DYNAMIC SIDE IMPACT TESTING WITH THE 50TH PERCENTILE MALE WORLDSID COMPARED TO THE ES-2RE

Allison E. Louden
National Highway Traffic Safety Administration
United States
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ABSTRACT

The agency released the final rule for Federal Motor Vehicle Safety Standard (FMVSS) No. 214 "Side Impact Protection" in September 2007, which put in place upgrades that involve moving deformable barrier (MDB)-to-vehicle and vehicle-to-pole crash tests with a 50th percentile adult male, the EuroSID 2re (ES-2re) and a 5th percentile adult female, the SID-IIs dummy. Recently, the National Highway Traffic Safety Administration (NHTSA) began evaluating the 50th percentile male WorldSID in these types of crashes using the same fleet vehicles. This paper includes an evaluation of the dummy's durability in crash testing and gives a comparison of the test results with those of the ES-2re dummy. The two dummies have different anthropometries and seating procedures which affect the final results. In general, the WorldSID produced more elevated responses than the ES-2re dummy for both test modes.

INTRODUCTION

The FMVSS No. 214 final rule upgraded the 50th percentile male dummy from the US SID to the ES-2re dummy. This dummy was a European enhanced side impact dummy which was used in the Economic Commission for Europe Standard, R95 (ECE R95). It was developed originally as the ES-1, which was later modified to ES-2. The ES-2 is the current dummy used in European standards. The ES-2 was modified with rib extensions, thus the name ES-2re and is the current dummy being used in the new FMVSS No. 214 test requirements. [1]

At the same time the EuroSID dummy was evolving, a second dummy was also being developed as a collaborative project to develop a world harmonized side impact dummy. The dummy's anthropometry was based on a NHTSA study done by the University of Michigan Transportation Research Institute (UMTRI) that looked at the anthropometry of actual humans in actual vehicle seats. [2][3] After extensive evaluations, the NHTSA concluded that the WorldSID was not ready for use in Federal regulations and its potential use had not been fully assessed by the agency for inclusion in the 2007 FMVSS No. 214 Final Rule. The agency further stated that, upon completion of its evaluation of the WorldSID, it would consider possible incorporation of the device in FMVSS No. 214. [4]

DUMMIES

ES-2re

The ES-2re sits in an upright position, with a seating height of 660mm (see Figure 1 for more details). It is instrumented with the following: an upper neck load cell, a shoulder load cell, three rib potentiometers that measure lateral deflection, three abdominal load cells that measure the lateral loads, a pubic load cell, and accelerometers at numerous locations to measure the "g" levels that are applied to the dummy during a side impact.

WorldSID

The WorldSID sits in a more slouched position and is slightly shorter than the ES-2re dummy (see Table 1 for more details). It was instrumented with the following: upper and lower neck load cells; IR-TRACCs in the shoulder, thoracic ribs, and abdomen ribs; a shoulder load cell; a pubic load cell; iliac and sacrum load cells; and accelerometers at numerous locations to measure the "g" levels that are applied to the dummy during a side impact. The WorldSID also has the option of having its data acquisition system onboard. All of the tests conducted with the WorldSID dummies utilized the onboard data acquisition system.

Table 1.
Dummy Anthropometry Measurements

	WorldSID	ES-2re
Shoulder width	480	485
Thorax width (nipple)	371	337
Pelvis width	410	355
Seating height (neck/torso interface)	600	660
Seating height (erect)	870	920
Leg Length	555	452

All measurements are in millimeters.

Both dummies are designed to study occupant response to potential injury in side impact crash tests. In Figure 1, the ES-2re is in the red suit (left) and the WorldSID is in the purple suit (right). As you can see, the ES-2re sits slightly higher than the WorldSID, which puts the head and ribs in different vertical locations.

Figure 1. ES-2re and WorldSID Dummies.

Anthropometry Analysis

Anthropometry had a large effect in the crash tests. The two dummies sat differently in the vehicle seats, which in turn allowed different body areas to be loaded, which caused differences in the final responses of the dummies.

Figure 2 shows the UMTRI manikin. [2] This manikin represents a series of real adult people and how they sit in vehicles. Figure 3 shows the ES-2re superimposed on the UMTRI manikin. The ES-2re sits taller and more upright in the vehicle seat. Notice the placement of the head and shoulder. The ES-2re head and shoulder are more vertical and rearward than those of the UMTRI manikin. The ribs of the ES-2re are approximately 20-25 degrees from horizontal, even though the dummy is sitting straight up.

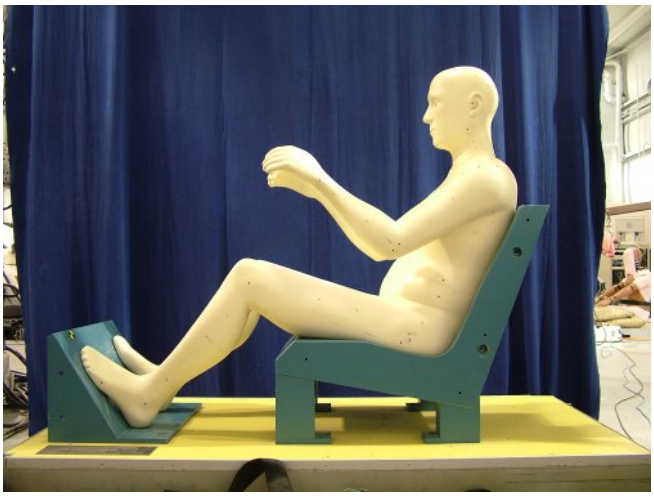

Figure 2. UMTRI Adult Male Manikin.

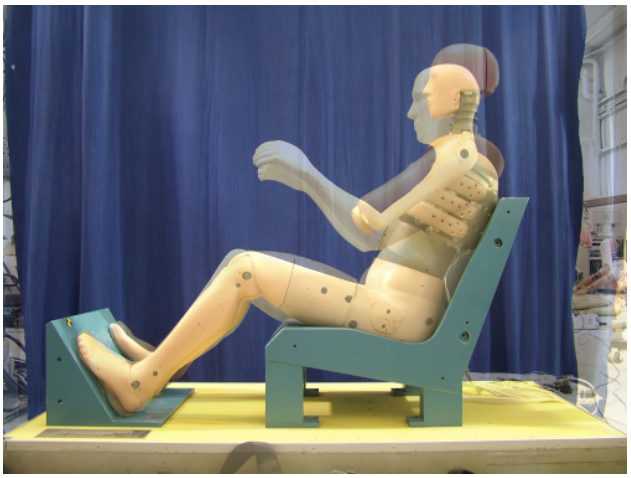

Figure 3. ES-2re Superimposed with the UMTRI Manikin.

Figure 4 shows the WorldSID dummy compared with the UMTRI manikin. The heads and shoulders are almost aligned with each other. The ribs of the WorldSID are in a horizontal plane. Figure 5 shows the ES-2re and WorldSID dummies superimposed on each other. The differences described earlier are more visible when the two dummies are superimposed. The ES-2re head and shoulders are above that of the WorldSID, and its ribs are angled compared to the WorldSID. Also note that the ES-2re dummy's abdomen vertically overlaps the WorldSID's lowest thoracic and top abdominal ribs.

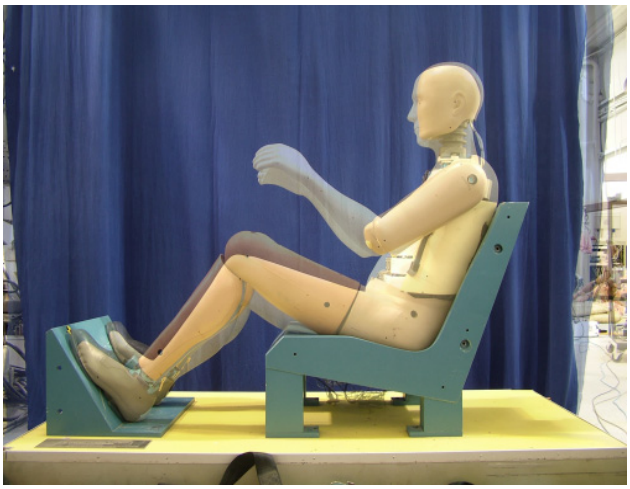

Figure 4. WorldSID Superimposed with UMTRI Manikin.

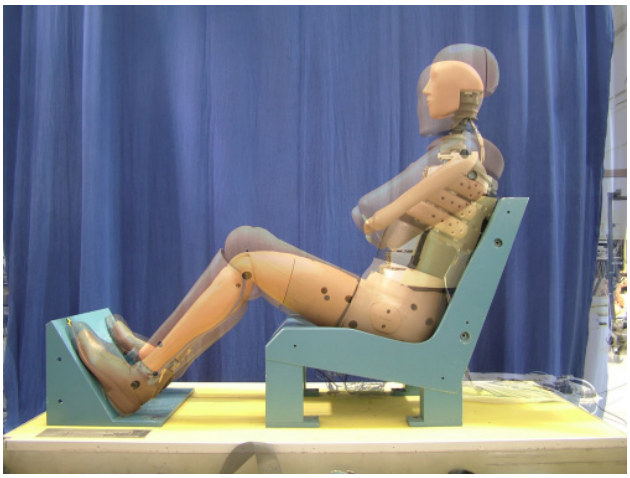

Figure 5. WorldSID and ES-2re Superimposed.

Figure 6 shows a side by side comparison of the two dummies without their jackets. The thoracic ribs do not align directly with each other as previously noted. This is especially important when analyzing the data. According to the pictures an assumption can be made about the approximate alignments of the ribs. The WorldSID shoulder rib aligns with the ES-2re's 2nd thoracic rib, and the WorldSID's 1st thoracic rib aligns with the ES-2re's 3rd thoracic rib. The ES-2re's abdomen aligns with the WorldSID's thoracic rib #3 and abdomen rib #1; the WorldSID's abdomen rib #2 is aligned with the ES-2re's pelvis.

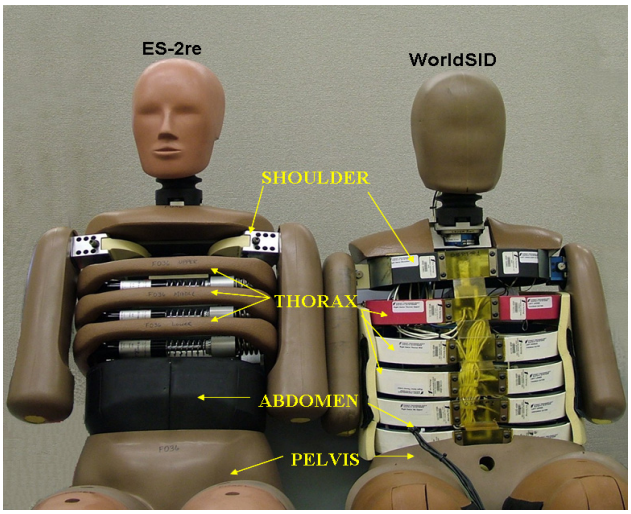

Figure 6. ES-2re and WorldSID Comparison View.

The anthropometry of the two dummies is very important in how the two dummies respond in the crash, especially in the pole test where the head CG determines the impact point on the vehicle.

TEST MATRIX and PROCEDURES

The NHTSA tested eight model year (MY) 2005 vehicles in the oblique pole test and five MY 2005 vehicles in the MDB test. The vehicles chosen to be tested with the WorldSID had been previously tested with the ES-2re dummy (Table 2). All of the vehicles had some form of head protection. The 2005 Subaru Forester and Volkswagen Beetle convertible had seat-mounted head and thorax air bags. The 2005 Saturn Ion had a head curtain but no thoracic air bag, whereas the other six vehicles had thoracic and head curtain air bags.

Table 2.
Test Matrix

Vehicles	MDB	Oblique Pole
2004 Honda Accord		√
2005 Subaru Forester	√	√
2006 Toyota Sienna		√
2005 Ford 500	√	√
2006 VW Jetta	√	√
2005 Saturn Ion	√	√
2005 Ford Expedition		√
2005 VW Beetle (Convertible)		√
2005 Honda CRV	√	

Test Setup

The tests were conducted per the FMVSS No. 214 2007 final rule test procedures. The dummies were instrumented with additional instrumentation than required by the rule. The MDB tests were conducted with two ES-2re or two WorldSID dummies seated in the left front and left rear seating positions. The oblique pole tests were conducted with one ES-2re or WorldSID dummy in the left front seating position.

The ES-2re dummies were seated in accordance with the final rule seating procedures; seat in midtrack, seat full down, and seat back angle determined by the OSCAR procedures (~25 degrees). The WorldSID was seated using the same initial conditions for the seat and adjusted per the seating procedures for the WorldSID dummy drafted by the WorldSID Task Group (version 1.0).[3] This seating procedure allowed for the seat back to be moved in both fore and aft directions in order to level the thorax and the head. In some of the vehicles, the seat back was moved one or two notches forward or rearward from the initial position.

The final seating position of the dummies plays a vital role in determining the vehicle-to-pole impact location in the oblique pole test. The final impact point is based on the head center of gravity (CG). In some instances, there was a difference in the final head position between the ES-2re and the WorldSID dummy.

Injury Criteria

The injury criteria used for the ES-2re were those specified in FMVSS No. 214. Some of the injury responses represent a 50% risk of AIS 3+ injury where others represent a 25% risk of AIS 3+ injury. [4] The WorldSID's injury criteria used for this testing were formulated by the WorldSID task group. Table 3 shows the corresponding injury assessment reference values (IARVs) used for both dummies. The WorldSID proposed values represent a 50% risk of AIS 3+ injury. [3]

Table 3.
Injury Assessment Reference Values (IARVs)

	WorldSID*	ES-2re
HIC36	1000	1000
Thorax Deflection (mm)	56	44
Abdomen Deflection (mm)	53	n/a
Lower Spine Resultant (g's)	78	82**
Abdomen Force (N)	n/a	2500
Pubic Force (N)	1790	6000
Pelvis Resultant (g's)	77	n/a

*WorldSID values are proposed IARV's by working group.
**Not in used in final rule, but used to monitor the lower spine results.

TEST RESULTS

The vehicles chosen for this testing were not designed to meet the requirements of the oblique pole test; however the purpose was to compare the different dummy responses. The dummy responses for each test are shown in the Appendix.

The MDB tests produced similar responses between the two dummies, although the WordSID had more elevated responses (i.e. 80-99% of the proposed IARV) for both occupants than the ES-2re dummy. The pole tests resulted in some vehicles exceeding the IARVs for both dummies. The WorldSID produced more elevated injury responses in both of the test modes.

MOVING DEFORMABLE BARRIER

The MDB tests resulted in all vehicles meeting IARVs for their corresponding dummy. For the WorldSID tests, the 2005 Saturn Ion met the IARV for maximum rib deflection by a very narrow margin (55.98 mm). It also had elevated responses for the abdomen deflection, pubic force, and pelvis acceleration (Figure 7). In the ES-2re tests, the 2005 Honda CRV had an elevated thorax deflection response in the left front seat. These minor differences may be attributed to the differences in dummy positioning in the vehicle and seat. The rib responses may also differ due to how the ribs react with the deformable barrier and door intrusion. Unlike the ES-2re's rib modules, which are constrained to deflect only in the pure lateral direction, the IR-TRACCs in the WorldSID's ribs may deflect obliquely, and the IR-TRACCs are

designed to measure displacement in the direction of the rib loading.

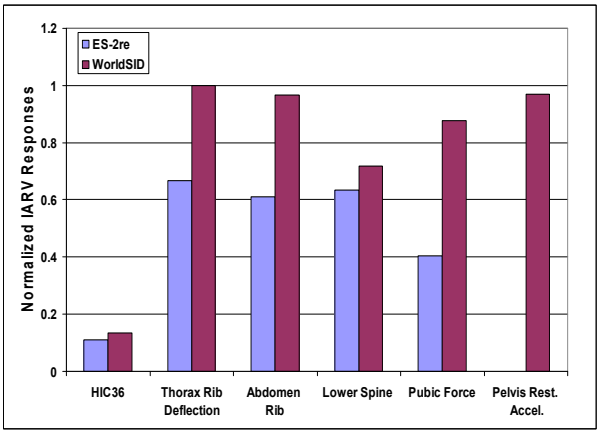

Figure 7. 2005 Saturn Ion Normalized IARV Responses.

OBLIQUE POLE

The test results for the oblique pole varied for each dummy, and the injury responses can be found in the Appendix. The tests with the ES-2re dummy resulted in five of the eight vehicles exceeding at least one IARV. The VW Jetta, Honda Accord and VW Beetle Convertible met all IARVs. The tests with the WorldSID dummy also had five of the eight vehicles exceeding at least one of the proposed IARV responses. As with the ES-2re, the Jetta and Accord met all the IARVs with the WorldSID, but the third vehicle was the Toyota Sienna rather than the VW Beetle.

Head Positioning and Responses

The impact point of the oblique pole test is determined by the final location of the head CG. Comparing the same vehicles with the two different dummies, a general trend was noticed. For the vehicles tested, the two dummies sat differently in the same vehicle seat. This was due to the differences in the dummies' anthropometries and to the WorldSID's seating procedure which allows the seat back to be moved to level the thorax and pelvis. These differences changed the impact point on the vehicles depending on which dummy was used. On certain vehicles, this difference affected the deployment time and path of the air bag, and also the structural deformation of the door during impact. This resulted in some significant differences in the HIC36 responses (Figure 8).

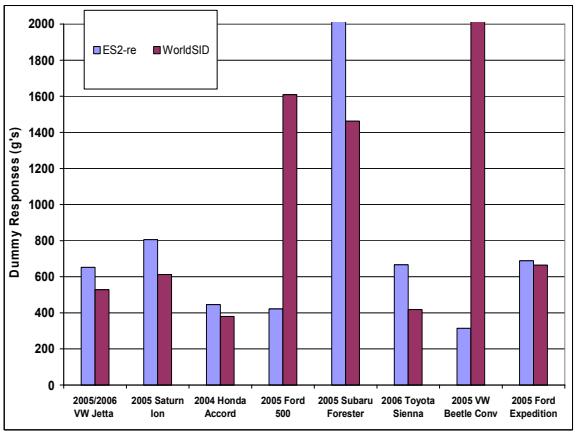

Figure 8. HIC 36 Responses for ES-2re and WorldSID.

Three vehicles, 2005 Ford Five Hundred, 2005 Subaru Forester, and 2005 Volkswagen (VW) Beetle, had very different HIC36 responses when comparing the two dummies. The Ford Five Hundred and the VW Beetle resulted in high HIC responses when tested with the WorldSID and low responses when tested with the ES-2re. The Subaru Forester resulted in high HIC responses for both dummies, but they were higher for the ES-2re.

In the 2005 Ford Five Hundred, the WorldSID's head CG was lower and 3½ inches more forward than the ES-2re in the same vehicle model (Figures 9 and 10). Therefore, the pole struck the vehicle more forward, and the air curtain deployed approximately 15 ms later than in the ES-2re test. This resulted in the WorldSID head striking the pole, which resulted in a HIC36 of 1609 compared to the ES-2re HIC36 of 422.

Figure 9. ES-2re Head Position in 2005 Ford Five Hundred.

Figure 10. WorldSID Head Position in 2005 Ford Five Hundred.

The 2005 VW Beetle also showed a large difference in the HIC36 response between the ES-2re and WorldSID. The HIC36 for ES-2re was 315 compared to 3630 for the WorldSID. As shown in Figure 11, the final placement of the WorldSID in the seat resulted in the seat back being more reclined and the dummy's head CG 1½ inches more rearward than the ES-2re. This affected the impact point of the pole and most likely, the deployment path of the seat mounted combination air bag. In the WorldSID test, the air bag inflated rearward from the side of the seat and didn't get in between the dummy's head and the pole in the correct time, thus resulting in a high HIC response.

Figure 11. ES-2re and WorldSID at 55ms in 2005 VW Beetle.

Thorax and Abdomen Responses

The WorldSID measures the deflection of three thoracic ribs and two abdominal ribs, whereas the ES-2re measures the deflection of three thoracic ribs and the force applied to the abdomen (Figure 6).

The thorax and abdomen directly interact with the door liner, arm rest, and/or thoracic air bag. When comparing the two dummies, the WorldSID gave higher thoracic responses than the ES-2re in four of the eight vehicles tested (Figure 12). The differences in the responses between the two dummies were minimal (within 10%) for four of the vehicles, while they were larger for the other four. The WorldSID had higher abdominal responses than the ES-2re in seven of the eight vehicles, and the responses from the eighth vehicle were nearly identical (Figure 13). The differences in the responses between the two dummies were minimal for three of the vehicles, while they were larger for the other five.

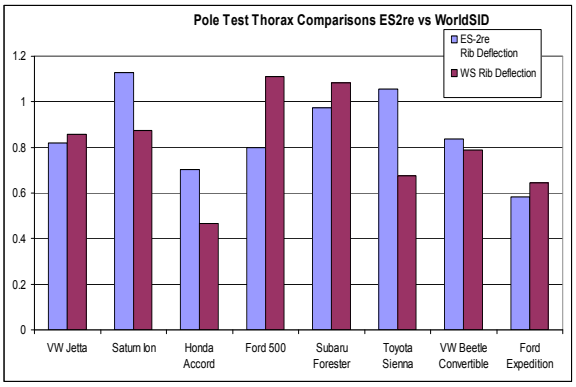

Figure 12. ES-2re and WorldSID Normalized Thorax Responses for Oblique Pole.

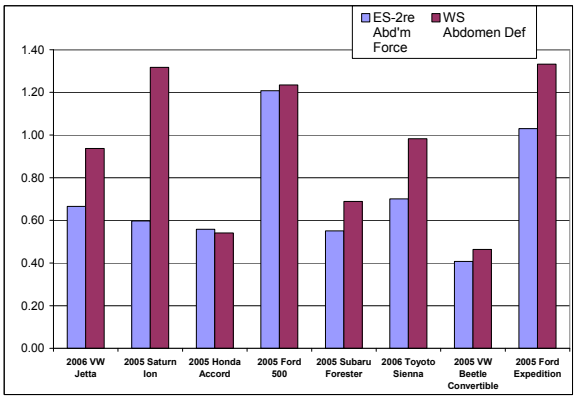

Figure 13. ES-2re and WorldSID Normalized Abdomen Responses for the Oblique Pole.

It is believed that the differences in the thoracic and abdominal responses between the two dummies can be attributed to the differences in their seating postures and positions. Even though the seat back positions were only different by a notch or two, the dummies responded differently. The WorldSID had higher rib responses in Rib 1, whereas the ES-2re had similar responses for all three ribs, and it usually was lower than the deflection that occurred in the WorldSID.

For example, the normalized abdominal responses for the 2005 Saturn Ion went from 0.60 with the ES-2re to 1.32 with the WorldSID. This could be due to the interaction of the armrest, which directly loaded the WorldSID's abdominal ribs, while it loaded the lower half of the abdomen and the upper edge of the pelvis in the ES-2re.

The posture differences in the dummies can possibly create different impact locations, structural deformation, and air bag deployments. These differences can also create different alignment of body regions and interior door surfaces.

Pelvis Responses

The WorldSID and ES-2re pubic load cell are located in very similar areas, but the pelvic areas surrounding the pubic load cell are made of different materials. Also, as discussed previously, the dummies have different abdomen designs. The WorldSID has two abdominal ribs whereas the ES-2re has three abdominal load cells, and the pelvic skin of the ES-2re extends higher than that of the WorldSID (Figure 6).

The WorldSID produced similar responses in all of the vehicles, while the ES-2re responses were more varied (Figure 14). Although low, the WorldSID produced higher responses than the ES-2re in five of the eight vehicles, and they were nearly identical in two of the others.

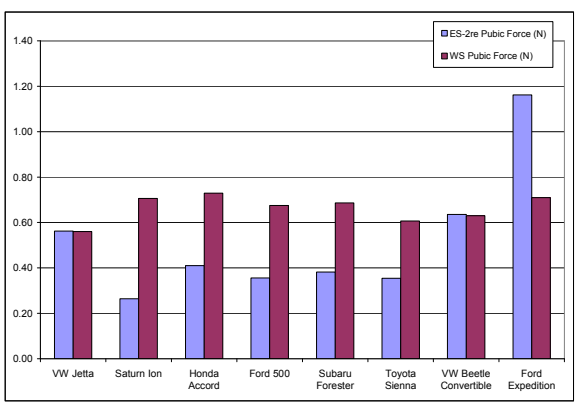

Figure 14. Normalized Pubic Load Cell Responses for ES-2re and WorldSID.

DUMMY DURABILITY

The WorldSID dummies were examined after each test, and pre and post test calibrated after the 3rd use. The dummies only had minor damages; the damage that did occur was a result of the oblique pole testing.

The maximum shoulder deflection was reached during four of the eight oblique pole tests. The shoulder IR-TRACC was damaged during one of these tests. Both ends were bent and one end was damaged (Figure 15). Also, over the testing period, the rib damping material de-bonded from the metal ribs.

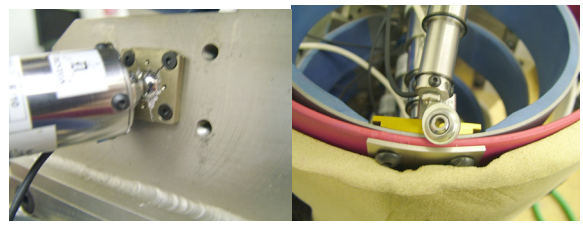

Figure15. WorldSID IR-TRACC Damage.

CONCLUSIONS

- Regardless of which dummy was used, the following were determined:
  - In the MDB tests, all dummy responses were below their corresponding IARVs for all five of the vehicles tested, although several had elevated responses. The driver WorldSID in the Saturn Ion had a maximum thoracic rib deflection of 55.98 mm, which was below the proposed IARV by a very narrow margin (56 mm).
  - In the oblique pole tests, at least one IARV was exceeded for the Saturn Ion, Ford Five Hundred, Subaru Forester, and Ford Expedition.
  - In the oblique pole test, all dummy responses were below their IARV for the Volkswagen Jetta and the Honda Accord.
  - In the oblique pole test, the 'meet/exceed' performance of the Volkswagen Beetle and the Toyota Sienna depended on which dummy was used. The VW Beetle exceeded the HIC criterion with the WorldSID and the ES-2re exceeded the HIC criterion in the Toyota Sienna.
  - In both the MDB and oblique pole tests, the WorldSID dummy produced more elevated (80-99% of proposed IARV) and high (exceeded IARV) responses than the ES-2re.
- The 50th Male WorldSID and ES-2re have different dummy anthropometries.
- The WorldSID is based on the UMTRI anthropometry study, which is based on actual humans sitting in vehicle seats.
- WorldSID sits in a more slouched position and sits lower in the seat than the ES-2re. This places the body regions of the WorldSID and ES-2re in different locations.

- Different head positions produce different impact locations in the oblique pole tests. This may affect the head impact location on the air curtain, sensor responses, and structural deformation.
- The WorldSID and ES-2re thorax and abdomen are aligned differently with the vehicle interior. This can produce different loading on the dummies (e.g. armrest to abdomen), possibly resulting in different responses.
- The overall WorldSID dummy durability is good.

REFERENCES

[1] "Specification of the EEVC Side Impact Dummy Eurosid 1", European Experimental Vehicles Committee, April 1990

[2] "Development of Anthropometrically Based Specifications for an Advanced Adult Anthropomorphic Dummy Family"; Volume 1-2, University of Michigan, December 1983.

[3]http://www.worldsid.org/Work_Items/Worldsid_Official_Documents.cfm

[4] "FMVSS No. 214 Final Rule", Federal Register, 72 FR 51907, September 11, 2007.

APPENDIX: DUMMY RESPONSES

Table 1.
MDB Driver WorldSID Responses

Vehicles	HIC36	Thorax Deflection (mm)	Abdomen Deflection (mm)	Lower Spine (G's)	Pubic Force (N)	Pelvis Resultant (g's)
Proposed Injury Criteria	1000	56	53	78	1790	77
VW Jetta (C+T)	131	37	26	48	1355	44
Saturn Ion (C)	136	56	51	56	1571	75
Ford Five Hundred (C+T)	42	17	22	47	778	38
Subaru Forester(Combo)	33	19	9	35	849	55
Honda CRV (C+T)	47	17	8	31	746	40

Table 2.
MDB Passenger: WorldSID Responses

Vehicles	HIC36	Rib Deflection (mm)	Abdomen Deflection (mm)	Lower Spine (G's)	Pubic Force (N)	Pelvis Resultant (G's)
Proposed Injury Criteria	1000	56	53	78	1790	77
VW Jetta (C+T)	131	18	23	38	871	47
Saturn Ion (C)	260	39	41	55	1192	54
Ford Five Hundred (C+T)	242	36	32	46	1068	68
Subaru Forester(Combo)	122	21	30	36	n/a	43
Honda CRV (C+T)	89	21	32	39	1052	74

Table 3.
MDB Driver: ES-2re Responses

Vehicles	HIC36	Rib Deflection (mm)	Lower Spine (G's)	Pubic Force (N)	Abdomen Force (N)
IARVs	1000	44	82	6000	2500
VW Jetta (C+T)	101	26	28	1969	733
Saturn Ion (C)	110	29	52	2431	1524
Ford Five Hundred (C+T)	66	25	35	1176	1006
Subaru Forester(Combo)	44	21	33	1694	598
Honda CRV (C+T)	100	35	31	1137	524

Table 4.
MDB Passenger: ES-2re Responses

Vehicles	HIC36	Rib Deflection (mm)	Lower Spine (G's)	Pubic Force (N)	Abdomen Force (N)
IARVs	1000	44	82	6000	2500
VW Jetta (C+T)	211	29	53	2542	1378
Saturn Ion (C)	168	27	47	2275	1511
Ford Five Hundred (C+T)	213	25	44	1407	1649
Subaru Forester(Combo)	226	23	35	1948	967
Honda CRV (C+T)	126	5	33	1847	1192

Table 5.
Oblique Pole Driver: WorldSID Responses

Vehicles	HIC36	Thorax Def. (mm)	Abdomen Def. (mm)	Lower Spine Result. (g's)	Pubic Force (N)	Pelvis Result. Accel. (g's)
Proposed Injury Criteria	1000	56	53	78	1790	77
2006 VW Jetta (C+T)	528	48	50	63	1002	57
2005 Saturn Ion (C)	612	49	70	80	1264	68
2005 Honda Accord (C+T)	380	26	29	52	1305	53
2005 Ford 500(C+T)	1609	62	66	82	1209	66
2005 Subaru Forester (Combo)	1463	60	37	79	1227	77
2006 Toyota Sienna (C+T)	418	38	52	68	1085	62
2005 VW Beetle Convertible(Combo)	3680	44	25	69	1127	81
2005 Ford Expedition (C)	665	36	71	77	1270	86

Table 6.
Oblique Pole Driver: ES-2re Responses

Vehicles	HIC36	Rib Deflection (mm)	Lower Spine (G's) (monitored)	Pubic Force (N)	Abd'm Force (N)
IARVs	1000	44	82	6000	2500
2006 VW Jetta (C+T)	652	36	60	3372	1663
2005 Saturn Ion (C)	806	50	76	1585	1494
2005 Honda Accord (C+T)	446	31	52	2463	1397
2005 Ford 500 (C+T)	422	35	68	2133	3020
2005 Subaru Forester (Combo)	2054	43	46	2291	1377
2006 Toyota Sienna (C+T)	667	47	60	2127	1751
2005 VW Beetle Convertible (Combo)	315	37	69	3815	1018
2005 Ford Expedition (C)	689	26	75	6973	2575

Legend:
Lower than 80% of IARV 80%-99% of IARV Exceeding IARV
C=Curtain only; C+T=Curtain and thorax; Combo=Head thorax combination