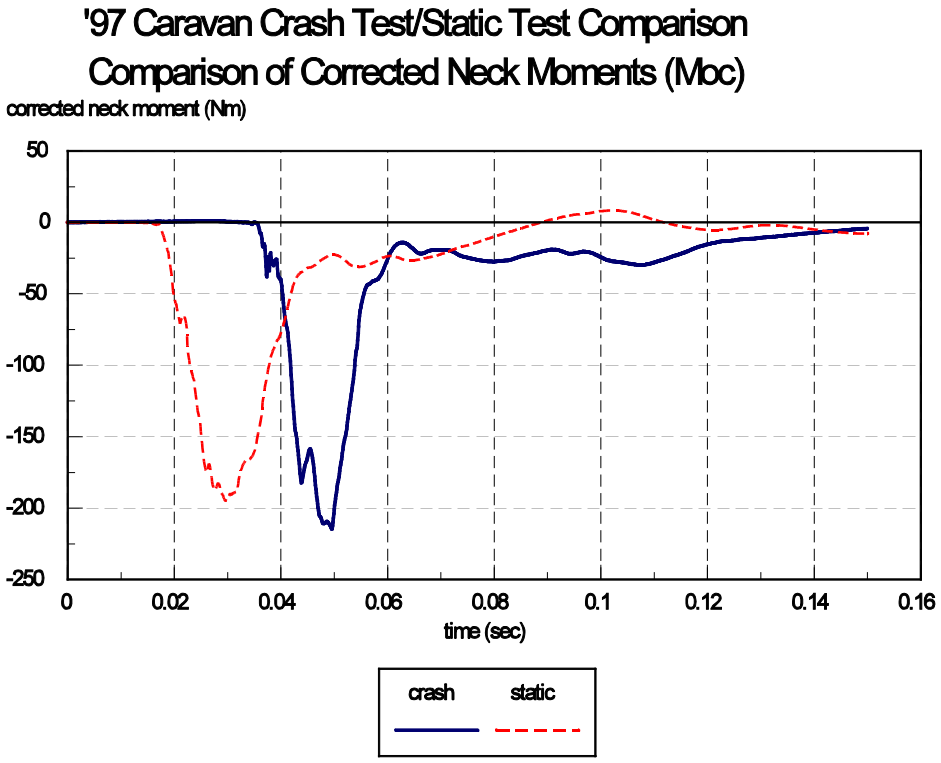


Fig. 7. Comparison of Corrected Neck Moments in Crash Test and Static Replication Tests

Test #04340101

In the second test, the TMJ head skin was placed onto the dummy to determine if the new skin would prevent the cushion from trapping under the dummy's chin. Following the test, two ruptures, or tears, were observed in the cushion. One rupture measured approximately 2" x 1.5" while the other was approximately 0.75" x 0.13". However, review of the high speed film indicated that the cushion did not deploy under the dummy's chin. In this test, the cushion deployment was slightly higher, making first contact with the dummy just above the chin line. The cushion pressed against the chin, pushing it downward and forcing the neck into flexion.

Test #04340102

This test was an attempt to repeat test # 04340101. Again, cushion tears were observed post-test, the largest of which measured 1.25" x 0.63". The high speed video revealed that the cushion deployed under the chin in this instance, again resulting in high neck injury responses.

This result led to a thorough video review of tests #101 and #102. In this analysis, it was observed that variations in the unfolding and filling of the cushion could explain the difference between the results in these two tests. In test #101, the unfolding cushion first moves rearward in the vehicle and contacts the dummy just above the chin. As the bag continues to inflate upward, the cushion simply slides up along the face of the dummy and pushes rearward on the dummy's chin. In test #102, however, the cushion first contacts the dummy just below the chin. As the airbag tries to inflate upward this time, the chin is in its path and acts as a leverage point for the

airbag to force the head upward and backward, placing the neck into extreme extension. There are only a couple of inches difference in where the unfolding airbag contacts the dummy, but the end result is significantly different. (See Fig. 8.)

Fig. 8. Cushion Unfolding Differences

Test # 04340101 Test # 04340102

t = 14 ms

t = 14 ms

t = 21 ms

t = 21 ms

t = 35 ms

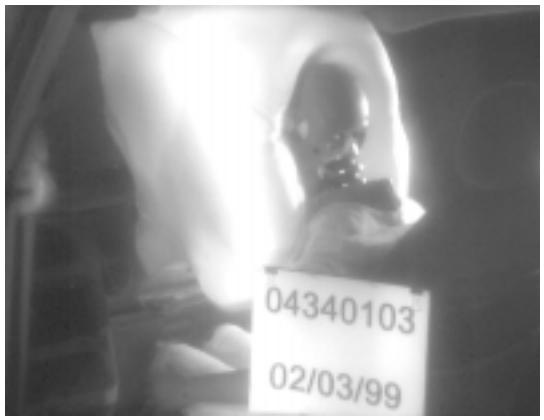
t = 35 ms

Test #0434103

In this test, the replacement cushion was used to determine how its performance would compare to that of the original airbag. The dummy responses in this test confirm the result of the inflator tank test; that is, the replacement bag was much less aggressive. The cushion unfolding kinematics were significantly different as well. In this test, the cushion unfolded much higher resulting in a particularly benign contact with the dummy. (See Fig. 9)

Fig. 9. Cushion Unfolding in Test # 04340103 (Replacement Airbag)

t = 14 ms



t = 21 ms

t = 35 ms

Test #04340104

This test was the same as test #101 and #102, except a neck wrap was added to the dummy. The neck wrap used was previously recommended for use by the SAE and it is also commonly referred to as the "mouse pad" neck wrap (see Fig. 10). The results of this test were similar to that observed in test #101 in that the airbag contacts the dummy's face above the chin, resulting in neck flexion. There were no ruptures in the airbag observed. Since the airbag did not get into the neck area, it was not known if the SAE neck wrap affected the previous high neck extension response.

Fig. 10. TMJ Head Skin and SAE "Mouse Pad" Neck Wrap

Test #04340105

This test was a repeat of test #104. The results were the same as in test #104 with the airbag hitting above the chin, causing neck flexion. There were some small ruptures observed in the bag. The affect of the neck wrap was still not determined.

Testing - Series 2

Analysis of the first test series indicated that significantly different dummy neck responses were observed due to variation in the cushion unfolding during inflation.. As the bag unfolds, the first point of cushion contact with the dummy is in the area of the dummy's chin. If the point of contact is just above the chin, the cushion is free to slide up along the face and merely forces the chin down and creates a neck flexion injury mechanism. If, however, the point of contact is at the bottom portion of, or just below the chin, then the cushion's upward motion is impeded by the presence of the chin. As the bag continues to inflate beneath the dummy's chin, considerable

pressure is built up within the cushion until the pressure becomes so high that it projects the head upward and rearward, generating a severe neck extension injury mechanism. In the five tests conducted with the original generation airbag system, two cases resulted in neck extension while three cases resulted in neck flexion. Figure 11 describes the approximate location of first airbag contact with the dummy's head for each of the five tests. Note that tests 0 and 2 resulted in extension while tests 1, 4, and 5 generated flexion. Also note that there is only approximately 1.8 inches difference in the point of contact between the highest point which resulted in neck extension and the highest point which resulted in neck flexion.

From the perspective of this effort, little or nothing is learned when the bag deploys above the chin and the neck flexion mode is observed. Thus, for the sake of efficiency it was proposed that the dummy's seating position be altered such that the chin would be 2 inches higher than it was in the initial test series. This would increase the likelihood of the airbag contacting on the bottom portion of, or just below the chin and developing neck extension loading. To achieve this increase in height, 2 inch blocks were placed beneath the seat at the attachment point to the vehicle floor.

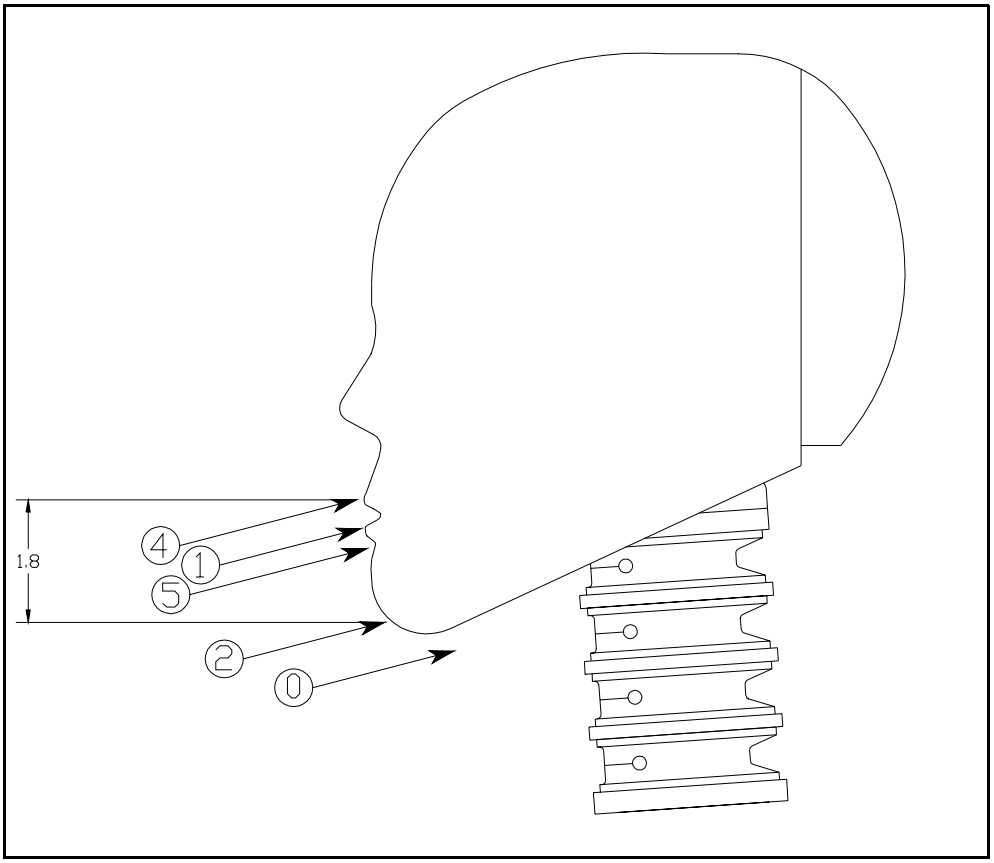


Fig.11. Location of Airbag Contact for Series 1 Tests
(Note: number in balloons are last digit of test number; i.e. "0" represents test 04340100.)

Following is a brief summary of each test conducted after raising the seat height by 2 inches.

Test #04340106
In this test the TMJ head skin and the SAE neck wrap were used. There were two objectives of this test: (1) to confirm that raising the dummy 2" improved the likelihood that the airbag's first point of contact was below the chin; and (2) to determine if the SAE neck wrap would have a significant effect on the interaction of the airbag with the neck region. The first objective was confirmed for this test; the airbag contacted well below the chin on the dummy's neck and as a result the dummy experienced neck extension. The resulting Nij for this test was 4.1 in extension-tension mode (see Table 1 for all results). Thus it was determined that although the neck responses were slightly lower with the SAE neck wrap (4.1 vs. 4.7), it did not have a significant effect on the interaction of the airbag with the neck region.

Test #04340107 thru 304340109
For these tests, VRTC used a modified head skin which was referred to as the contour head skin. The skin was modified by attaching a flap of skin to the bottom of the jaw-line and tapering the skin down to meet the neck at the top of the dummy's torso (see Fig. 12). An Ethafoam 220 plug was placed behind the skin to fill in the air-gap between the neck and the skin extended from the chin (see Fig. 13). It was believed that the dummy with only a neck wrap represented small females with a slender neck, thus exposing more chin/jawline to airbag forces. The skin flap and Ethafoam plug therefore represented small females with larger neck sizes and less chin/jawline exposed to the airbag.

Figure 12. Contour neck skin concept.

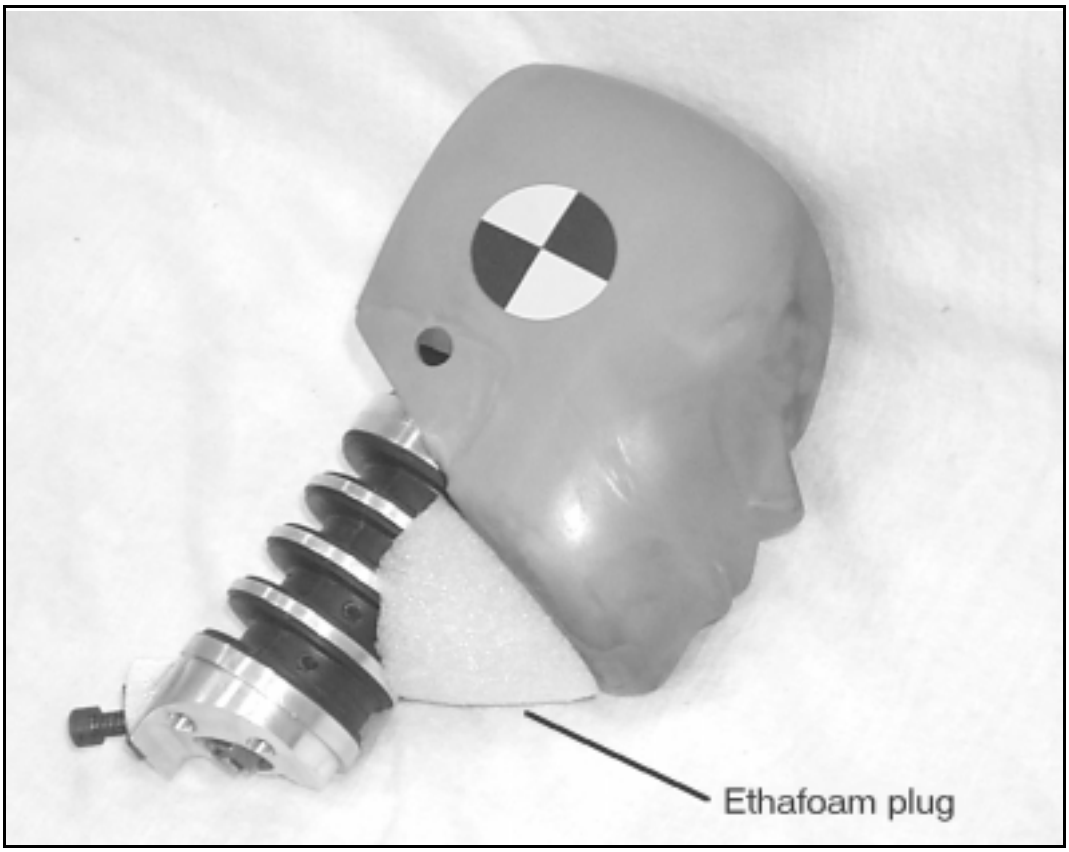


Figure 13. Ethafoam chin plug used in contour neck concept.

In test #107, the airbag first contacted the dummy right at or slightly above the chin. This would indicate that the cushion unfolding characteristics contained more variability than what was accounted for with the two inch increase in seating height of the dummy. As a result, the cushion did not deploy beneath the chin. The dummy's head begins to be projected rearward, but then the top half of the cushion slips above the chin and forces the neck into flexion. The peak Nij was 1.5 and occurred during the brief period of time that the neck started to go into extension.

In test #108, the airbag first contacted the dummy below the chin line. As the top half of the cushion inflates, the dummy's head is projected rearward. The cushion, however, experiences a severe rupture before completely pressurizing. The peak Nij was 3.1 in extension-tension mode.

In test #109, the airbag again makes first contact with the dummy below the chin line. As in test #108, the head is projected rearward, generating severe neck extension. In this test, though, the cushion remains intact with no observed ruptures. The peak Nij was 4.1 in the extension-tension mode.

Test #0430110

The standard head skin with no neck wrap was used for the final test. With the exception of the two inch increase in seating height, this test was essentially a repeat of test #100. The purpose of repeating this condition was to determine if the two inch increase in dummy seating height would have any significant effect on the dummy's responses. The results indicate that change in seating position had very little or no effect. The peak Nij was 4.6 in extension-tension mode.

Component Level Testing with Head/Neck Assembly

In addition to the static tests with the 5th female dummy that were conducted, component level testing was conducted on a 5th female head/neck assembly. The purpose of the testing was to investigate public statements made by Daimler-Chrysler representatives, that the relatively high neck shear loading in the crash and static tests could only occur if the air bag became "entrapped" in the cavities of the jaw structure of the dummy.

The component tests were an attempt to explore the relative magnitude of neck axial and shear loading that could result without entrapment. The concept of the tests was to apply an upward vertical load to the underside of the dummy chin, in a manner that clearly had no entrapment, and record the loadings that occur. The shear loading thus measured would be caused by non-entrapment factors such as friction and typical reaction loading.

A 5th female head neck assembly, complete with head and upper neck instrumentation was mounted to a rigid horizontal surface. A nylon strap (seat belt webbing) was placed under the chin, and loading was applied to the nylon strap (see Figure 14). The loading was accomplished by a cable, pulley and weight arrangement, and the loads applied to the dummy were measured with a load cell attached to the cable. The weight was approximately 50 lb.

Several tests were conducted at incrementally increasing drop heights to find a height that resulted in significant loading to the neck, but would not damage the hardware or instrumentation. A drop height of 7 feet was finally selected, after which 2 tests (numbered sequentially as tests 9 and 10) were conducted and complete measurements were taken.

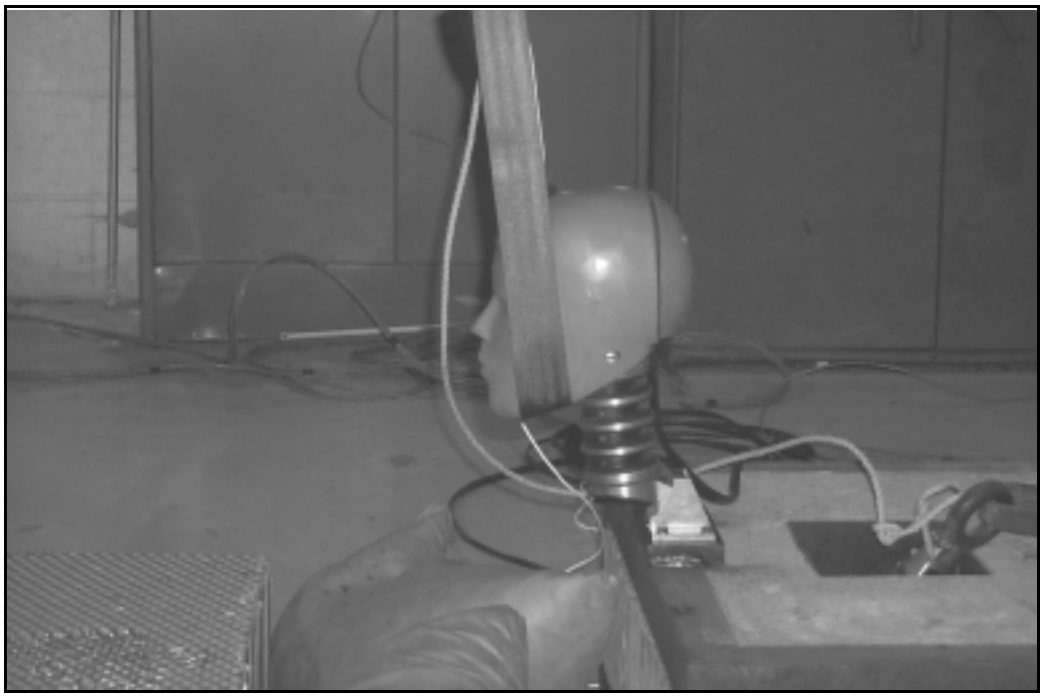


Figure 14. Head/Neck Component Test Setup

Component Test Results

Table 2 contains some of the peak values recorded in the two component tests, along with corresponding values from the static and crash tests. The component tests resulted in responses that were similar to, but still less severe than the crash and static tests. The upward loading on the dummy chin produced sizable sheer loads at the upper neck load cell, very similar in proportion to the axial neck load as for the static and crash tests. The shear loads are a result of the reaction force of the head acceleration and the friction of the strap against the chin as the head begins to rotate. The magnitude of the frictional loading was estimated by subtracting the head inertial load (head acceleration in X direction multiplied by 10 lb.) from the total shear load. This estimate is shown in the second from the last column on Table 2. The final column of the table is the ratio of the estimated friction to the peak axial load of the test. This could be likened to a coefficient of friction for the test. It was judged that the values are reasonable for frictional loading, both for the component tests and for the static and crash tests.

Based on the component level testing and the analysis of the measurements taken, it was judged that the magnitude of the shear loading could be accounted for without entrapment of the air bag in the cavities of the dummy jaw or neck. This was further evidence that no changes to the dummy were required for use in this type of testing.

Summary

The most important findings of this research were:

- There are two different passenger airbag systems which can be used in the ‘97 Caravan. These two systems have distinct performance differences. The original system is significantly more aggressive than the replacement system.
- Testing with the original airbag system indicated that significantly different dummy neck responses will be observed due to variation in the cushion unfolding during inflation. If the first point of contact of the airbag with the dummy is above the chin, the neck is placed into flexion and the dummy’s Nij response is in the range of 0.8 to 1.3. If, however, the first point of contact is below the chin, the neck is subjected to severe extension bending and the resulting Nij response is in the range of 3.1 to 4.8.
- Several different variations of head skin and neck skin were tested to determine their effect on the interaction of the airbag with the dummy’s head and neck. These include the TMJ head skin, the SAE "mouse pad" neck wrap, and the contour neck skin. The results indicate that the different neck skins had minimal effect on the neck response. Thus, no further modifications to the dummy are recommended at this time.
- High shear loads can be produced in the dummy neck without entrapment.

Table 2. Comparison of Component, Static, and Crash Test Results

50 Lb. Drop Test	Drop Ht.	Strap Orientation	Max Nij	Neck Moment	Neck Moment O.C.	Peak Cable Tension	Peak Neck Shear	Peak Neck Axial	Peak Head X - Accel	Peak Head Z-Accel	Peak Head Inertial	Peak Friction Shear	Ratio Friction to Axial
	(ft.)			(ft-lb)	(ft-lb)	(lb.)	(lb.)	(lb.)	(G)	(G)	(lb.)	(lb.)	
			[1.0]		[44 ft-lb]			[719 lb]					
50 Lb. Drop Test													
9	7	12 deg	3.2	-162	-115	800	-817	590	38	40	380	-437	0.74
10	7	0 deg	3.5	-178	-124	1005	-927	793	44	24	440	-487	0.61
Air Bag Static Tests													
100			4.8	-213	-144		-1323	1451	60	56	600	-723	0.50
102			4.7	-246	-167		-1798	1437	70	40	700	-1098	0.76
106			4.1	-201	-139		-1178	1032	67	20	670	-508	0.49
109			4.1	-169	-111		-1056	1336	65	25	650	-406	0.30
Caravan Crash Tests													
			4.4	-209			-1573	1226	144	74	1440	-133	0.11