EVALUATION OF THE HYBRID III 5TH FEMALE MODIFIED CHEST JACKET & SPINE BOX

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ABSTRACT

The SAE has coordinated development of a new chest jacket and spine box for the Hybrid III (HIII) Fifth Percentile Female Crash Test Dummy. The proposed modifications intend to correct dimensional inconsistencies in the chest jacket drawings, make the jackets in accordance with the new drawings and eliminate a potential source of mechanical noise in the data. NHTSA procured two new chest jackets, one from each supplier for evaluation. The following questions were investigated through series of inspection, certification, and out-of-position (OOP) and sled tests.

- Are the two new design chest jackets effectively the same shape, construction and performance?
- Do they both meet the drawing specification?
- Is the noise eliminated?

The study presents data collected on both Robert A. Denton (Denton) and First Technology Safety Systems (FTSS) produced dummies**.** The companies have since merged into Humanetics Innovative Solutions, Inc. The dimensional inspection data presented includes a comparison of the anthropomorphic characteristics to the design specifications. The performance of the dummy is evaluated through analysis of the three types of dynamic test data. This includes deflection, acceleration, loads and high speed video from certification tests, low risk deployment tests and sled tests. The analysis of injury values is also performed. The authors' hypothesis is that the new dummies all produce comparable dimensional data and test results. The actual variances are documented. Preliminary comparison showed dimensional compliance within 3 mm and good repeatability. Inspection reports provided dimensional data for both jackets along with laser scan results. Dynamic test data provided deflection, acceleration and load data from certification, OOP and sled testing. The data was analyzed using standard hypothesis test methods (student t-test) to accept or refute the hypothesis that the jackets are effectively the same. The test matrix was limited in sample size for both the OOP and sled tests. The use of a mandrel to assure that the jackets are dimensionally correct is a novel approach for improving quality.

INTRODUCTION

The HIII 5th percentile female is regulated by the Code of Federal Regulations (CFR), Title 49, Part 572 Subpart O. The Agency owns over 20 dummies mostly of the FTSS brand. There are noticeable differences in the location and shape of the breast of the chest flesh assembly between the FTSS and Denton brands that have been resolved by the new jackets. Since 2006 NHTSA has been providing both brands of dummies to its contracted test sites so that NHTSA's Federal Motor Vehicle Safety Standard (FMVSS) No. 208 tests, especially the low risk deployment tests can be conducted with the same dummy type (Denton or FTSS) 5th percentile female that was used by the vehicle manufacturer in its development tests (as requested by the Alliance of Automotive Manufacturers [1]). In addition, it has also been suggested that high frequency noise from metal-to-metal contact is entering the dummy chest accelerometers during low risk deployment tests may be related to the spine design [2].

The chest jackets from the suppliers, FTSS and Denton were not the same nor did they fully agree with the drawings where they were inconsistent. To resolve these issues the SAE has coordinated development of a new chest jacket, modified the spine box and created a mandrel and recommended drawing changes [3, 4] (Figures 1 to 3). At this time Humanetics manufacturers both jackets.

Figure 1. Harmonized chest jackets.

Figure 2. Harmonized spine boxes.

Figure 3. Harmonized chest jackets on harmonized mandrels.

The purpose of NHTSA's evaluation was to determine if the modified HIII 5th female dummies were acceptable for incorporation into Part 572. The dummies were evaluated through a series of inspection, certification, and low risk deployment and sled tests. Evaluations were performed of the repeatability and reproducibility (R&R), durability, measured injury assessment reference values, new parts, and drawings. Two laboratories (VRTC and TRC) were used to conduct R&R testing on the dummy certification. A 2006 Volkswagen Passat was used for the low risk deployment tests and Transportation Research Center HYGE sled was used to simulate a 2010 Ford Taurus NCAP crash pulse.

The SAE Dummy Test Equipment Committee has developed two "J" documents, recommended practices, to document the harmonized chest flesh (SAE J2921) and spine box changes (SAE J2915) [3, 4]. It should be noted that while SAE J2921 evaluates the response of the dummy to thoracic impact it does not address torso flexion response which is a Part 572 requirement. The committee has since decided to address the torso flexion response [5].

METHODS

The modified chest flesh assemblies and spine boxes were procured from both FTSS and Denton. The parts were installed on two dummies (144 and 416) from NHTSA's inventory that were prepared with parts entirely from those original equipment manufacturers. These modified dummies were compared with two 5th female dummies one from each manufacturer that were built in accordance to the CFR Part 572. Dummies 140 and 509 were prepared with parts entirely from those of the original equipment manufacturer and did not have the modified chest flesh assemblies or spine boxes. Denton dummies used in this study were serial nos. 140 and 144 and FTSS dummies were 416 and 509. In addition, chest assembly mandrels and a 3-D inspection file were also procured to be used for dimensional comparisons.

Throughout this program, head, chest and pelvis acceleration, neck, lumbar and femur load and chest rotary potentiometer displacement data were inspected for any indications of mechanical noise.

Inspection

The inspection of the FTSS and Denton chest jackets and spine boxes were conducted by measuring the dimensions and comparing them to either the Part 572 specification or the SAE proposed specification. This assured that the project was evaluating jackets that had not shrunk and were within the Part 572 requirements and that the new modified jackets complied with the SAE specification. The specifications for the jackets included three drawings: the chest flesh front, side view and the sternum pad. Five drawings defined the modified spine box with its new side plates [3, 4].

The mandrels were inspected by scanning them with a FARO Technologies 3-D Platinum Laser Arm [6] and InnovMetric Software Incorporated's PolyWorks 3-D scanning software [7]. A 3-D file of the Denton mandrel served as the reference. The best fit alignment between the mandrel from each manufacturer and the reference was established through use of the PolyWorks ImInspect program. Thirteen points were selected for comparison.

Certification Testing

The certification tests used to calibrate the dummy and to determine the repeatability and reproducibility of the HIII 5th Female dummy are defined by CFR title 49 part 572, section 130 [8]. The tests specified by Subpart O include head drop, frontal neck flexion and extension, thorax impact, knee, knee impact, and torso flexion. All tests were performed except for the knee impact test. The dummy set up for the thoracic impact and torso flexion tests is shown (Figures 4, 5).

Low Risk Deployment Testing

The new spine box attachment bolts were tightened to the 28 Nm recommended by SAE [4] whereas the original spine box bolts were tightened to 21.5 Nm [9]. Each of the four dummies was seated in driver low risk deployment position #2 in a 2006 Volkswagen Passat using the procedures specified in title 49 part 571.208 §26.3 [10] and TP-208-14 [11],

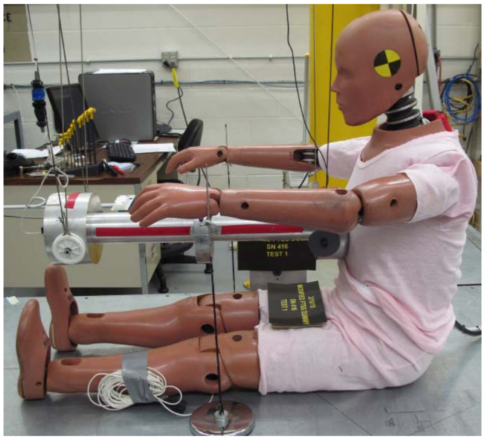

Figure 4. Thorax certification test.

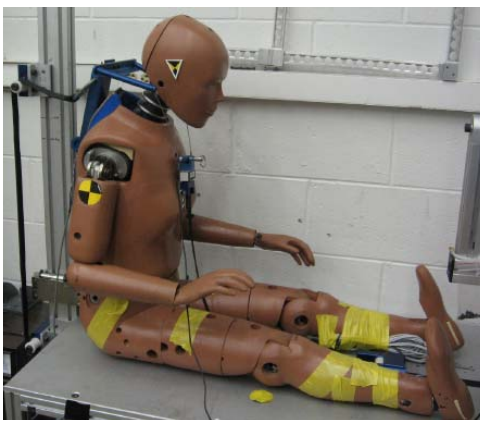

Figure 5. Torso flexion certification test.

with the chin on the rim of the steering wheel and the chest on the air bag module. The dummy is shown seated for a test in Figure 6. The tilt steering column was placed in the middle elevation and telescoped positions. Prior to the test, the dummy's position relative to the restraints and vehicle was measured. The second stage of the air bag fired 200 msec after the primary stage. After each test the steering column, steering wheel and air bag module were replaced and the dummy was inspected. The inspection evaluated rib security, spine box movement as well as verifying the torque on each bolt attaching the spine box to the lumbar load cell or adaptor. Any damage to the chest jacket and chest jacket foam was recorded. The distance between the ribs and the spine box was also measured to check for permanent rib deformation.

Sled Testing

Sled testing was performed using a 35 mph delta V

Figure 6. Low risk deployment test.
Sled Testing

sled pulse with a peak acceleration of 28g, and a duration of 92 msec based on a 2010 Taurus NCAP crash test. For each test the sled buck seats consisted of flat, rigid wood surfaces (depicted by the blue line in Figure 7), designed to position the dummies, relative to the seat belt anchorages, similar to the driver seating position in a 2010 Ford Taurus (depicted by the gray line in Figure 7). No knee bolster or attempt to restrict leg movement was used.

To achieve the seating reference locations, a 5th female dummy was seated in a 2010 Ford Taurus. Using a FARO arm, locations of the D-ring, retractor, and seat belt anchors were measured. Also dummy reference locations including H-point, head CG, shoulder, elbow, knee and tip of toes were measured. Comparisons were made between the dummy seated in a 2010 Ford Taurus and the dummy seated on the sled buck (depicted by the diamonds in Figure 7).

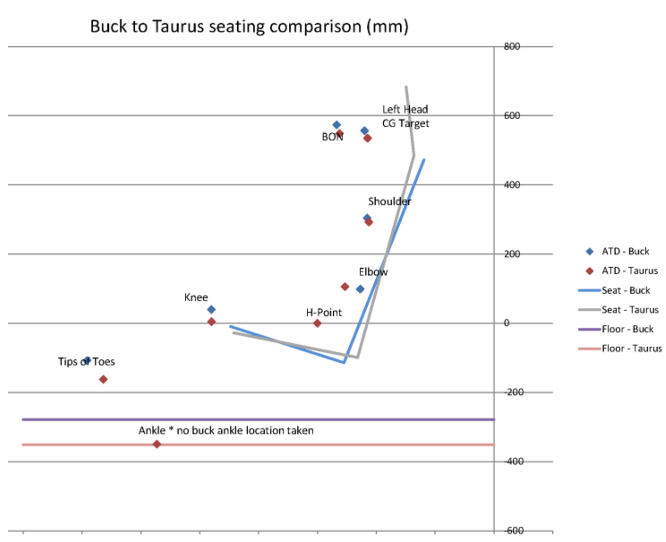

Figure 7. Seating from vehicle-to-buck.

For each test, the dummy was positioned on the hard seating surface by setting the pelvis and tibia angles to ~18.5 and ~57 deg respectively, and knee-to-knee distance to ~170 mm and recording 17 dummy and restraint system measurements. The example test setup is depicted in Figure 8.

Repeatability and Reproducibility

Three statistical measures were used to assess the dummy repeatability and reproducibility (R&R) of the dummy design. The traditional method used the coefficient of variation (CV) of peak response measures with the following assignments (Table 1). A CV less than **5**% is excellent; 5 – 8% is good; 8 – 10% is acceptable and above 10 is unacceptable [12].

Figure 8. Sled test.

Table 1
Coefficient of Variation (CV %)

	Color Code
Excellent	Less 5
Good	5 to less than 8
Acceptable	8 to less than 10
Unacceptable	Greater than 10

This method was also applied to the time of peak response. Another method used is an average CV determined from all points in the central portion of the channel time history (excluding the lower fifty percent to avoid large variances and small means with possible division by zero). Shaw (2007) showed that with a sample size of six, an average CV below 5% is excellent [13]. In this test program, sample sizes were 3, 5, 8 and 16 so CV of sets with fewer than 6 samples would lead to larger confidence interval corridors. For example, the confidence interval for n= 3 is ± 10% and for n= 5 is ± 7%. Lastly, a comparison of the dummy means is made with the student t-test to assess if the difference between two dummy means is greater than 10% of the entire dummy population mean [13]. See Equations 1 through 3.

$$CV_{peak} = \frac{S}{\bar{X}} \quad \text{Where:} \qquad (1).$$

S = standard deviation, $\bar{X}$= mean

$$CV_{50\%avg} = \frac{\sum_{i=1}^{n} \frac{S_i}{\bar{x}_i}}{n} \quad \text{Where:} \qquad (2).$$

S_i = standard deviation, $\bar{x}$ = mean, n = sample size
i = ith sample

$$T = \frac{\sum_{i=1}^{d} [|(0.1)(\mu_i)| - |\mu_{1i} - \mu_{2i}|]}{S/\sqrt{d}} \quad \text{Where:} \qquad (3).$$

μ_i is the mean of the means
μ_{1i} and μ_{2i} are sample means
d = number of pairs of data points
S = standard deviation of differences

If the two dummies are judged to be from the same population (i.e. they are reproducible) the same CV calculations performed for repeatability are made for the combined results from both dummies for reproducibility.

RESULTS

Inspection

<u>**Chest Flesh**</u> The inspection of the chest flesh resulted in several observations, the most important of which are where deviations occurred (Table 2). First, the access holes on the front of the jacket did not match the SAE drawing. Second, the diameters of the holes behind the breasts on the sternum pad are greatly different between the brands. Finally, the Part 572 thickness was not defined. The chest jacket thickness meets the new SAE specification and is 0.1 inch thicker at the bottom than the existing jacket.

Table 2.
Chest flesh assembly inspection results summary

Front View	**SAE**	**FTSS**	**Denton**
Access hole height	8.63	6.375	6.375
Hole diameter behind breast	none	0.625	0.375
Thickness	0.50	0.50	0.50

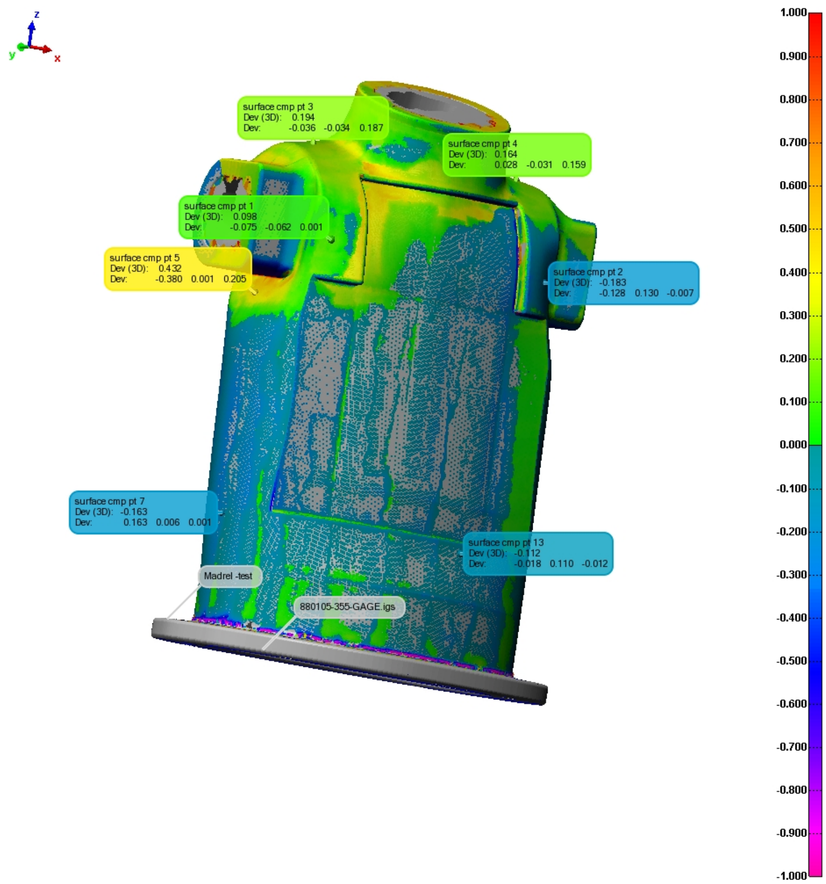

Figure 9. FTSS mandrel front view compared to Denton mandrel .Iges data set (mm).

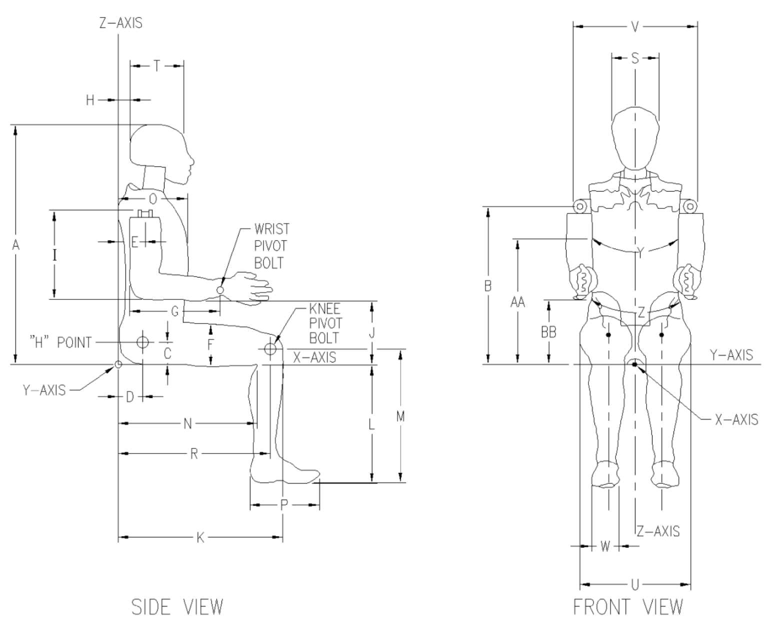

Figure 10. Reference diagram for anthropomorphic dimensions.

Table 3.
Dummy external dimensions summary

Description	Key	Specification (mm)	Results by Dummy (mm)				Pass
			D140	D144	F416	F509	
Total Sitting Height	A	774.7-800.1	784	786	778	784	Yes
Shoulder Pivot Height	B	431.8-457.2	450	445	448	450	Yes
Shoulder Pivot from Backline	E	68.6-83.8	81	82	83	81	Yes
Head Back to Backline	H	43.2-48.2	45	46	46	45	Yes
Elbow Rest Height	J	182.8-203.2	193	199	185	195	Yes
Chest Circumference with Jacket	Y	850.9-881.3	865	862	869	869	Yes
Reference Location for Chest Circumference	AA	332.7-358.1	345	345	354	350	Yes

Table 4.
Torso flexion certification results summary

Hybrid III 5th Female Torso Flexion*						
Dummy No.	**Test No.**	**Test Site^**	**Initial Angle (deg)**	**Difference between Return & Initial Angle (deg)**	**Max Force at 45 deg during 10 sec (N)**	**Rotation Rate (deg/sec)**
Specification			**≤ 20**	**+/- 8**	**320-390**	**0.5 – 1.5**
D140	**Mean**	TRC	15.5	5.0	363.8	1.0
D144 w/modified parts	**Mean**	TRC1 n = 3	14.0	3.9	371.1	0.99
	Std. Deviation		0.8	0.6	6.4	0.01
	CV (%)		5.4	15.4	1.7	0.59
	Mean (Fails)	TRC2 n = 6	13.6	3.8	**427.7**	1.0
	Std. Deviation		1.6	0.8	39.9	0.0
	CV (%)		11.9	20.4	9.3	1.2
F416 w/modified parts	**Mean**	TRC1 n = 3	19.3	5.2	345.9	1.0
	Std. Deviation		0.9	0.3	22.5	0.0
	CV (%)		4.7	5.9	6.5	0.6
	Mean (Fails)	TRC2 n = 3	17.8	4.0	**408.0**	1.0
	Std. Deviation		1.1	0.3	23.8	0.0
	CV (%)		6.1	8.7	5.8	0.0
F509	**Mean**	TRC	17.1	5.1	379.4	1.0

*See table 1 for color key. ^All torso flexion tests were conducted at the TRC test facility with n = 2 for D140 and F509.

Table 5.
Thorax certification results CV summary

CV (%)*							
Dummy No.	**Test Site****	**Impact Speed (m/s)**	**Fmax in 50 – 58 mm (kN)**	**Fmax in 18 to 50 mm (kN)**	**Maximum Deflection (mm)**	**Internal Hysteresis (%)**	**Sample Size**
Specification		**6.59-6.83**	**3.9-4.4**	**≤4.6**	**50-58**	**69-85**	**n**
D144	1	0.2	0.7	0.4	0.2	0.6	3
	2	0.0	0.6	1.8	1.2	0.0	5
	Mean	6.74	4.30	4.18	54.99	73.63	8
	1 & 2	0.4	0.8	1.4	1.8	1.2	8
F416	1	0.0	0.9	1.6	0.6	1.4	3
	2	0.2	1.3	1.8	2.5	0.6	5
	Mean	6.73	4.25	4.25	52.81	72.25	8
	1 & 2	0.2	1.5	2.0	4.2	2.2	8
Combined	1 &2	0.2	1.3	2.0	3.9	2.1	16

*See table 1 for color key. **Test site 1 = VRTC, Test site 2 = TRC

Chest Jacket Mandrel The thirteen points examined on each mandrel were within the 0.5 mm NHTSA tolerance that was applied to the 3-D digital model (see Figure 9 for the front view).

Spine Box The unmodified spine boxes were within tolerances specified by Part 572. The modified spine box uses a small (0.75" x 0.2") plate attached to each side wall of the thoracic spine that is secured with three DOT Side Impact Dummy (SID) modified 5/16-18 x 5/8" screws. No anomalies were noted.

Chest Flesh on Mandrel In contrast to the original jackets the recently manufactured modified jackets easily fit on the mandrels, and the zipper closed easily demonstrating good fit for use on dummies.

Assembled Dummy The dummy external dimensions associated with the spine box and chest jacket were within the tolerance specified on the Part 572 and SAE drawing (Figure 10 and Table 3).

Certification Testing and Repeatability and Reproducibility

The heads, necks, thoraxes, torsos and knees of all four dummies were qualified. Only the thorax and torso flexion tests of the modified dummies were evaluated for repeatability and reproducibility since the changes to the dummy involve only those regions.

Torso Flexion Certification Test The torso flexion certification results CV summary is shown in Table 4. Although the repeatability was acceptable both the Denton and FTSS brands failed the maximum force requirement at forty-five degrees flexion. For this reason their reproducibility was not calculated. Figure 11 illustrates the interaction between the thorax chest jacket and pelvis skin near the 45 degree flexion angle. Although some interaction is normal it was recommended to the DTEC to address this in the torso flexion test [5].

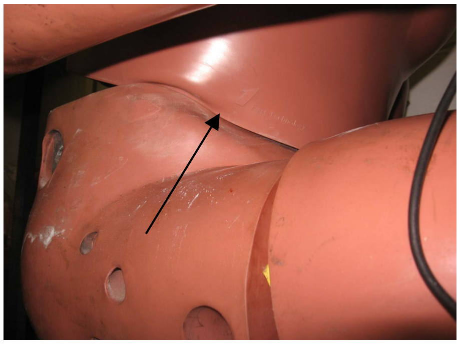

Figure 11. Torso flexion resistance by modified chest flesh interaction with pelvis flesh.

Thorax Certification The thorax certification results CV summary is shown in Table 5 and the thorax response in Figures 12 through 14. The thorax response was excellent for both modified dummies, with all dummies passing the certification corridor. The FTSS modified dummy force time history and deflection time history responses in the Vehicle Research and Test Center (VRTC) tests occur slightly before the TRC responses.

All Other Certification Test The modified dummies passed the head, neck, and knee certification tests. Since they were not influenced by the changes to the thorax, the data will not be presented here. However, during the thorax certification test, noise was evident in the chest and pelvis accelerometers. Once the femur was reinstalled and tightened with the nylon plunger in the pelvis the noise did not reoccur.

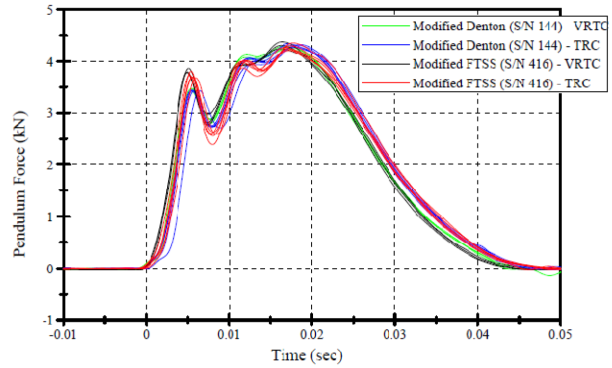

Figure 12. Thorax pendulum resistive force time history for both modified dummies.

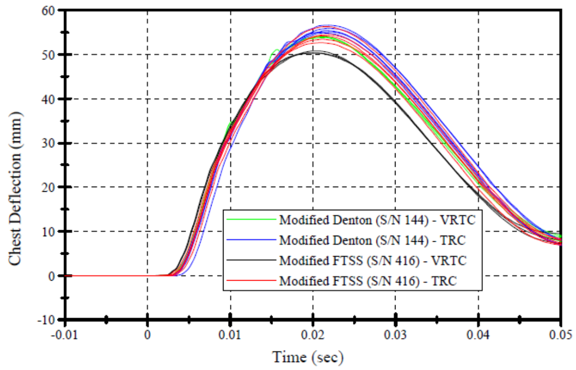

Figure 13. Chest deflection time history for both modified dummies.

Low Risk Deployment Testing

Each dummy was tested once. The chest acceleration and deflection response is shown in Figures 16 and 17. These plots show a significant test-to-test variation in both chest acceleration and chest

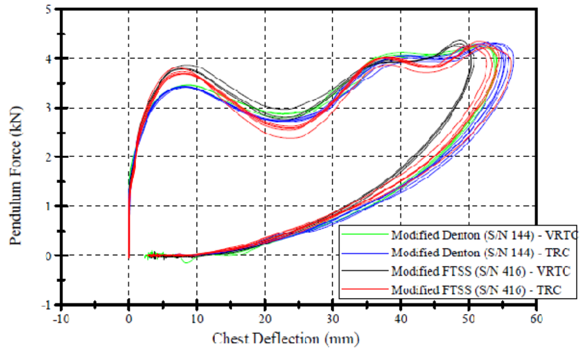

Figure 14. Thorax force deflection response for both modified dummies at two labs.

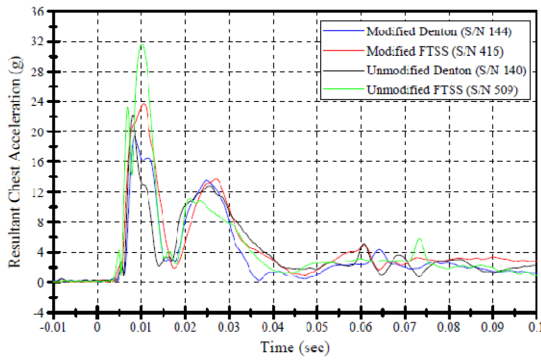

Figure 16. Chest acceleration during exposure to low risk deployment.

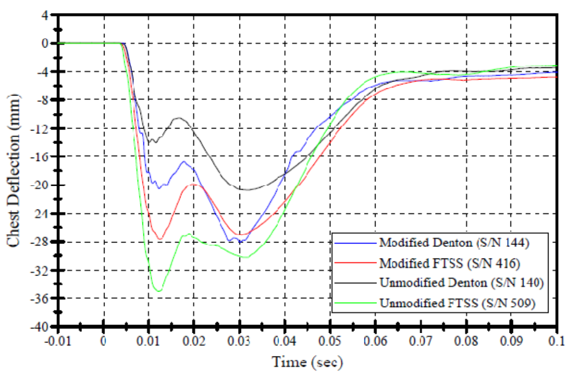

Figure 17. Chest deflection during exposure to low risk deployment.

deflection. Clearly some of the differences seen in chest deflection among the dummies are due to the initial setup, specifically, the chest-to-air bag module distance. While the average distance was 41 mm, dummy 509 was the closest to the module at 19 mm and dummy 140 was the farthest at 51 mm. Variations in air bag deployment may also be contributing factors to the variation in chest response.

Injury Criteria The chest accelerations and deflection of the dummies with the modified chest jacket and spine box fared better than their counterparts with the original jackets (Table 6). The percentage of injury values achieved by both the modified and the unmodified dummies are well within the allowable FMVSS No. 208 Injury Assessment Reference Values (IARV) for low risk deployment. The modified dummies' largest variation among the injury values is 13% in the chest acceleration (3ms Clip) and the chest deflection. Comparison of the variation in IARV range for the original dummies is similar and the range for chest acceleration in the unmodified dummies is slightly larger (15%).

Durability Spine box post-test torque checks indicate no loosening of the spine box anchor bolts. Also, there were no mechanical noise issues observed in the chest acceleration data or any other channel. The rib depths remained constant across the series of four low risk deployment tests for each dummy and were nearly identical between dummies with a rib 1 range from 160 to 162 mm and rib 5 ranges from 154 to 156 mm.

Table 6.
Low risk deployment results percentage of injury value summary

Injury Criteria	FMVSS 208 Max IARV	Percentage of Injury Value Achieved*			
		140	144 Mod	416 Mod	509
HIC[15]	700	2	2	3	3
Clip[3 ms]	60	27	22	35	42
Chest Deflection	52	54	40	53	67
Max [NIJ]	1	30	30	29	44
Max[NTE]	1	30	30	29	44
Max[NTF]	1	23	20	21	22
Max[NCE]	1	6	7	10	4
Max[NCF]	1	21	17	22	26
Neck Load Tension	2070	27	29	29	34
Neck Load Compression	2520	5	3	7	6
Left Femur	6805	6	N/A	5	6
Right Femur	6805	7	N/A	6	7

*displayed for unmodified dummies serial no. 140 and 509 and modified dummies 144 and 416

Sled Testing

Chest acceleration and deflection traces are shown in Figures 18 and 19. Although the sled acceleration and velocity were very consistently reproduced it should be noted that there is some variation in the lap belt force (CV 12%) and inner buckle firing time (CV 26%) that may introduce data variations (Table 7).

Examining the individual channels that factor into the IARVs provides further insight into the dummies' R&R for HIC, Chest Depth and Nij (Table 8). The Injury Assessment Value (IAV) results achieved by both the modified and the unmodified dummies are shown in Table 9. All measured IAVs are well within the allowable FMVSS No. 208 IARVs for a 2010 Ford Taurus frontal crash test simulated by these low risk deployment tests. The original dummies exhibit similar means to the modified dummies.

Repeatability and Reproducibility The modified dummies exhibited excellent to good repeatability in peak IAVs, excluding Nij, despite variation in lap belt forces and inner seat belt forces and inner seat belt buckle firing times. It should be noted that the chest deflection repeatability is excellent to good and is one of the primary interests of this report. The 10 % reproducibility of the chest deflection IARV was acceptable (Table 8). The modified dummies' peak chest deflection and acceleration CLIP [3ms] were nearly identical to those of the unmodified dummies.

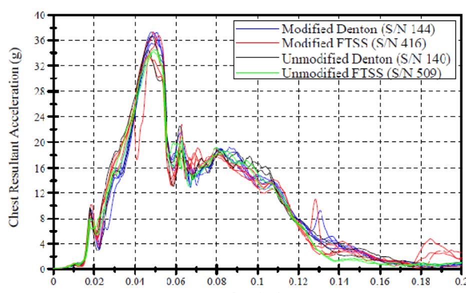

Figure 18. Chest acceleration from sled tests

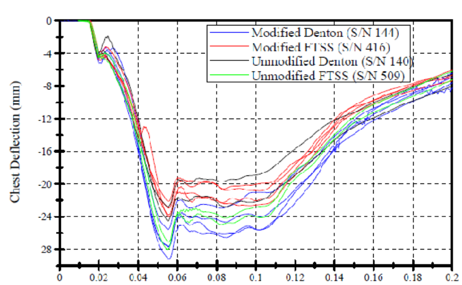

Figure 19. Chest deflection from sled tests

Table 7.
Sled and Restraint Inputs to HIII 5th Female Test Results Summary

Channel	Unit	Filter[1]	Avg	Std	%CV
Sled Accel.	g	60	28.0	0.11	0.4
Sled Vel.	mi/h	60	34.8	0.06	0.2
Lap Belt	N	60	5548.1	644.81	11.6
	msec	60	52.2	1.56	3.0
Shoulder Belt	N	60	5717.0	144.43	2.5
	msec	60	50.2	0.38	0.8
Inner Buckle	msec	none	15.5	4.04	26.0
Limiter Volt.	msec	none	57.6	1.85	3.2
Limiter Amp.	msec	none	52.8	0.20	0.4
Buckle Volt.	msec	none	12.8	0.20	1.5

*See table 1 for color key.

Table 8.
Sled peak response results CV summary

Channel	144	416	144 416
	CV %*		
Head Res. Accel	1	2	3
Up. Neck X-Axis Force	4	3	5
Up. Neck Z-Axis Force	2	8	5
Up. Neck Y-Axis Moment	3	10^	9
Low. Neck X-Axis Force	9	4	8
Low. Neck Z-Axis Force	4	9	7
Chest X-Axis Accel.	2	5	5
Chest Z-Axis Accel.	3	5	6
Chest Res. Accel.	2	6	4
Chest Defl. X-Axis	5	4	10
Pelvis X-Axis Accel.	2	6	7
Pelvis Z-Axis Accel.	4	10^	6
Pelvis Res. Accel	1	7	6
Femur L. Z-Axis Force	2	4	5
Femur R. Z-Axis Force	1	4	8

*See table 1 for color key. ^ Exceeded 10 but rounded here.

Durability Results Although there were minor screw impressions on the foam layer inside the dummy jackets after the sled tests, no problems with dummy durability was observed. The chest depth for each dummy remained constant across the series of six sled tests and was nearly identical between dummies. There were also no indications from torque measurements on the spine box anchor screws that the spine box anchor screws had loosened. Finally, a

Table 9.
Sled injury assessment value results mean and CV summary

Simulated 2010 Taurus with NCAP 2010 Taurus Sled Pulse*											
Channel	**Units**	**Filter[1]**	**IARV**	**D144**		**F416**		**Combined**		**D140**	**F509**
				Avg^	**CV %**	**Avg**	**CV%**	**Avg**	**CV%**	**Avg**	**Avg**
HIC[36]		1000	1000	196	7	183	2	191	6	191	197
T1(Begin)	ms	1000		64	1	60	1	62	3	64	63
T2(End)	ms	1000		100	1	96	1	98	2	100	99
Avg. g T1 to T2	g	1000		31	3	30	1	31	3	31	31
HIC[15]		1000	700	107	5	88	3	99	11	98	92
T1(Begin)	ms	1000		67	1	65	1	66	2	67	64
T2(End)	ms	1000		82	1	80	1	81	1	82	79
Avg. g T1 to T2	g	1000		35	2	32	1	34	4	33	33
Max[NTE]	N	600	1	0.45	9	.51	4	0.48	10	0.36	0.65
Max[NTF]**	N	600	1	0.30	3	.16	10	0.24	30	0.29	0.24
Max[NCE]**	N	600	1	0.08	59	.21	6	0.14	58	0.15	0.22
Max[NCF]**	N	600	1	0.11	107	.01	78	0.07	144	0.01	0.01
Neck Loads- Max Shear -X-Axis	g	1000	1950	546	4	508	4	530	5	525	622
Neck Loads- Max Axial Z-Axis	N	1000	2520C 2620T	1190	2	1160	2	1177	2	1156	1135
Clip[3 ms]	g	180	60	36	2	34	5	35	5	35	34
T1 (Begin)				46	2	44	2	45	2	44	47
T2 (End)				49	1	47	2	48	2	47	50
Chest Deflection	mm	600	52	28	5	23	4	26	10	24	28
Femur Loads Right Max Tension	N	600	6805	2823	1	2478	5	2675	8	2627	2522
Femur Loads - Left Max Tension	N	600	6805	3011	2	2803	5	2922	5	2777	2737

* See table 1 for color key.
^n=4 for D144 and F416. N= 2 for D140 and F509.
**experience has shown that small values in Nij have large coefficient of variations due to variations between the time of peak moment and peak axial force. Note: generally as the magnitude of the Max Nij decreases from 0.5 to 0.01 the repeatability and reproducibility decreases and is in the red zone.

review of the data channels did not indicate any signs of metal-to-metal contact within the dummy during the test and there were no signs of unexplained spikes in the chest acceleration or any other channel.

DISCUSSION

Inspection

The two brands of chest jackets are now identical in appearance and compare well to the SAE drawings, although there are slight variations in the height of the access holes and in the hole diameter in the sternum pad with respect to the drawing. The spine boxes, mandrels and assembled dummies were within tolerance of the SAE drawings. The modifications to the spine boxes are identical, each having three countersunk through holes in each side plate through which three 5/16 x 18 x 5/8” screws anchor the spine box to the lumbar load cell or load cell simulator.

Certification Testing

The dummies configured to the CFR passed the certification tests. However, while the modified dummies passed the thorax Part 572 response requirements, they did not pass the torso flexion requirement. The torso flexion force response was high; therefore, the torso is stiff in flexion. Evaluation of the new harmonized jackets for the Hybrid III small female dummy by the Japan Automobile Manufacturers Association, Inc. and Japan Automobile Research Institute also noted stiffer torso flexion responses [14].

Repeatability and Reproducibility

The thorax of the dummies proved to be repeatable and reproducible (Table 10). However, while the performance in torso flexion testing was repeatable, it did not pass the maximum force requirements at 45 degrees flexion. Therefore the reproducibility of the dummy in torso flexion was not determined.

The SAE Hybrid III Dummy Family Task Force shared similar findings [14]. Table 10 shows a comparison between the two methods used to determine the CV. The thorax reproducibility is excellent as determined by both the $CV_{50\%avg}$ and CV_{peak} methods.

Low Risk Deployment Testing

During certification testing dummies were instrumented as they would be for low risk deployment and sled testing to look for signs of noise. Noise was detected in the chest and spine accelerometers but it was attributed to the femurs and resolved by tightening the femur plungers beyond the one g requirement specified for setting up the dummy for testing.

Table 10.
CV comparison of peak and time series with T statistic for repeatability and reproducibility

Thorax certification response in corridor		Repeatability				Reprod.		
		$CV_{50\%}$ Avg		CV Peak		T-Statistic**	$CV_{50\%}$ Avg	CV Peak
		VRTC	TRC	VRTC	TRC			
Force	144	1.3	2.9	0.7	0.9			0.8
	416	1.6	3.1	0.9	1.3			1.5
	144 416	2.4	3.5	1.2	1.1	3.3	4.6	1.3
Deflection	144	0.7	2.3	0.2	0.5			1.8
	416	0.5	2.9	0.6	0.6			4.2
	144 416	3.7	3.0	3.7	2.3	2.3	4.6	3.7

*See table 1 for color key. ** - from VRTC Data. TRC T-statistic was even larger (4.9 for force and 111 for deflection). Note: Combining dummy serial nos. 144 & 416 indicate reproducibility.

No anomalies other than differences between the chest deflection values were noted during the low risk deployment tests and the IARVs were within the FMVSS No. 208 requirements. The variations are attributed to a combination of variation in air bag deployment and variation introduced by the setup.

Sled Testing

The IAVs were within established FMVSS No. 208 limits (Table 9). The modified dummies exhibited excellent to good repeatability in peak IAVs and acceptable reproducibility. The average CV method incorporates a significant portion of the time-history using a threshold for analysis from the first occurrence of 50% of the peak value to the last occurrence of 50% of the peak value. Except for the upper neck y-moment the average CV method indicates acceptable dummy repeatability with the repeatability for the chest acceleration and deflection good to excellent. However, the reproducibility of the head acceleration was poor. With the t-distribution critical value = 2.353 the T statistic indicates that neither the head resultant acceleration, chest deflection, nor the y-moment were reproducible in the sled tests (Table 10). In contrast, the traditional method used for calculating repeatability and reproducibility, when applied to the time of the instantaneous peak responses, yields excellent results except for the neck y moment (Table 11).

Table 11.
Average CV repeatability & reproducibility for dummy serial numbers

Sled test response	$CV_{50\%avg}$			$T_{50\%}$
	144	**416**	**144 416**	**144 416**
Head Resultant Accel.	9.4	9.3	11.8	2.2
Chest Resultant Accel.	3.8	6.6	7.2	15
Chest Deflection	6.6	4.8	10.1	-52.3
Upper Neck Z-Force	6.1	6.6	8.0	9.9
Upper Neck Y-Moment	18.6	12.4	18.8	-13.7

Table 12.
Peak CV repeatability & reproducibility

Sled test time of peak response	CV_{peak}		
	144	**416**	**144 416**
Head Res. Acceleration	*1.8*	*1.6*	*3.7*
Chest Res. Acceleration	*2.5*	*6.2*	*5.0*
Chest Deflection	*0.2*	*0.2*	*0.4*
Upper Neck Z Force	*4.1*	*1.6*	*3.0*
Upper Neck Y-Moment	*4.3*	*10.2*	*10.8*

Durability

Although the modified dummies were only exposed to eight certification tests, a single low risk deployment air bag test and four sled tests there were no problems with dummy durability observed other than possible the neck on dummy serial no. 416. There were minor screw impressions on the foam layer inside the dummy that developed over the course of the four low risk deployment and six sled tests. There were no signs of noise and the tests showed that the phenomenon of spine box internal motion about mounting screws did not occur.

Drawings

The chest flesh, spine box, assembled dummy, and mandrel drawings were reviewed and prepared for federalization. The few minor dimensional issues identified on the chest flesh and sternum pad drawings can easily be resolved by changing a few drawings.

CONCLUSIONS

The FTSS and Denton modified chest jacket, spine box, chest jacket mandrel, assembled dummies and SAE drawings that were evaluated in this study provided comparable dimensional data and test results. A few areas were identified where the drawings were unclear and where the parts were dissimilar but these were minor inconsistencies.

The dummy passed the thoracic certification test with excellent repeatability and reproducibility based on peak CV. The average CV yields good reproducibility. While the repeatability of the torso flexion test maximum force at 45 degrees is acceptable, it fails the force limit. It should be noted that the existing chest jacket specified by the CFR passes the force limit and the torso flexion test. Further work on the jacket is needed to address the shortcomings evidenced by the torso flexion test results.

The modified dummies demonstrated the ability to assess the IARVs in low risk deployment and sled testing. There were no indications that noise was introduced into the dummy during low risk deployment tests, where the dummy's chest was exposed to air bags or as a result of the sled tests.

The dummy R&R was also examined for the sled tests. Based on peak CV values the resultant chest acceleration responses have excellent to good repeatability and excellent reproducibility. The values of the chest deflection also exhibited excellent to good repeatability but only acceptable reproducibility.

The dummies R&R was similar when applying the 50% CVavg method: the chest acceleration and deflection response repeatability of the dummies was excellent to good. The reproducibility of the chest acceleration was good and chest deflection was acceptable. Even though there is variability in the sled test restraints the dummies chest performed at an acceptable level.

Both the average CV and peak methods indicate unacceptable repeatability performance of the dummy serial no. 416 neck. While the neck passed the certification requirements exploration of the reasons for its unacceptable repeatability was not within the scope of this study. Further evaluation of the neck is planned and will begin by examining its repeatability and reproducibility in neck certification testing.

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