EVALUATION OF THOR DUMMY PROTOTYPE PERFORMANCE IN HYGE SLED TESTS

Masahiro Ito, Koshiro Ono
Japan Automobile Research Institute (JARI)
Yoshihisa Kanno
Japan Automobile Manufacturers Association (JAMA)
Japan
Mark Haffner
National Highway Traffic Safety Administration
Nagarajan Rangarajan, Tariq Shams
GESAC, Inc.
United States
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ABSTRACT

The THOR-50M dummy being developed as the next generation dummy for frontal impacts was leased out by NHTSA. This was mounted on a white body of a compact passenger car, and analyzed mainly were motions under relatively severe impact conditions using a HYGE sled at JARI. The characteristics of the THOR dummy were obtained by comparing the results with those of the HyIII dummy evaluated at 30 mph speed under three test conditions: an airbag only, a 3P seat belt only, and a 3P seat belt with an airbag system.

INTRODUCTION

R & D activities on advanced dummies were initiated in the USA in 1985 for further enhancement/improvement of conventional HyIII-50M (Hybrid III-50 Percentile Adult Male Dummy). As a result, TAD-50M (Trauma Assessment Device - 50 Percentile Adult Male Dummy) and THOR (Test Device for Human Occupant Restraint - 50 Percentile Adult Male Dummy) have been prototyped so far. One of the aims of the THOR development program is the international standardization of advanced dummies. JAMA/JARI decided to participate actively in the R & D work on the THOR dummy as an international evaluator for NHTSA[1]. We set the following objectives for the development/enhancement of advanced dummies in order to make proper proposals by conducting tests and evaluations of the dummy performance.

1) Identification of problems related with the HyIII dummy
2) Collection of basic data to ensure conformity with the dummy design requirements
3) Timely feedback of improvement measures, etc. for the development of advanced dummies, based on the information collected in 2) above
4) Contribution to the development of "easier to use dummies"

This paper describes our evaluation results of prototype THOR head, neck, chest, hip and thigh assemblies leased from NHTSA. THOR's impact responses were compared with those of the HyIII dummy in relatively severe HYGE sled tests.

TEST METHOD

The THOR dummy was seated in a white body of a compact passenger car of mass production mounted on a HYGE sled, and tested for the evaluation of impact responses. The HyIII dummy was also tested under the same impact conditions for the comparison of responses.

Table 1 shows the list of the test conditions and Figure 1 shows the sled pulse. Each dummy was seated in either the driver seat or front passenger seat, and tested at the sled velocity corresponding to the vehicle impact speed of 30 mph. The dummy restraint condition was varied - with an airbag only, a 3P seat belt only, or the combination of an airbag and a 3P seat belt. Data recorded in this study were the acceleration, displacement, load, moment and angle of each region of dummy, airbag deployment timing, sled acceleration, etc.

Table 1.
Test Conditions

Test No.	Restraint System	Impact Vel.	Setting Position	Dummy
DT30AB	3P Belt with Airbag	30mph	Driver	THOR
DT30A	Airbag			
PT30AB	3P Belt with Airbag		Passenger	
PT30B1	3P Belt			
PT30B2				
DH30AB	3P Belt with Airbag		Driver	HyIII
DH30A	Airbag			
PH30AB	3P Belt with Airbag		Passenger	
PH30AB2				
PH30B2	3P Belt			

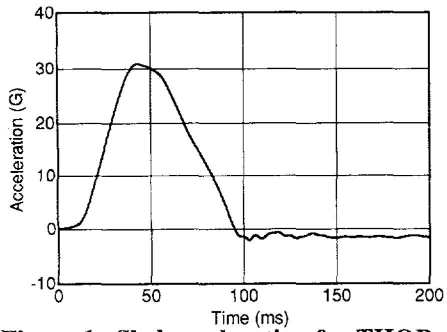


Figure 1. Sled acceleration for THOR and HyIII comparative HYGE sled tests

TEST RESULTS

Impacts were applied to the THOR and HyIII dummies by means of HYGE sled, and their responses were measured under the different restraint conditions. The practical applicability of the THOR dummy, items to be studied in future, have also been evaluated. Tables 2 and 3 show the responses of the dummies.

Table 2.
Summary of HYGE Sled Tests (Driver Side)

Configuration	30mph			
	3P Belt with Airbag		Airbag	
Test Number	No.1	No.2	No.3	No.4
	DT30AB	DH30AB	DT30A	DH30A
Dummy	THOR	HyIII	THOR	HyIII
HIC 36	277	559	419	300
HIC 15	199	330	242	204
Max. Head Resultant (G)	48	61	67	61
Max. Chest Resultant (G)	67	69	71	55
Max. Pelvis Resultant (G)	75	76	71	66
Lap Belt Force (kN)	8.06	11.03		
Shoulder Belt Force (kN)	10.6	10.63		
Max. Chest Deflection (mm)				
HyIII Sternum	—	-48	—	-55
THOR Right Sternum X	-44	—	-66.9	—
Left Sternum X	-43.6	—	-61.3	—
Right Lower Cage X	-59.3	—	-11.5	—
Left Lower Cage X	14.7	—	-14	—
Max. Lower Abdomen Deflection (mm)				
THOR Right X	-24	—	7.5	—
Left X	-16.9	—	7.4	—

Table 3.
Summary of HYGE Sled Tests (Passenger Side)

Configuration	30mph					
	3P Belt with Airbag			3P Belt		
Test Number	No.1	No.2	No.3	No.4	No.5	No.6
	PT30AB	PH30AB	PH30AB2	PT30B1	PT30B2	PH30B2
Dummy	THOR	HyIII	HyIII	THOR	THOR	HyIII
HIC 36	641	858	808	904	664	1045
HIC 15	324	399	419	502	330	541
Max. Head Resultant (G)	65	62	64	84	63	72
Max. Chest Resultant (G)	90	64	62	92	81	68
Max. Pelvis Resultant (G)	74	68	68	75	75	72
Lap Belt Force (kN)	10.39	11.23	12.06	11.01	10.13	12.59
Shoulder Belt Force (kN)	11.89	9.96	9.91	11.5	11.25	10.37
Max. Chest Deflection (mm)						
HyIII Sternum	—	-50.3	-48.8	—	—	-44.9
THOR Right Sternum X	-44.3	—	—	-56	-24.7	—
Left Sternum X	-48.7	—	—	-42.4	-58	—
Right Lower Cage X	17.6	—	—	10	14.8	—
Left Lower Cage X	-58.6	—	—	-61.9	-55.2	—
Max. Lower Abdomen Deflection (mm)						
THOR Right X	-13.8	—	—	-12.2	-16.7	—
Left X	-23.4	—	—	-22.6	-26.8	—

HIC - The HIC 36 values of THOR dummy were in the range of 277 to 904 in this test series, while those of the HyIII dummy tested for comparison were in the range of 300 to 1045. Although the number of tests conducted was limited, the relationship between the THOR and HyIII dummies in terms of HIC values is shown in Figure 2 by dummy restraint conditions. The HIC values of THOR are approximately 70 to 80 % of those of HyIII, similar to the tendency found between the TAD and HyIII dummies tested in 1995[2].

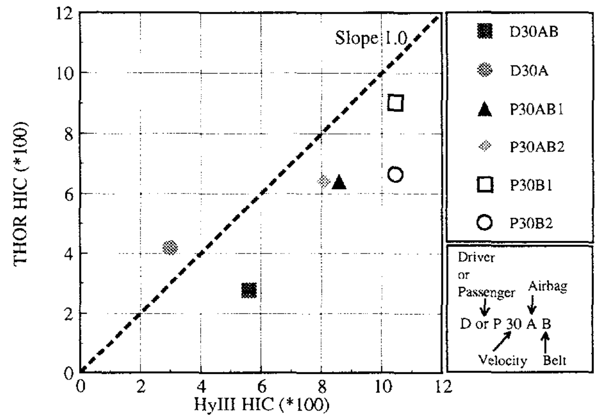


Figure 2. HIC Correlation between THOR and HyIII

Head Acceleration and Head Displacement - The relationship between the head X acceleration and the displacement was calculated by integrating the value of acceleration against the sled twice (the X-component of head C.G. acceleration and of sled acceleration was used). The comparison between the two dummies is shown in Figure 3 for each type of restraint. The values of displacement are greater for the THOR in each case though the initial rise tends to lag behind that of HyIII. In case of the comparison

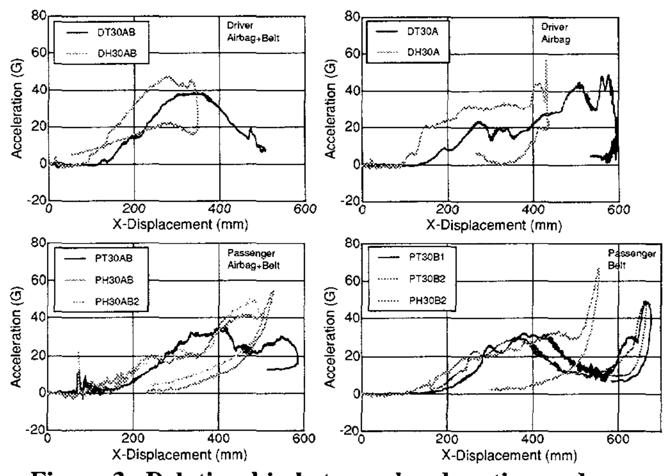


Figure 3. Relationship between head motion and head acceleration

at the front passenger seat, the deceleration rate of each dummy dropped once before reaching the peak value, but this tendency was more obvious for the THOR dummy. In case of a 3-point seat belt alone in particular, the displacement was 200 mm or so and the acceleration was reduced by 20 G in that period. It is deduced that this phenomenon was caused by the difference in neck stiffness, since it occurred around 75 to 100 ms (see Figure 4).

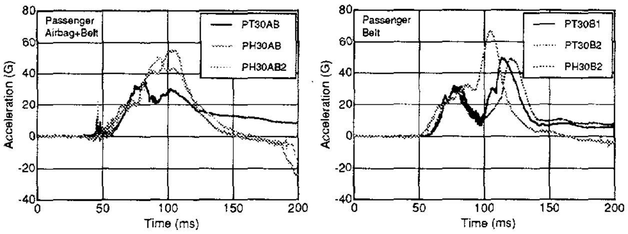


Figure 4. Comparison of THOR and HyIII head acceleration

Neck Bending Moment - The THOR head-neck assembly as tested at JARI permitted measurement of forces and moments transmitted at the occipital condyle joint representation, but the prototype tested was not instrumented to measure moment contributions from the neck cable elements[3), 4)], installed to make the neck bending characteristics similar to those of humans (Figure 5). Therefore, the THOR neck moment around the Y-axis is much smaller and the rise of moment is also slower than those of the HyIII, as shown in Figure 6 (passenger seat with the seat belt restraint). Therefore, all moments applied to the upper portion of neck could not be compared directly with those of HyIII.

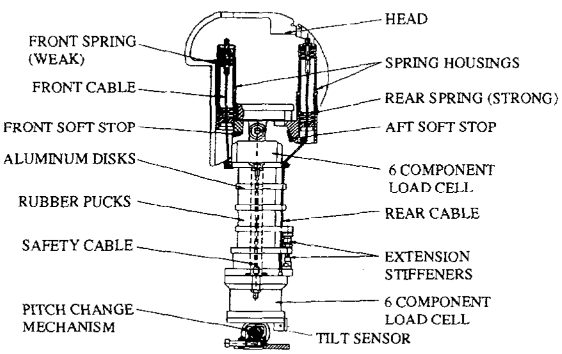


Figure 5. THOR Neck structure

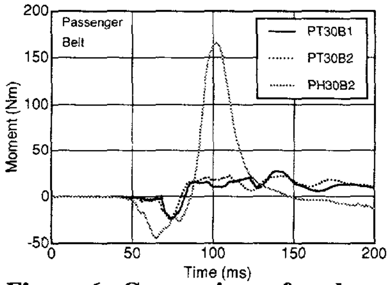


Figure 6. Comparison of neck moment between THOR and HyIII

Chest Acceleration and Displacement - The chest displacement in the X direction was calculated by integrating the acceleration against the sled twice (the X-component of chest C.G. acceleration and of sled acceleration was used), and the relationship between the chest acceleration and the displacement was determined. Comparisons of waveforms between the two dummies restrained under the same condition are shown in Figure 7. The THOR shows greater displacements in every case as in the case of head, and the rise of acceleration also tends to occur later for THOR. This is probably due to the softer chest of the THOR as compared to the HyIII chest, as in the case of TAD tested before[2)]. After the tests, evidence of metal-to-metal contact was found on the plate located at the bottom of the lower flex joint. A peak in the waveform caused by metal-to-metal contact is observed in the THOR dummy chest acceleration where the dummy is seat in the front passenger seat (Figure 8).

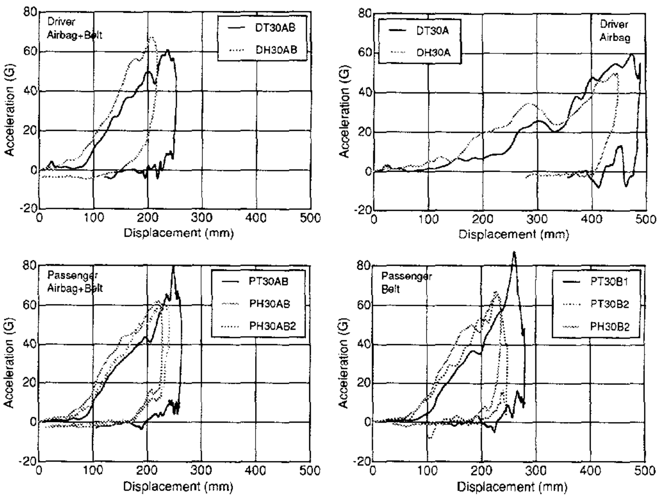


Figure 7. Relationship between chest displacement and chest acceleration

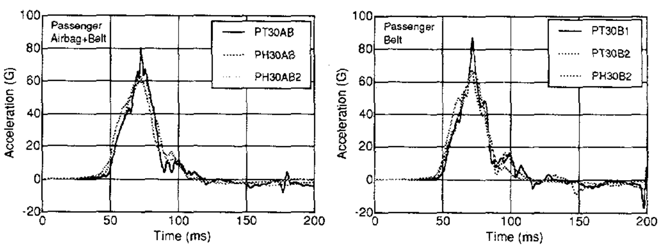


Figure 8. Comparison of THOR and HyIII chest acceleration

Chest deflection - Figure 9 shows the THOR chest and abdomen deflection coordinate system. Figure 10 shows the chest displacements for each dummy location and the

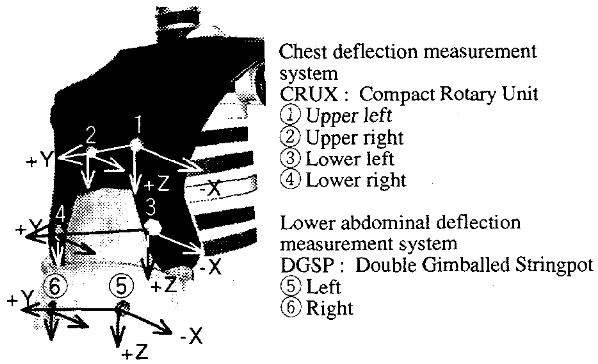


Figure 9. The chest and abdomen deflection coordinate system of THOR

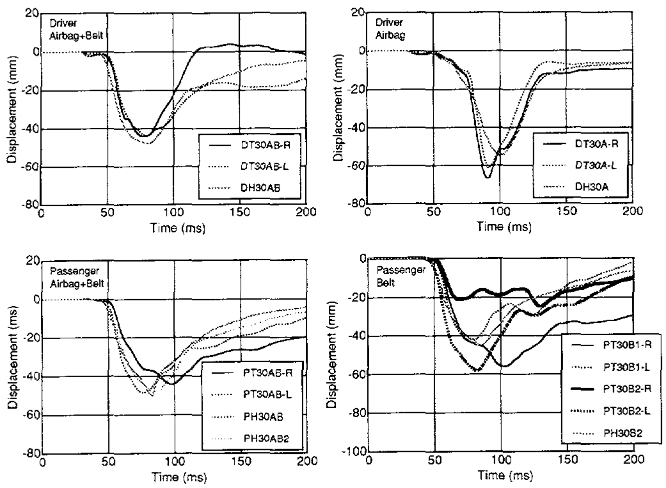


Figure 10. Comparison of THOR and HyIII chest deflection

type of restraint.

1) Comparisons between THOR and HyIII - Direct comparison of chest deflection between the two dummies could not be done due to differences in location and number of displacement gauges used in the dummies. However, deflections on right and left sides around the sternum in the X direction (longitudinal direction) were compared between the two dummies.

2) On driver seat - THOR upper ribcage displacement rises more rapidly to peak value than does HyIII chest displacement for the case of airbag only restraint. A sternal velocity comparison should show significant difference between the designs for this case. The differences between the left and right sides of THOR sternal displacement are difficult to find with the airbag alone. In the case where both the airbag and seat belt were used, hardly any difference was found in the tendency before reaching the peak, then the displacement of HyIII dummy became roughly the same as the average value of the displacements on the left and right sides of sternum.

3) On front passenger seat - Although some difference is found in the peak value with the seat belt only, the waveform on the left side of THOR sternum and the tendency of HyIII are relatively similar. On the right side of sternum, however, the waveform of THOR shows a different tendency despite being under the same restraint system. Some difference is also found in the peak value on the left side of sternum. With the combination of seat belt and air bag, the waveforms of both dummies on the left side of sternum tend to become similar, while those on the right side show different tendencies.

<u>**Comparison of Displacement by Restraint System for THOR**</u> - Figures 11 and 12 show the three-dimensional displacements measured on left and right sides of sternum and lower ribs, for the different dummy seating locations.

1) Airbag only - Only one case is available as an example of test results on the driver side, but it is found that the displacement is relatively simple in comparison to the displacement with the seat belt restraint. That is, the displacements concentrate in the X (longitudinal) direction toward the upper chest near sternum, without much

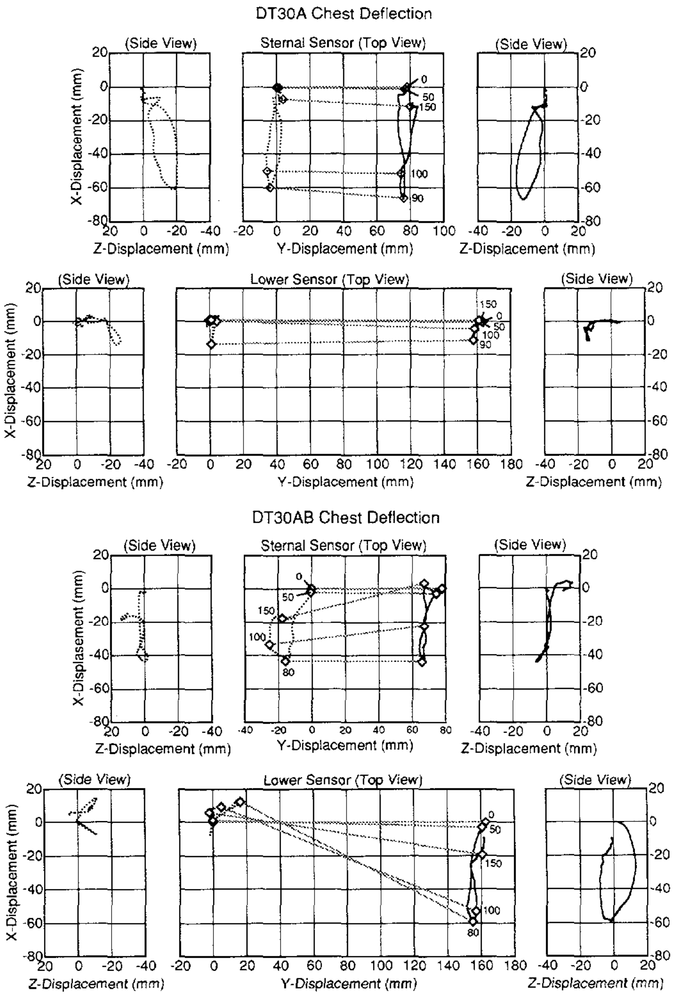


Figure 11. Three-dimensional chest deflection (THOR Driver side)

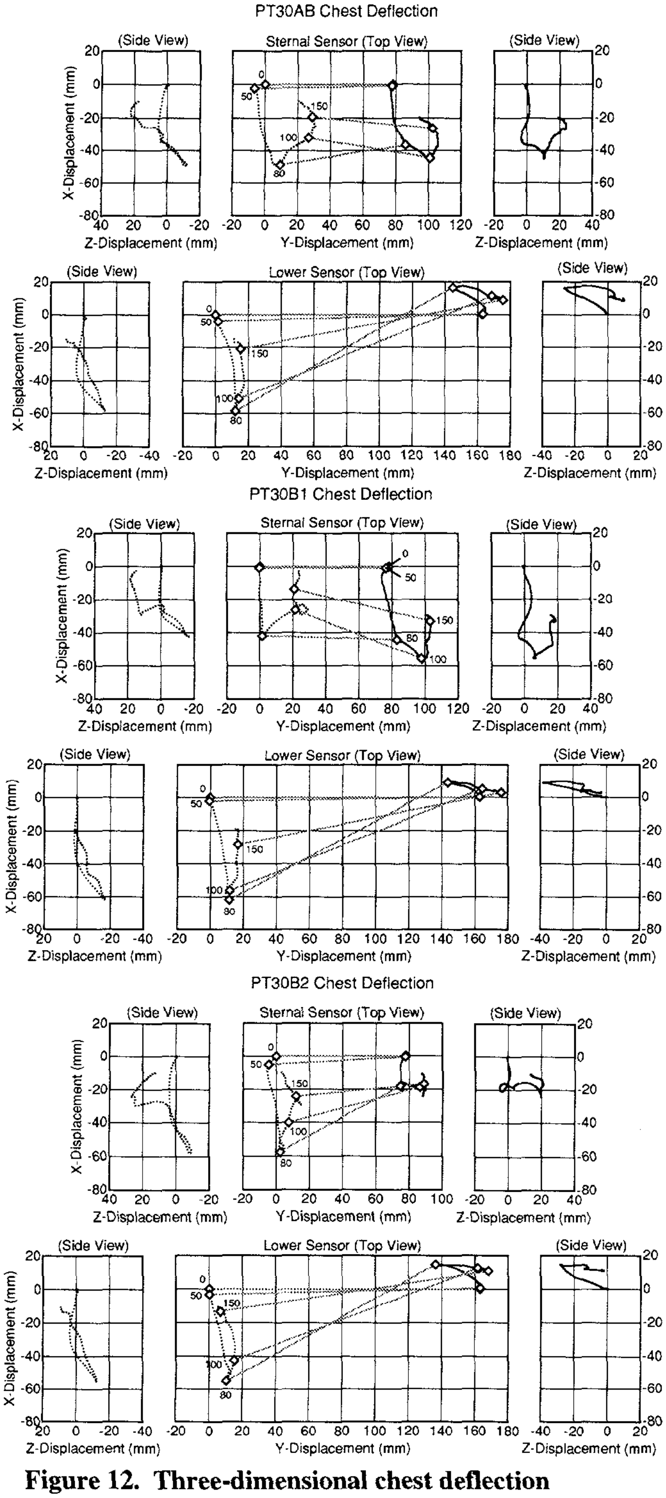


Figure 12. Three-dimensional chest deflection (THOR Passenger side)

difference between right and left sides, with the displacement becoming larger than that with the seat belt only. Around the lower ribs, the effect of airbag is reduced and the displacements in the X direction and the Y direction (lateral direction) are very small. In the Z direction, the displacement is equivalent to, or somewhat greater than that with the seat belt only.

2) Seat belt only, and seat belt + airbag - The X displacement is the greatest for both right and left sides of sternum, but the Y-axial displacement is also large toward the D-ring of the shoulder belt for both right and left sides of sternum. The Z displacement undergoes a somewhat complex process. Initially the ribs tends to stay level and then moves in the negative direction, and finally toward the positive direction. Around the lower ribs, displacements on the opposite side of buckle occur in such a manner that the chest expands toward the X with displacements in Y and Z directions becoming greater than the X displacement. On the buckle side, the X displacement becomes the greatest, with relatively small displacements in the Y and Z directions. On the driver side, however, the Z displacement is somewhat different from that on the passenger side, due to the difference in interference with the airbag.

Deflection of Abdomen - In case of THOR, abdomen displacements can be measured at three locations of abdomen - at the upper center, the lower right and left sides[3), 5)]. In this report, displacements at the lower right and left sides of abdomen will be described. Figures 13 and 14 show the three-dimensional displacements for each dummy location. The displacement observed on the XY plane shows a similar tendency to that of the lower rib displacement. In case where the dummy is restrained by both the seat belt and airbag, the displacement in the X direction on the buckle side is greater than that on the opposite side of buckle. However, the displacement that has caused the expansion in the X direction on the opposite side of buckle observed at the lower ribs is not found in this case. The expansion observed due to the force of inertia in the case with the airbag only, though the general tendency of displacement is similar to that of lower ribs.

Observation of displacements on the XZ plane reveals that the Z-displacement at the lower abdomen becomes

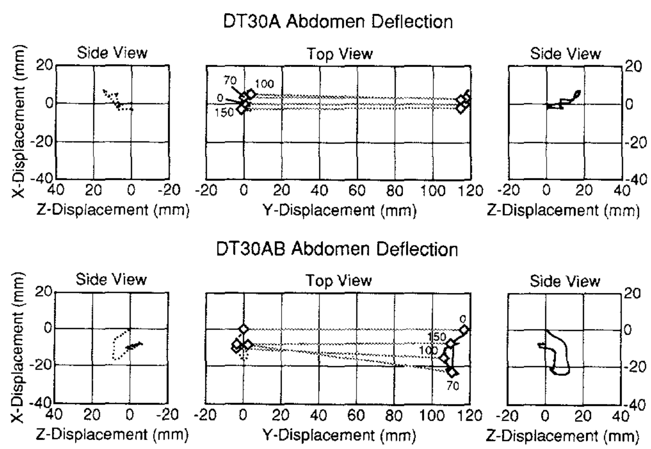


Figure 13. Three-dimensional abdomen deflection (THOR Driver side)

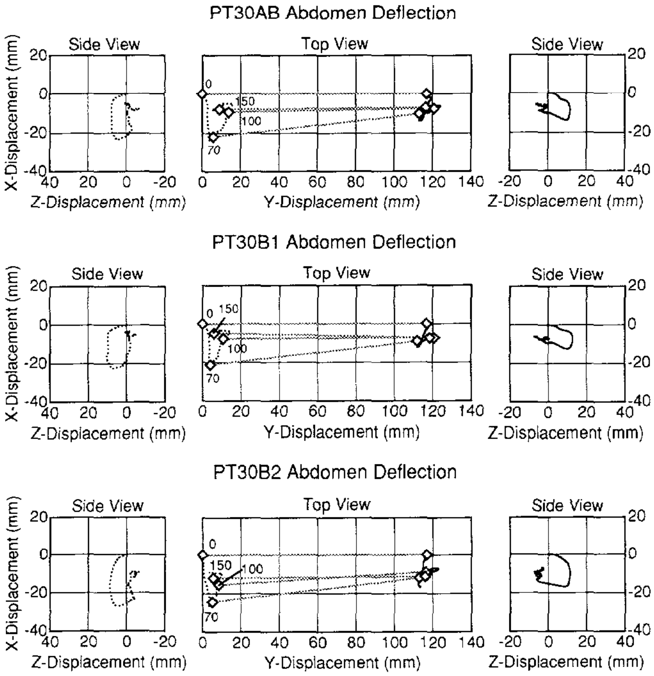


Figure 14. Three-dimensional abdomen deflection (THOR Passenger side)

positive with time in most cases, contrary to the upward (negative) displacement observed at the lower ribs. The tendency towards positive displacement is also found with the airbag only. Therefore, it is presumed that the difference in dummy posture upon impact also constitutes a factor of such displacements in addition to the effect of seat belt.

Dummy Trajectories - Figure 15 shows trajectories of heads, shoulders and knees of the THOR and HyIII dummies, for each dummy location and the kind of restraint system.

1) Comparison with airbag restraint - Comparison of head trajectories on the driver side with those with the airbag only shows that the head of HyIII starts going down sharply from 80 ms, while the head of THOR continues a linear motion as shown in Figure 16. The pelvis forward trajectory of HyIII is longer than that of THOR, and the pelvis slips down from the front end of seat cushion as the displacement attain maximum value. The pelvis forward trajectory of THOR is shorter than HyIII, and the change in pelvis position is also smaller. As shown in Figure 17, the upper torso of THOR is bent forward, while the upper torso of HyIII is not bent but the pelvis is submarined. This is presumably due to differences in shape of pelvis and the manner thighs are attached to the pelvis.

2) Comparison with seat belt restraint - Comparison of head trajectories on the front passenger side with the seat belt only shows that the head of THOR makes a larger circular motion than that of HyIII as shown in Figure 18. There are also differences between the two dummies in terms

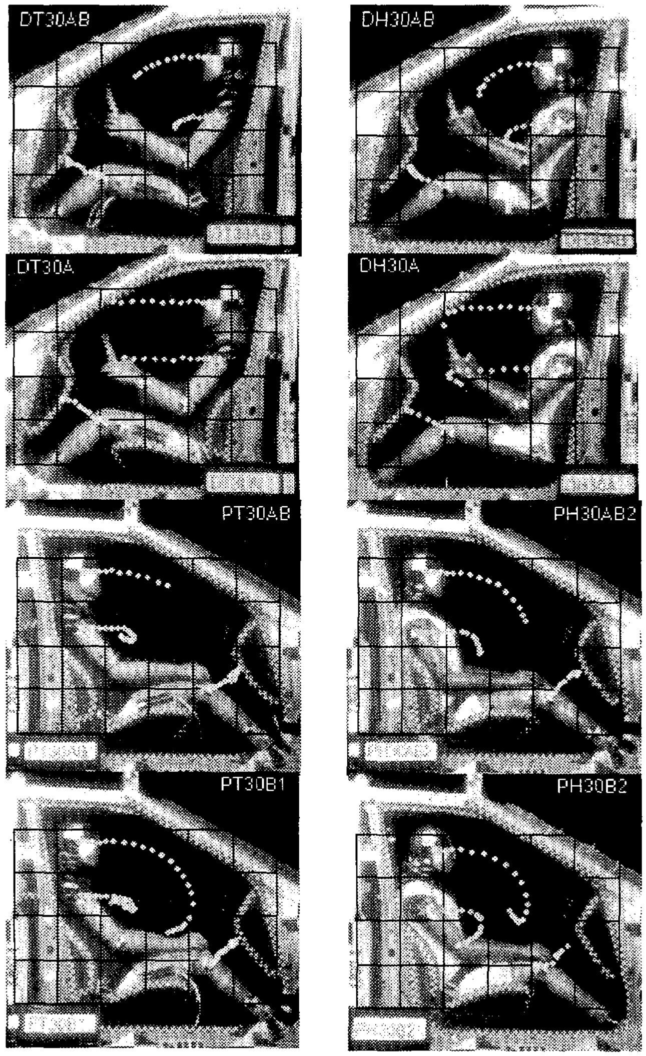


Figure 15. Dummy trajectories

of chest deflection and neck bending angle. Namely, the upper torso of THOR with a less stiff chest is bent forward more than that of HyIII, and the head of THOR contacts the upper portion of thighs as the neck is bent forward furthermore, which is not found in the HyIII dummy. The shoulder trajectory, on the other hand, is longer for HyIII which makes a larger circular motion than THOR which moves roughly linearly. This is presumably due to the effects of differences in chest stiffness and the trajectories of the upper extremities caused by the difference in shoulder structure.

COMPARISON OF THOR AND HyIII BIOFIDELITY

Characteristic features of the THOR and its differences from the HyIII have been evaluated through a series of experiments conducted under this study, which will be described below. If those features and differences are

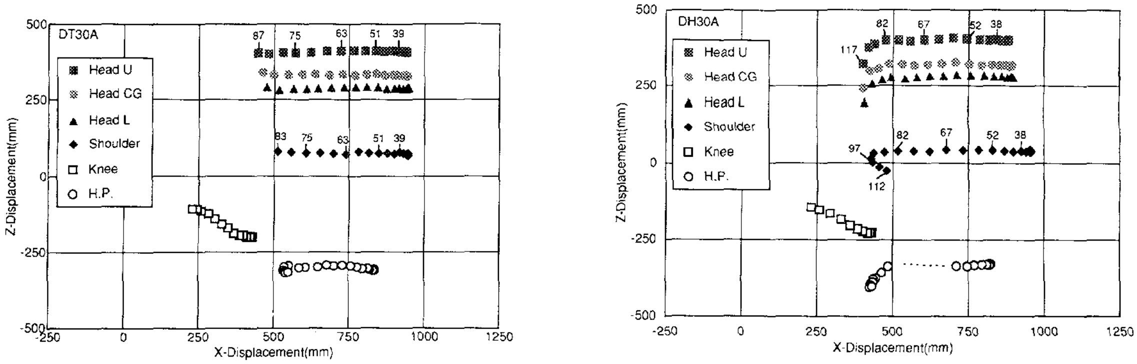
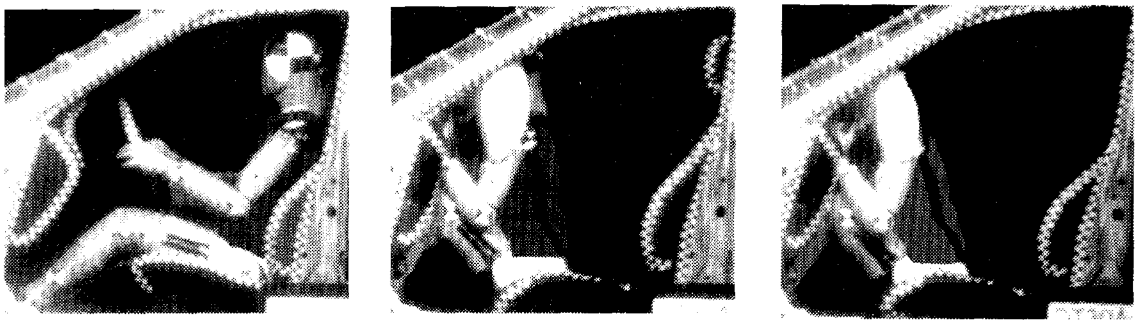
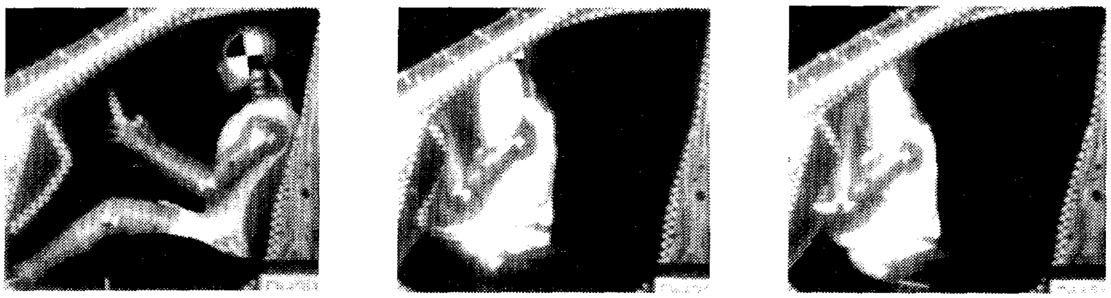


Figure 16. Comparison of trajectories between THOR and HyIII (Driver, Airbag only)



DT30A-0ms DT30A-89ms DT30A-109ms



DH30A-0ms DH30A-87ms DH30A-107ms

Figure 17. Comparison of dummy posture between THOR and HyIII (Driver, Airbag only)

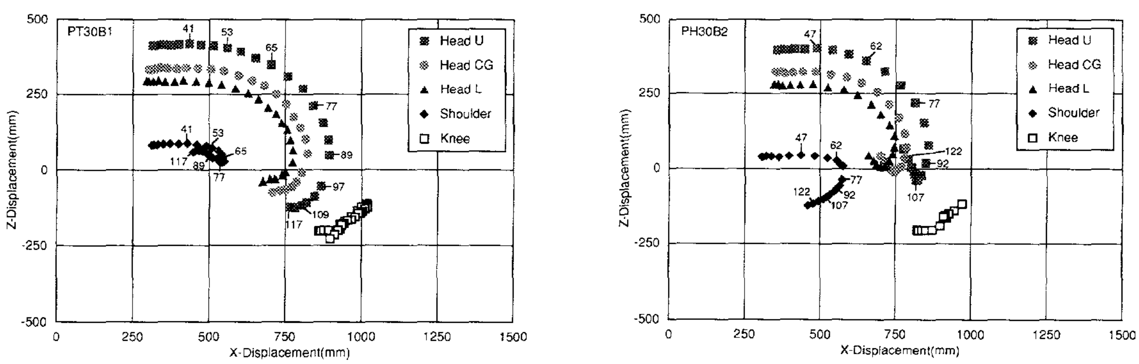


Figure 18. Comparison of trajectories between THOR and HyIII (Passenger, 3P seat belt only)

reflecting human characteristics with a higher accuracy, the utility of THOR as an evaluation tool will be enhanced.

1) The neck structure of the THOR is softer than that of the HyIII, resulting in a large bending motion of the lower region upon impact.
2) Difference in shoulder trajectory between THOR and HyIII - presumably due to the difference in structure - and the difference in trajectories of upper extremities caused by the above were particularly significant where only the seat belt was used.
3) The value of lower rib displacement was negative on the buckle side, while that on the opposite side was positive with the seat belt. Such rib displacements had been also observed in the tests conducted on the TAD in past[2].
4) In case where only the airbag was used as the restraint system, the lower abdomen expanded outward due to the force of inertia where the abdomen did not interfere with the airbag, resulted in a positive value on the displacement gauge.
5) The upper torso of THOR tended to bend forward more than that of HyIII upon impact, due to differences in shape of the pelvis and segmentation of the pelvis and femur in the two dummies.

APPLICABILITY OF MEASURED DATA TO INJURY ASSESSMENT

Some differences from the HyIII have been observed in the THOR in terms of regions that have become possible to measure and the measured values as described below. Clear determination of the correlation between the measured data and human injuries will be necessary.

1) Difference in HIC value is also observed between the THOR and HyIII, presumably due to the addition of articulation to the spine and the difference in structure of the neck. The HIC values of THOR are approximately 0.7 to 0.8 times of those of HyIII.
2) Significant difference is found in neck moment between the two dummies. This may be caused by the difference in neck structure and also because all data required to calculate neck moment for THOR were not available.
3) Chest vertical and lateral displacements can be measured with the THOR, same as the case with the TAD, which allows the determination of local displacements.
4) Displacement at the center of the upper abdomen and those on right and left sides of the lower abdomen can be measured with the THOR, which allows more accurate determination of interferences with the seat belt and/or airbag.

CONCLUSIONS

In keeping with the joint international R & D efforts by NHTSA, a prototype THOR dummy was leased to JARI/JAMA. We have measured THOR impact responses under the conditions used for the evaluation of occupant protection performance of Japanese mass production vehicles. We have also tested the HyIII dummy at the same time for comparison. The evaluation results of the THOR dummy obtained by the comparison are as follows.

1) The HIC of THOR dummy tends to show smaller values than those of the HyIII dummy, due to the differences in structures of the neck, chest and spine. Some difference in the head acceleration waveform is also found. It will be necessary to check on such differences in comparison to human characteristics.
2) The upper torso of the THOR shows more flexible motions than the HyIII dummy, due to the differences in structures of the neck, chest and spine. Some difference in trajectories of upper extremities is also found.
3) The THOR dummy chest acceleration waveform shows a slower rise than that of the HyIII dummy. Their peak values, however, are similar except for some case where there was metal-to-metal contact near the chest C.G. accelerometer housing.
4) Measured data of chest displacements cannot be compared directly between the two dummies. It appears, however, that both of them show similar tendencies according to the test data taken separately with each restraint system. The practical applicability as an evaluation tool also seems to have improved, as the displacements can be measured three-dimensionally at four points - at upper/lower and right/left regions of THOR dummy - and the influences of individual restraint systems on those regions can be also determined.
5) There is more information on displacements of abdomen as in the case of chest displacement. However, it will be necessary to further study factors that may influence additional displacement measurement.
6) We observed several differences between the response of the HyIII and the THOR dummy in our tests. These may have been caused by difference in design of the two dummies. It will be necessary to compare the response of THOR with cadaver under similar loading conditions in order to evaluate its biofidelity.

After the completion of our tests, improvement of spine structure to eliminate the metal contact, addition of neck and face load gauges, etc. have been done for the THOR dummy, and the evaluation tests are still going on. Therefore, it is expected that the THOR dummy will become a more practical and useful advanced dummy by utilizing the outcomes of the efforts mentioned above.

We have been unable to evaluate the durability and handling ease of the dummy sufficiently under this study, because of the relatively short dummy lease-out period.

ACKNOWLEDGMENT

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