DESIGN AND PERFORMANCE OF THE THOR ADVANCED FRONTAL CRASH TEST DUMMY THORAX AND ABDOMEN ASSEMBLIES

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Paper Number 98-S9-O-12

ABSTRACT

In May 1994, GESAC was awarded a contract to design an advanced frontal crash test dummy which has been named THOR. This paper describes the results of an intensive two-year effort to develop the design criteria, design, and test the thorax and abdomen of THOR and its associated instrumentation.

The paper will describe refinement of thoracic anthropometry, design of a realistic belt to shoulder interface, refinements in rib bonding procedures leading to greatly improved durability, design of a posture adjustment system, development of a new 3-D chest deflection measurement system capable of tracking chest compressive velocities up to 10 m/s, new upper and lower abdomen designs which permit continuous measurement of abdominal penetration by restraint and vehicle components, and other design features which have resulted in a more modular, serviceable design.

The paper will also present and summarize the extensive component and sled tests conducted both in the United States and in Canada, for the purpose of evaluating and documenting THOR thorax and abdomen performance against program goals.

INTRODUCTION

Since the early 1980s the NHTSA has supported the development of an advanced frontal crash test dummy with improved biofidelity under frontal impact conditions and with expanded injury assessment capabilities. The program consisted of first developing anthropometric specifications for a family of adult dummies in the automotive seating environment [Robbins,1983], followed by detailed analyses of available human impact response data in conjunction with a study of patterns of motor vehicle injuries [Melvin, 1985]. The primary purpose of these efforts was to provide a sound technical basis for the dummy design and development efforts to follow. Using the new specifications, the University of Michigan Transportation Research Institute (UMTRI) developed a new torso system that was integrated with the standard Hybrid III head, neck, and extremity components and was known as the 50th percentile male Trauma Assessment Device (TAD-50M) and described by Schneider [1992].

In 1994, NHTSA funded GESAC, Inc to begin a

[1] Currently with Acentech in Cambridge, MA.

major effort whose scope, in addition to the refinement of the torso design, also encompassed development of advanced representations of the head and face, neck, abdomen, pelvis, and femur. Improvements to various instrumentation systems were also to be investigated, and incorporation of additional sensors accomplished, so that the correlation of dummy responses to estimates of human injury potential could be achieved with greater confidence.

A systematic evaluation of design requirements for the body regions was first accomplished which included a review of the design elements incorporated in TAD-50M. The design of THOR resulted in improvements to all the dummy components except the arms (which remain Hybrid III stock pending conclusion of arm development efforts ongoing within the automotive industry). In particular the design criteria for the thorax was based on the recommendations of Schneider [1989], and the design criteria for the abdomen based on the recommendations of Rouhana [1989].

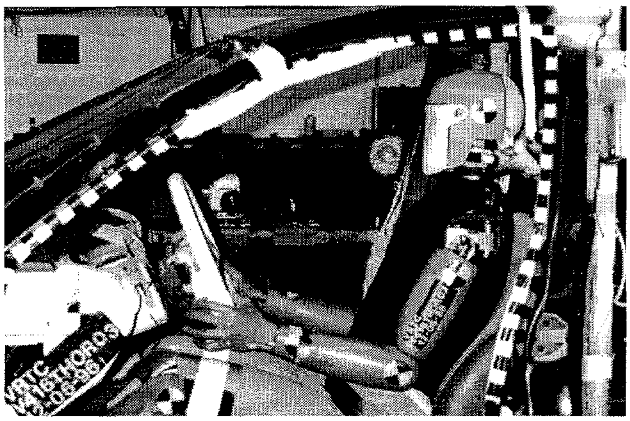

Figure 1. THOR in seated sled test environment

This paper will detail the design features and performance of the THOR thorax and abdomen assemblies. Figure 1 shows the new advanced frontal crash test dummy which has been named THOR (Test Device for Human Occupant Restraint), after the Norse god of thunder, strength, and healing art. Figure 2 presents an assembly drawing of THOR indicating its primary new features. Currently, two dummies have been fabricated and they have been undergoing extensive testing at a number of laboratories under various test conditions.

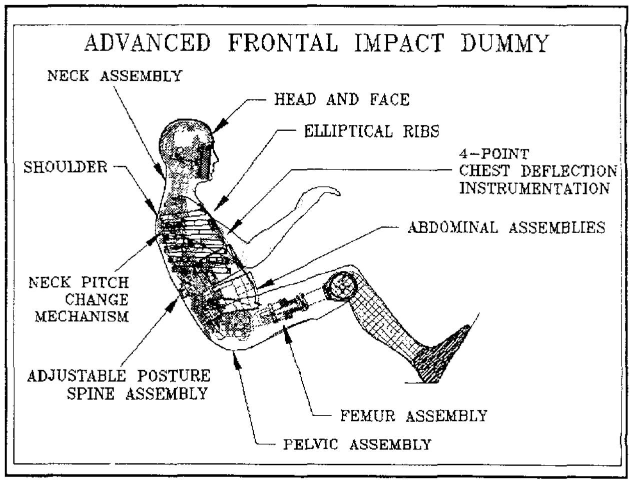

Figure 2. Principal features of THOR

DESIGN

Design of THOR Thorax

The THOR thorax includes improvements to the previous design developed for TAD-50M and addresses some of the problems encountered with its performance.

- Improved ribcage anthropometry and stiffness: Though the width and depth of the ribcage in TAD-50M generally reflected the dimensions of the human ribcage, the cross-section was still box-shaped, whereas the human shape is more elliptical. The ribs in THOR have been designed with an elliptical cross-section, but with the same width and depth as the TAD-50M ribs. Apart from improving the anthropometry of the ribcage, modeling and testing on single ribs indicated that the geometry reduced the stiffness of the ribs, in localized loading, by about 15%, which improves agreement with quasi-static stiffness obtained with humans.

- Improved rib fabrication procedure: A problem pointed out by several test laboratories in previous testing with the TAD-50M was the occasional debonding of the damping material from the steel. The new procedure includes thorough surface treatment of the metal and a controlled curing process after application of the adhesive. Testing at a number of different laboratories has indicated that the new procedure is working successfully, and debonding has been markedly reduced.

- New thorax instrumentation: A new two-bar linkage instrumentation system (shown in Figure 3) was developed to meet the more demanding performance requirements for measuring chest compression under out-of-position airbag exposures. The chest deflection measurement in TAD-50M was limited to measurement of compressive velocities below 7 m/s, too slow to measure the higher rates involved in impulsive loading from out-of-position airbags.

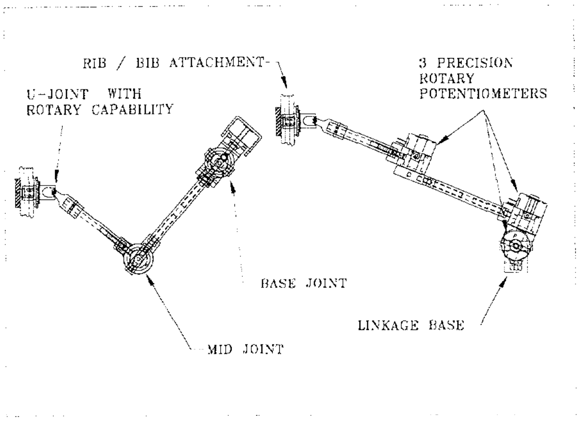

Figure 3. CRUX unit for measuring chest deflection in Thor.

Each linkage, called a CRUX, consists of two rigid links in which the relative motion between the links and the base attachment points are measured by precision rotary potentiometers. Once the system has been initially calibrated, recalibration between tests is not required. These transducer systems are attached to ribs 3 and 6 at each side of the centerline, at the rib attachment points to the bib. Extensive testing of these units has demonstrated their reliability, ruggedness and accuracy. The signals from the rotary potentiometers are processed in a dedicated algorithm to yield x, y, and z deflections of the four anterior rib attachments. The measurement system has been evaluated in several out-of-position airbag tests and has performed properly. The results from out-of-position tests done at VRTC are described later in this paper.

Design of Spine

The thoracic spine in THOR is divided into two sections connected through a deformable element at the location of T7/T8. This element was introduced in TAD-50M to provide an additional degree of flexibility to the Hybrid III spine which was considered too rigid [Melvin, 1985a]. Two new modifications have been made in the THOR spine design:

- The thoracic load cell has been moved from the lower lumbar part of the spine to the T12/L1 location. This change was undertaken to place the load cell at the location where the majority of automotive thoracolumbar spine injuries have been observed.

- A pitch change mechanism has been incorporated just below the thoracic spine. This allows the user to adjust the orientation of the pelvis relative to the thoracic spine and permits the dummy to assume various intial seated postures.

Posture adjustment in THOR - Under subcontract to GESAC, Reynolds at Michigan State University [1996] conducted a study of human posture in automotive seated position and defined spinal geometries for four postures. These positions are namely, erect, normal, slouched, and super slouched. The data from this study were analyzed and relative angles between the thoracic spine, lumbar spine and pelvis were estimated for the four positions. It was determined that a single posture adjustment mechanism placed a little above the T12/L1 joint could provide the range of movement that allowed a good fit to the above four postures. The different postures can be realized in THOR by means of a pitch change mechanism. The mechanism is a radial toothed circular section in which two matching segments are adjustable relative to one another. This mechanism permits pitch changes to be made in 3 degree increments. A similar pitch change mechanism has been placed under the lower neck load cell to allow the pitch angle of the head and neck to be changed. Using this mechanism, the head can be maintained in a horizontal orientation for different postures of the thoracic and lumbar spines.

Assembly of the spine components has also been simplified so that the spine and thorax subassemblies can be removed as individual units for service. Figure 4 presents a sketch of the THOR spine assembly with the location of the load cell and pitch change mechanism noted. Figure 5 presents the relative angles between the various spinal sections for the four primary orientations, from erect to super slouched (it can also assume positions in-between these).

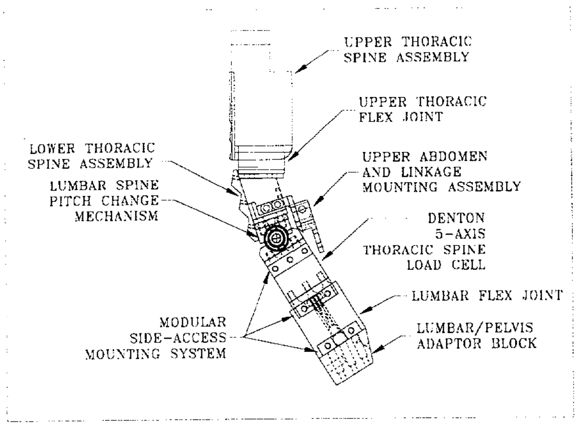

Figure 4. View of spinal assembly in Thor.

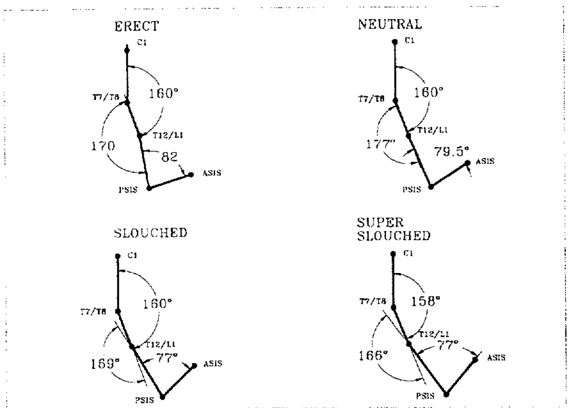

Figure 5. Four seating postures based on Reynolds' data.

Design of Shoulder Complex

Figure 6 presents a drawing of the shoulder complex that is incorporated into THOR. The clavicle is designed to approximately represent the human structure and to couple loads applied to it to the sternum and ribs. This was meant to provided more realistic interaction of the shoulder belt with the torso. The clavicle was designed to prevent the shoulder belt from being snagged in the support structure when the shoulder belt was oriented in an outboard position. The shoulder structure is designed to permit controlled fore and aft motions. Further, an elevation/depression degree of freedom was added to provide more realistic interaction of the shoulder belt with the shoulder complex.

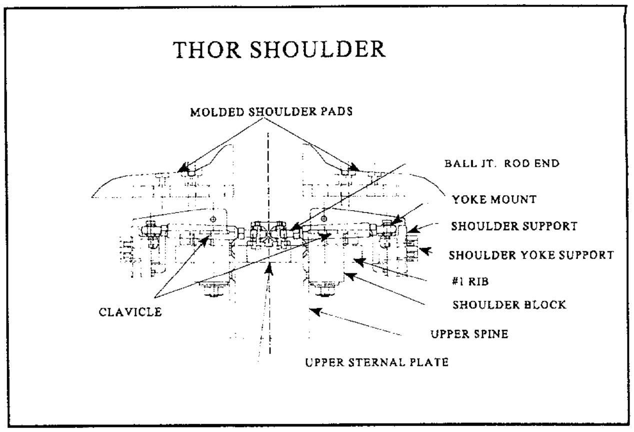

Figure 6. Thor shoulder assembly.

Design of Abdomen

The abdomen design developed for THOR consists of an upper and a lower unit. The upper unit is attached to the thorax through ribs 5, 6, and 7 and the lower unit fills the space between the lower ribs and the pelvis. A cross-sectional drawing of the upper abdomen unit is shown in Figure 7.

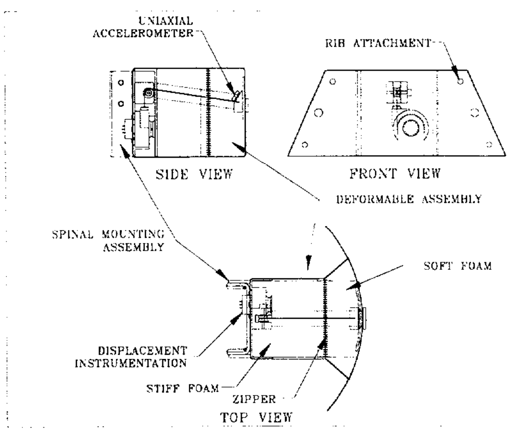

Figure 7. Upper abdominal assembly.

The front of the abdomen is attached to the ribs and the rear is attached to the spine through a structural bracket. The interior of the abdomen is layered with foam of two different compressive stiffnesses; soft foam is placed in the front, backed by a stiffer foam in the rear. The foam is enclosed with a cloth cover that has a zipper to provide maintenance access. The upper abdomen unit is instrumented with a uniaxial accelerometer behind the anterior surface to sense possible impulsive air bag loading in the X direction, and a high-speed string pot to measure the deflection in the X direction.

The lower abdomen assembly is shown in Figure 8. The cloth-covered bag is similar in construction to the upper bag in that it is of layered foam construction. Instrumentation consists of bilateral advanced DGSP (double-gimballed string pot) assemblies and precision potentiometers that maintain permanent calibration. Three-dimensional deflections of the DGSP attachment points at the front of the bag are calculated via a dedicated algorithm, utilizing potentiometer outputs. It is noted that the signals obtained from this instrumentation assembly during impact loading are sufficiently smooth that differentiation of the calculated displacements to velocity is feasible. Overload protection is provided to protect the instrumentation if compression of the abdomen exceeds approximately 4.5 inches.

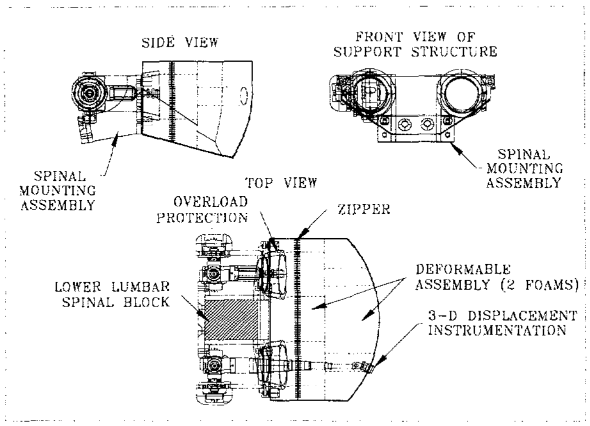

Figure 8. Lower abdominal assembly.

Because a gap can be created between the upper and lower abdomen units when the initial posture of the dummy is changed, a pie shaped insert has been placed in a pocket at the top of the lower abdomen unit to fill the gap between the two abdomen units. Tests have shown that this insert adequately prevents a striking object from penetrating this area during impact loading. Both the upper and lower abdomen assemblies have been designed as modular units so that with the removal of a few bolts at the spine attachment, the entire unit including instrumentation may be easily removed.

The abdomen assemblies have been extensively tested, and have been shown to maintain geometric and structural integrity under repeated impact loading and provide repeatable response.

TESTING

Two THOR prototypes were initially built. The first series of evaluation sled tests were conducted under the sponsorship of the Road and Safety Directorate of Transport Canada at the facilities of Defence and Civil Institute of Environmental Medicine (DCIEM) in Toronto. The second prototype was sent to the Vehicle Research and Test Center (VRTC) in East Liberty, Ohio for a series of component tests and full scale sled tests. It was the purpose of the test series to elicit suggestions regarding the performance of the dummy. The results from these tests and suggestions from the labs were reviewed and appropriate design changes made.

Testing at DCIEM in Canada

Full scale testing of THOR was performed at DCIEM on their HyGe accelerator sled using a crash pulse typical for a passenger vehicle, with a delta-V of 56 km/h and peak deceleration in the range of 20-25 G. A mock-up of the driver's side compartment of a standard size vehicle was mounted on the sled. This consisted of a rigid seat, dashboard, steering wheel, windshield and toepan. The seat and seat back was padded with polyethylene foam covered with a tweed seat cover.

A total of seven sled tests was performed. The dummy was restrained with independent lap and shoulder belts. The restraints were varied by changing the locations of the seat belt anchorages, the slack in the belt, and the contact location of the shoulder belt with the shoulder. A two point shoulder belt was used in one of the tests. Table 1 provides a summary of the seven tests performed in Canada. It describes the restraint system used and the basic configuration of the dummy.

The test data and film were used to evaluate the durabiltiy and general performance of the dummy. Instrumentation problems led to the loss of some data channels. Table 2 shows the maximum (absolute) values for the principal accelerometer channels and the shoulder belt loads. The maximums have been obtained from an inspection of the plots of the selected channels for the time interval 0 to .150 sec. The time at which the maximum values were attained are indicated below the value (also in seconds). For all the tests, the principal loading phase occurred in this interval. During this analysis, the unloading phase was not included.

Table 1. Summary of Canadian tests

Test #	Lap	Shoulder	Knee Bols	Toepan	Posture	Description
2585	taut	taut	yes	yes	erect	normal setup
2586	taut	taut	yes	yes	erect	shoulder belt placed near shoulder joint
2587	taut	taut	yes	yes	erect	repeat #2585
2588	v.slack	v.slack	no	yes	erect	almost unrestrained
2589	no	taut	yes	yes	erect	2 pt shoulder belt only
2590	slack,hi taut	no	no	no	slouched	attempt to induce submarining
2591	v.slack	v.slack	no	yes	erect	repeat #2588

Table 2. Maximum values of selected channels

Tests	Head-X (G)	Head-Z (G)	Chest-X (G)	Chest-Z (G)	Pelv-X (G)	Pelv-Z (G)	Shld(top) (N)
2585	-30	-70	-40	5	-40	*	10700
	0.08	0.07	0.05	0.05	0.04	*	0.05
2586	-28	-60	-40	12	-45	-	
	0.08	0.08	.065	0.07	0.06	-	
2587	-55	-65	-40	-10	-40	7	9800
	0.12	0.08	0.06	0.07	0.06	0.04	0.08
2588	-30	-30	-25	10	-15	5	7100
	0.10	0.08	0.07	0.07	0.06	0.04	.075
2589	-35	-20	-15	5	-20	5	13800
	0.09	0.08	0.07	0.07	0.07	0.04	.075
2590	-150	-55	-60	-35	-55	5	10900
	0.09	0.08	0.07	.075	0.07	0.04	0.07
2591	-60	-40	-50	10	-50	7	8500
	0.14	0.10	0.07	0.10	.075	0.04	0.07

In some tests (e.g. #2587, 2591) the higher head X-acceleration was due to a chin-chest contact. The very high value seen in Test #2590 was due to a steering wheel contact. From an initial review of the behavior during unloading, there appears to be a secondary and positive peak at around 250 msec. From the films, this appears to correlate with impact with the seat back. It is not clear whether there is some contribution from the rear stop at the bottom of the head when it contacts the neck.

There is some variation in the chest and pelvis accelerations, though they also seem to fall within a physically reasonable range. One sees that for the first very slack belt test (Test #2588), the chest and pelvis accelerations are low, as are the lap and shoulder belt loads. But for the repeat of the test (Test # 2591), the chest and pelvis accelerations were appreciably higher. In the latter test, contact with the windshield occurred after the shoulder belt was torn by the metal neck guard.

One of the items of interest in this first series of tests with Thor was the performance of the deflection transducers in the chest and abdomen. The maximum deflections in the X direction (perpendicular to the ribcage) ranged from 40 to 70 mm. A significant amount of deflection in the Y direction was also measured by the lower right CRUX unit. The CRUX units responded in a smooth fashion, but since the initial angular positions of the pots were not obtained, a detailed analysis of the deflection results was not possible.

Testing at Vehicle Research and Test Center, Ohio

A comprehensive set of component tests were performed at VRTC, followed by a series of sled tests and two out-of-position airbag tests.

Table 3. Component Tests at VRTC

Comp-onent	Location	Description	Impactor/ indentor
Thorax	mid-sternum	quasi-static compression	3" disk or 6" square
Thorax	CRUX locations	quasi-static compression	3" disk or 6" square
Thorax	mid-sternum	Kroell type impact	15 cm disk
Thorax	3rd rib	oblique impact	15 cm disk
Thorax	left & right lower ribcage	oblique impact	15 cm disk
Abdomen	upper	quasi-static compression	3" disk or 6" square
Abdomen	lower	rod impact	2.5 x 30 cm rod
Abdomen	lower	steering wheel impact	-
Femur	left & right knee	pendulum impact	4.6 kg; 3 cm disk
Neck	frontal & lateral	head/neck sled test	-

Table 4. Sled Tests at VRTC

Location	Belt	Airbag	Description
Driver	3-pt	yes	frontal impact
Driver	no	yes	frontal
Driver	yes	no	oblique 15 deg impact
Passenger	yes	no	frontal
Passenger	yes	no	frontal, with lap belt high on abdomen
Driver	yes	no	frontal
Driver	yes	no	D-ring moved outboard and forward
Driver	yes	no	seat 2" from full forward

Table 5. Out-of-Position Airbag Tests at VRTC

Location	Belt	Airbag	Description
Driver	no	yes	out-of-position, ISO 1
Driver	no	yes	out-of-position, ISO 2

<u>Component Tests</u> - The results of the Kroell tests performed at VRTC for 4.3 m/s and 6.7 m/s are shown in Figures 9 and 10 respectively and compared with the standard Kroell corridors at these speeds. The results from impact tests performed at GESAC, are also shown. The results for the 4.3 m/s impact show a somewhat stiffer response than the earlier GESAC results, while the results for 6.7 m/s are similar. The stiffer response seen in the 4.3 m/s impact may have been due to the presence of the central string pot, which was later removed.

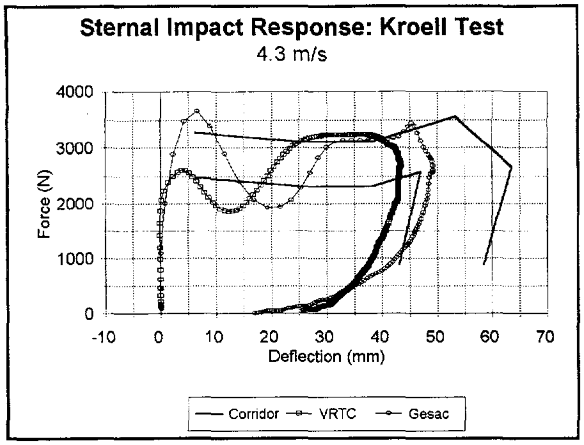

Figure 9. Kroell test results from VRTC and GESAC for 4.3 m/s impact

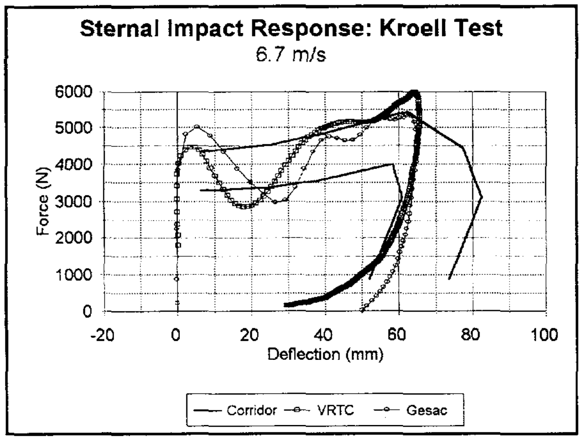

Figure 10. Kroell test results from VRTC and GESAC for 6.7 m/s impact

The lower abdomen response to a 25 mm rod impact at about 6 m/s is shown in Figure 11 and compared against the response corridor. The response corridor for force vs external deflection for rod impact at low speed (average impact speed of 6.1 m/s) has been defined by Cavanaugh [1986]. The external deflection was measured with a LVDT, and when compared with the corridor shows that the deflections are within the corridor for deflections somewhat greater than 75 mm which was the design range. Internal deflections within the lower abdomen are measured by the two DGSPs, and measurements made at both VRTC and GESAC are shown in Figure 12. The internal deflections from the VRTC testing show a slightly stiffer response than the internal deflections measured at GESAC. At VRTC, the pelvic skin in the area of the lower abdomen had been reinforced by several layers of duct tape which may have resulted in the increased stiffness.

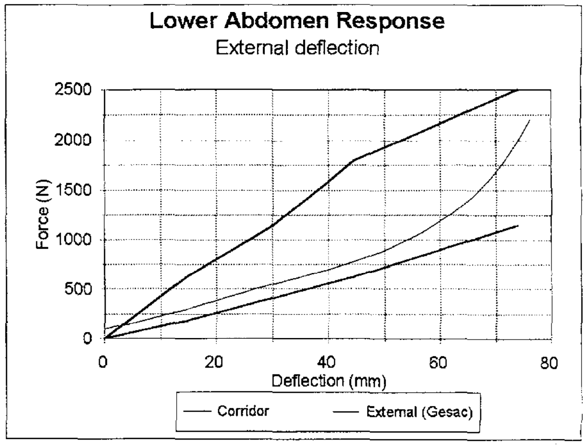

Figure 11. External deflections from 25 mm rod impact to lower abdomen at 6 m/s

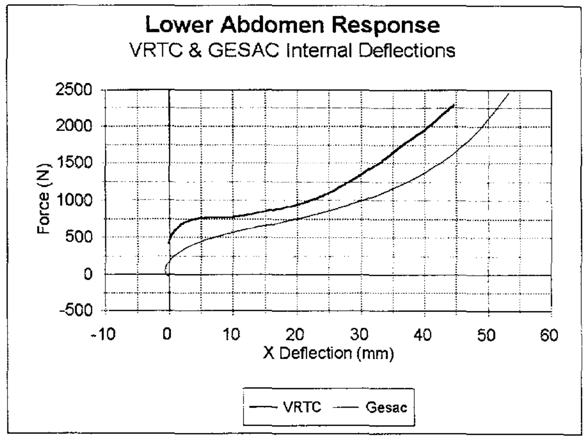

Figure 12. Internal deflections from 25 mm rod impact to lower abdomen.

<u>**Sled Tests**</u> - The crash pulse used in the VRTC sled tests corresponded to an impact speed of 56 kph (35 mph) with a peak deceleration of about 33 G. The pulse is shown in Figure 13.

During the first series of tests, the results for the airbag and 3-pt belt restraint condition were compared to those obtained for the corresponding tests with a Hybrid III dummy. There was fairly good agreement in total head and chest accelerations, in magnitude and duration. The total chest deflections, as measured by the CRUXes showed a slightly smaller deflection in Thor than in Hybrid III. Figures 14 and 15 show the comparison of head and chest resultant accelerations for Hybrid III and Thor.

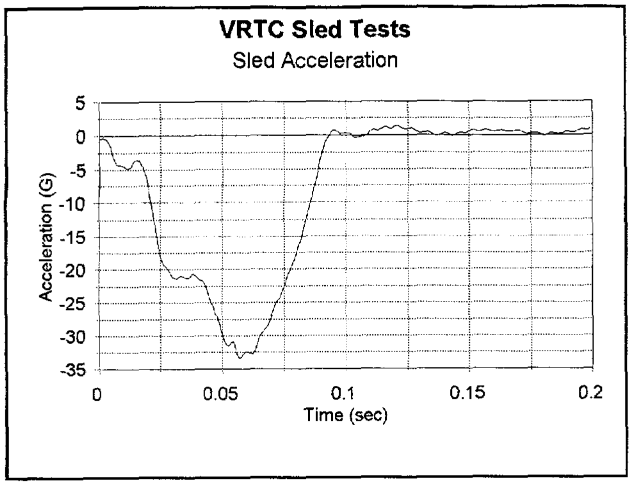

Figure 13. Typical sled pulse used in VRTC tests.

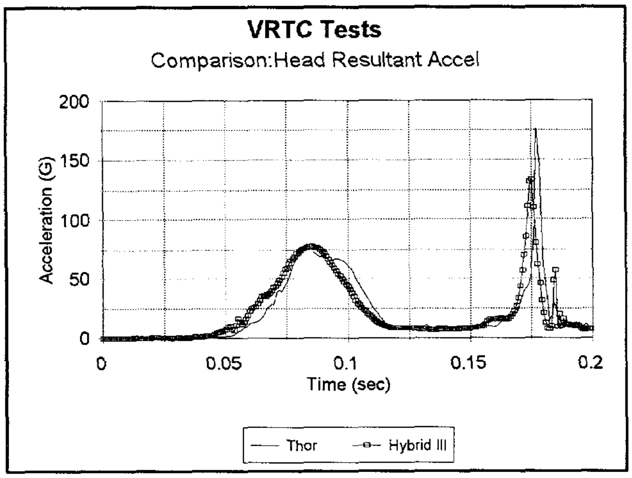

Figure 14. Comparison of Thor and Hybrid III resultant head acceleration.

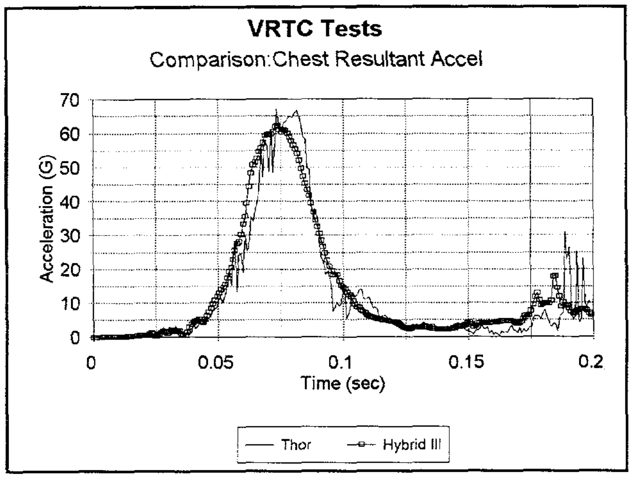

Figure 15. Comparison of Thor and Hybrid III resultant chest acceleration.

Figure 16 shows the comparison for the upper ribcage deflections.

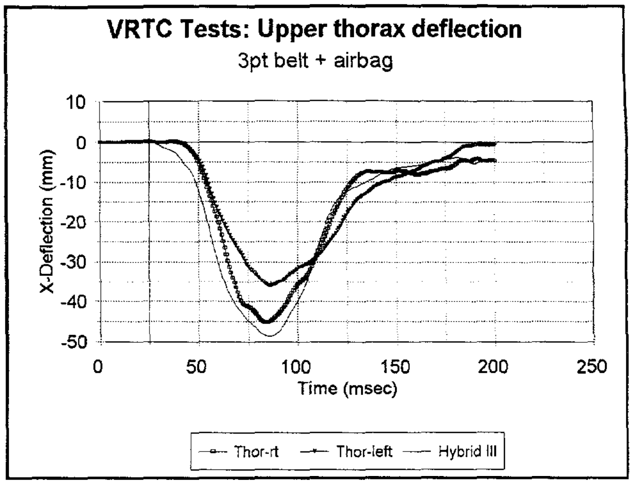

Figure 16. Comparison of Thor and Hybrid III chest deflections.

It is seen that there is some asymmetry between the right and left CRUX units, as might be expected in a restraint environment where the 3-pt belt influences the overall symmetry of the airbag loading. Also the Hybrid III deflection appears to be closer to the right side CRUX measurement.

Figures 17-19 show the chest deflections measured by the CRUX units for three different restraint conditions. Figure 17 and 18 show the responses for a bag and 3-pt belt restraint and an airbag only restraint respectively with a frontal deceleration pulse. Figure 19 shows the response for a 3-pt belt only condition with an oblique deceleration pulse . The deflections are shown in the horizontal plane (relative to the lower thoracic spine coordinate system), with the X displacement representing A-P motion and Y displacement representing right-left motion. The figures for the tests with belts show the characteristic asymmetry associated with 3-pt belts. The bag only test also shows some asymmetry. The video indicates a small degree of rotation during the unloading phase of the bag which likely explains the asymmetry. The 3-pt belt and airbag case also shows some small expansion of the lower left CRUX. This is not seen in the 3-pt only case, presumably since it is associated with significant rotation of the torso (generated from the obliquely applied crash pulse) .

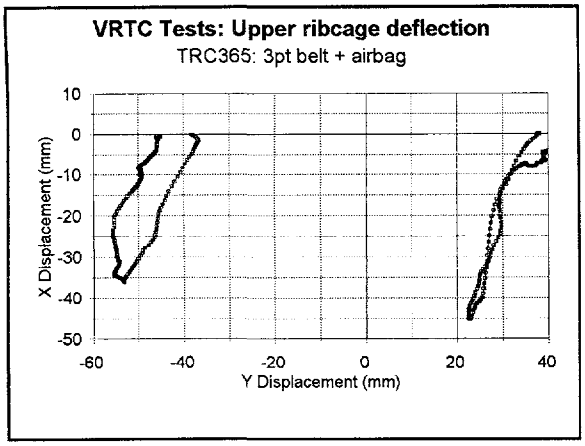

Figure 17. Upper chest deflections for airbag and 3-pt belt restraint.

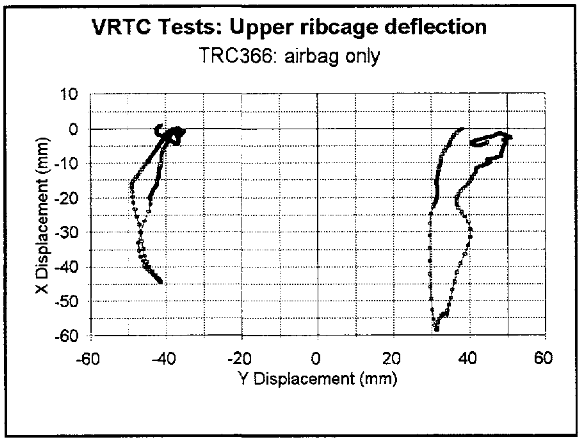

Figure 18. Upper chest deflections for airbag only restraint.

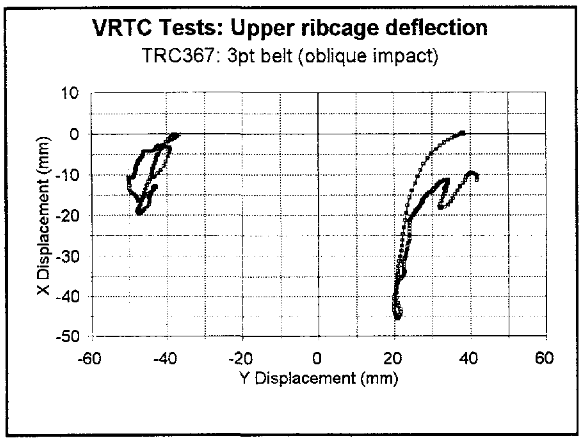

Figure 19. Upper chest deflections for 3-pt belt only restraint.

Figures 20 and 21 compares the responses of the right and left DGSPs (for the X-direction displacement) to two 3-pt belt tests. The belts were situated for a passenger, and in the first test, the lap belt was placed at its normal position on the iliac spine. For the second test, the lap belt was placed higher to allow for maximum abdominal penetration. The responses indicate that an additional 15 mm of penetration occurred with the second setup for the right side, and additional 5 mm penetration for the left side.

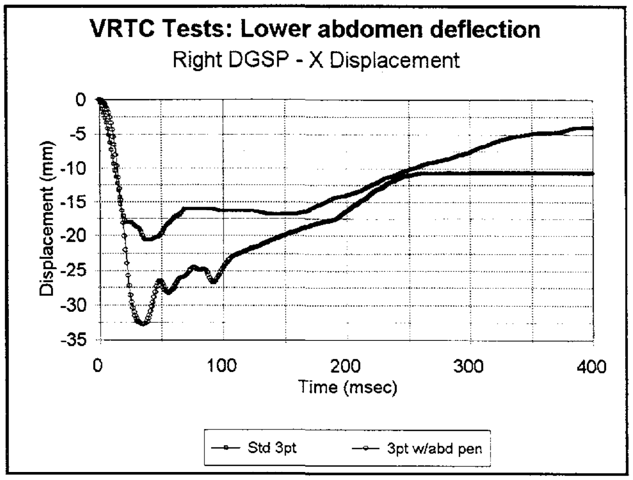

Figure 20. Lower abdomen penetration (by lap belt) as measured by the right DGSP.

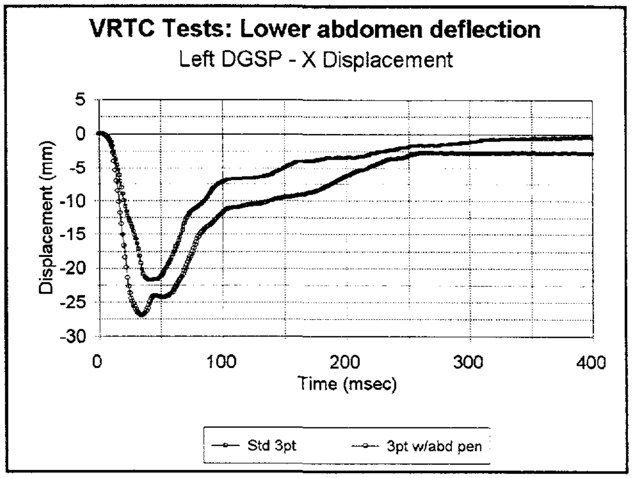

Figure 21. Lower abdomen penetration (by lap belt) as measured by the left DGSP.

Another test situation of interest was the out-of-position airbag test with THOR being put in both standard ISO configurations. The chest on module configuration with the associated high rate of chest compression allowed us to gauge how the new CRUX system performed in this condition. Figure 22 shows the comparison of the rate of compression measured by the left and right CRUXes (by computing the derivative of the displacement) and the corresponding measurement from the sternal accelerometer (by integrating the acceleration).

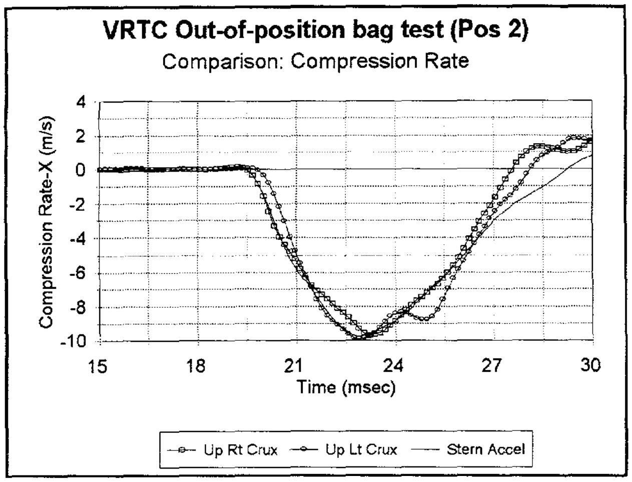

Figure 22. Comparison of compression rate from CRUX and accelerometer for OOP test.

It shows that there is good agreement between the CRUXes and the accelerometer during the main loading period (the plot shows only the significant loading duration). In this test, the maximum deflection rate reached about 9.5 m/s and the tests showed that the CRUX units successfully measured deflection rates of this magnitude. Figure 23 shows the actual X-Y deflections seen by the CRUXes, showing the symmetric displacement pattern associated with airbag loading.

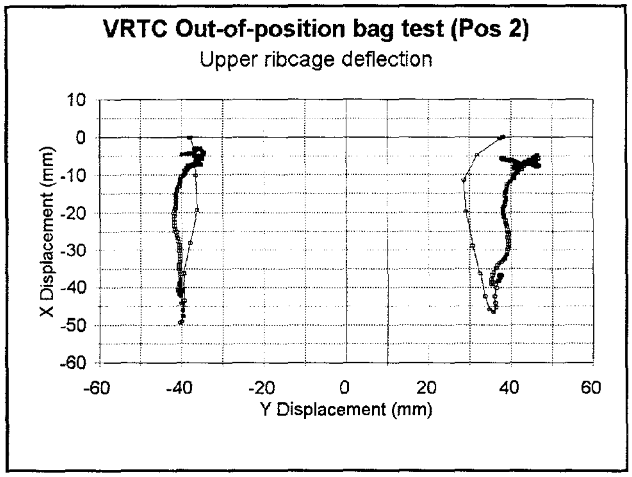

Figure 23. X-Y deflections measured at upper chest during OOP test.

Design Modifications

Based on the results of the tests conducted in Canada and VRTC and feedback from the laboratory staff, a number of design revisions to THOR were made to address some problems of durability and to make improvements to the appearance and performance of the dummy. The principal revisions are described below.

- Molded urethane pads more closely resembling the human shoulder contour replaced the steel flanges on the shoulder. The steel flanges, originally installed to avoid the belt from sliding across the shoulder and loading the neck, tore the shoulder belt in two of the Canadian tests.
- The mid-sternal string pot was removed after it was seen to be making contact with the ribcage. The string pot was probably responsible for increasing the stiffness of the ribcage, which was noticed in the Kroell tests at VRTC.
- The CRUX units were redesigned to avoid any interference between the units and the ribs and upper abdomen. The procedure for processing the CRUX data was improved to avoid measurement problems that had been initially encountered.
- The size and shape of the lower abdomen was slightly modified to allow for better integration with the upper abdomen and interaction with the lap belt.
- A new pelvis skin was created to reduce damage seen in the tests with the original pelvis skin that had been attached with Velcro fasteners. Improvements were also made in the jacket design to reduce burns and tears.
- Strain relief was added to all wires to minimize the likelihood of wires breaking during the motion of the dummy.

DISCUSSION

The first two prototypes of THOR, the new advanced frontal crash test dummy, have been tested at DCIEM in Canada and at VRTC in Ohio. The results from these tests have been evaluated along with comments from the laboratories. The tests in Canada were used to make a preliminary evaluation of the motion of THOR in a 3-pt belt and 2-pt belt environment; to check the new deflection measurement systems in the chest and abdomen; and to assess the durability of the various dummy components. The tests at VRTC were more comprehensive in nature, with both component and full sled tests being performed. The component tests were meant to evaluate the biomechanical response of several dummy parts, such as the thorax, abdomen, femur, and neck. One of the sled tests was performed to provide a comparison with Hybrid III for the case of an airbag and

3-pt belt restraint.

The results from the two series of tests were very helpful in suggesting a number design revisions to improve the performance of the dummy. These revisions have been carried out, and the redesigned prototype has been subsequently tested at a number of additional research laboratories.

CONCLUSIONS

The first two series of tests with the new THOR dummy, in Canada and at VRTC, allowed us to evaluate its performance in a number of different environments. The following could be concluded from this evaluation:

- The dummy was quite robust and the principal components held up well under 56 kph deceleration pulses and peak decelerations greater than 30G. This was true in oblique testing with this pulse. Smaller components such as foam inserts and parts of the skin received some damage, problems which have been addressed in the revised design.
- The CRUX units worked well and were able to provide 3-D deflection information at the four sites on the ribcage. The deflection patterns produced could distinguish differing restraint systems. In the tests, the deflections at the four locations distinguished between airbag only, belt only, and bag and belt combinations.
- Out-of-position airbag tests indicated that the CRUX units were able to operate properly at sternal compression rates of above 9 m/s.
- The DGSPs used for measuring abdominal deflections provided smooth time history data for abdomen penetrations. The penetrations were found to be sensitive to lap belt location.
- In one test, where comparison was made with Hybrid III response, the head, chest, and pelvis accelerations were found to be similar in magnitude and shape. The upper chest deflections were comparable, though the Hybrid III showed a slightly greater deflection at the sternum.

ACKNOWLEDGMENT

The efforts reported in this paper were supported by the National Highway Traffic Safety Administration of the U.S. Department of Transportation under contract DTNH22-94-C-07010. We are grateful to the NHTSA staff for their technical guidance and support. We are also grateful to Transport Canada for supporting the initial round of testing at DCIEM in Canada, and to Biokinetics, Inc for providing very helpful technical and logistical support. We are grateful to VRTC for providing excellent support and critical feedback during testing at VRTC. The sled tests at VRTC were performed at the Transportation Research Center, Inc (TRC).

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