INVESTIGATION OF THOR-M THORAX BEHAVIOUR

Richard Brown
Gareth Stokes
Jaguar Land Rover
UK

Zaifei Zhou
Humanetics Inc.
USA

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ABSTRACT
The dramatic reduction in death and serious injury that has been achieved within the existing vehicle crash testing framework has, in some cases, reached a plateau. Consumer and regulatory organisations are studying those crash modes that are predominantly responsible for the remaining types of injury, and new test requirements are under development, with the aim of driving further enhancement in occupant protection. One such proposal involves a moving deformable barrier impacting the front of a stationary vehicle at an angle of 15° and with an overlap of 35%, and this oblique impact introduces a lateral component of motion into the vehicle response. In parallel with the development of additional impact modes, a new frontal crash dummy, the Test Device for Human Occupant Restraint (THOR), is being investigated as a replacement for the traditional Hybrid3. The THOR ATD (Anatomical Test Device) provides a more bio-fidelic response, in particular to the lateral component of vehicle motion created by an oblique impact, and it is being considered for introduction into this and other crash test scenarios. THOR is based on a completely new internal structure, and incorporates several new sensors to increase the amount of information available for assessing the severity of the crash from an occupant point of view. Optimal occupant protection relies on a careful matching of restraint specification to the response of the ATD, and a detailed understanding of the internal structure and instrumentation features of THOR is essential in achieving this.

State-of-the-art vehicle development makes extensive use of virtual test methods, and relies on having sufficient confidence in the virtual toolset. Highly fidelic ATD computer models have been used for many years, and a model of THOR is undergoing rapid refinement to meet its increasing relevance within new test regimes.

This paper describes a test and simulation project designed to study the internal structure and behaviour of THOR, and to investigate the quality of the DYNA simulation model. In order to remove as many sources of variability as possible, testing was carried out using the ATD on its own, as well as with a disassembled thorax. The use of CAE models to derive load cases representative of THOR behaviour in a vehicle crash led to a set of test data relevant to in-service loadings. A comparison of simulation and test results allowed a detailed assessment of the quality of the model, and formed a basis for its future development.

It was concluded that the behaviour of THOR is complex and significantly different to that of the Hybrid3 that it replaces, which reinforces the need for detailed understanding of the internal structure and its interaction with vehicle systems. It was also concluded that the existing DYNA model is adequate for guiding development of vehicle systems in respect of protecting THOR, but that some further refinement in specific areas is required.

THOR will be increasingly relevant as it is introduced into the oblique and other crash test cases, and the understanding of its characteristics is developing rapidly. It is hoped that this study will contribute to this knowledge base.

INTRODUCTION

As a result of the development of a wide-ranging crash testing framework over more than 50 years, there have been radical improvements in vehicle crash safety and in the number of fatalities and serious injuries caused to occupants in road traffic accidents. Most of the test regimes currently used to assess frontal crash make use of well-established load cases and employ measurement systems based on Hybrid3 ATDs of various sizes, which have been in use since the start of main-stream crash regulation and consumer information programmes. Although over this period the method of rating crash severity has been refined, the basic vehicle loadings and ATD output signals have not changed significantly. However, new test modes are in development to drive improvement in occupant protection in those crash scenarios that are most predominant in the remaining types of injury. A number of proposed modes are illustrated in figure 1, and include an oblique impact, based on a moving deformable barrier of 2486kg that strikes the vehicle at 90kph, and an offset moving deformable barrier of 1400kg, with both vehicle and barrier moving at 50kph. These tests involve significantly more kinetic energy, which has to be managed by the vehicle systems.

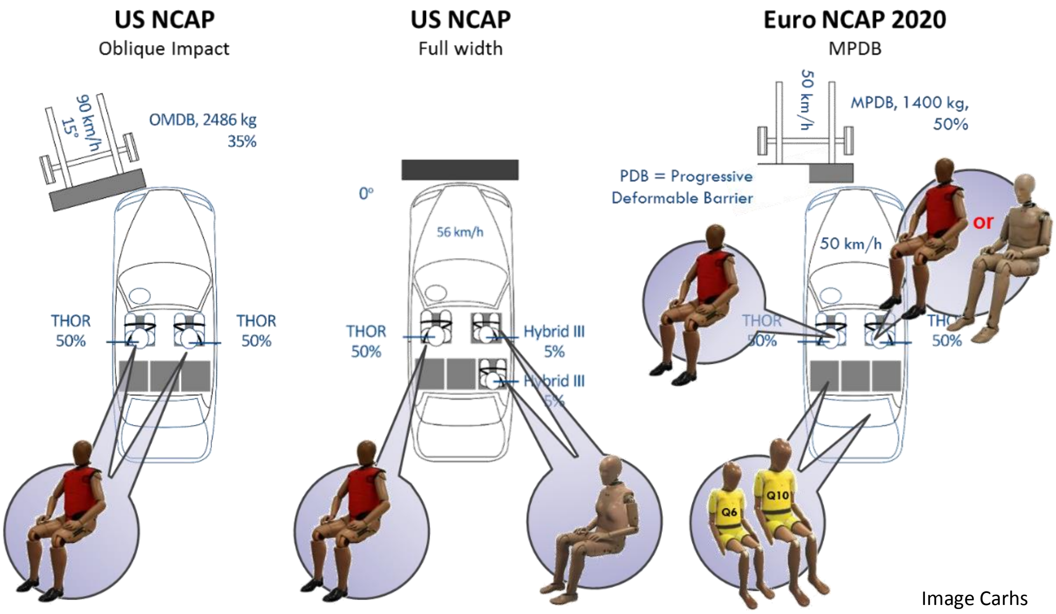
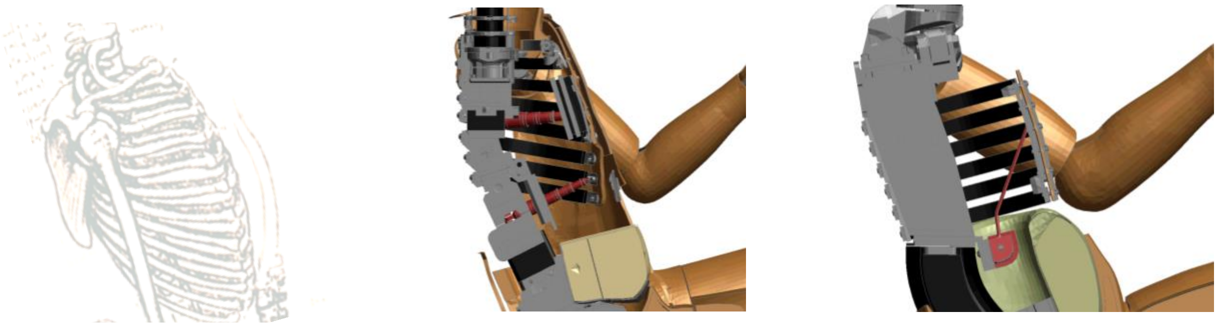


Figure 1. Proposed test modes incorporating THOR

The oblique load case is currently under consideration for incorporation into the USNCAP programme at a point in the near future, and the offset barrier test is planned for introduction in EuroNCAP in 2020. These new test protocols will incorporate the THOR ATD to replace or supplement the Hybrid 3. Originally the Hybrid 3 was developed to assess predominantly longitudinal crash modes, and it has a number of characteristics that limit the precision of measurements that can be made with it, particularly in non-longitudinal crash modes such as the oblique impact. THOR is intended to overcome some of these limitations. Although various THOR versions have been available since the early 2000s, it is now receiving significantly more attention as a result of its proposed introduction. Until recently the THOR specification was still being finalised, and the number of new units in general circulation was limited, so a main-stream evaluation and investigation by a multitude of users was not feasible.

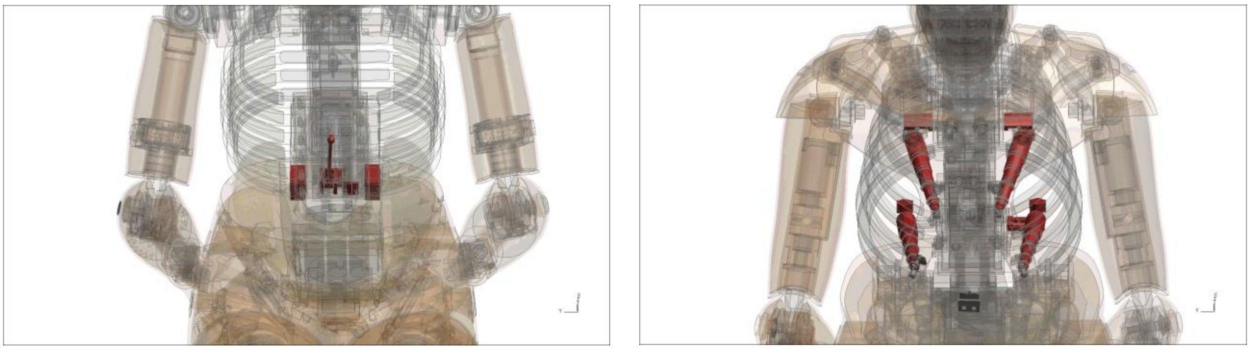
Many aspects of THOR construction differ from Hybrid 3, and it is considered to represent a step-change in bio-fidelity. As a result, interactions with vehicle systems such as restraint components are likely to be different to Hybrid 3. In interpreting the THOR output signals, a detailed understanding of these interactions is essential, and this requires knowledge of the construction, mechanisms and mechanical and electrical responses of THOR. Thorax injury is a key concern in assessing the severity of occupant loading and THOR thorax construction is compared with Hybrid 3 and a human thorax in Figure 2.



THOR Hybrid 3

Figure 2. Comparison of human thorax, THOR and Hybrid 3

Instead of the single, central potentiometer used by Hybrid 3 to measure chest deflection, THOR is fitted with 4 telescopic IRTRACC systems as shown in figure 3, making an understanding of these systems and the supporting structure very important.



Hybrid 3 THOR

Figure 3. Chest deflection measurement in THOR and Hybrid 3

Modern vehicle development relies on the use of CAE techniques to predict the response of safety systems, including ATDs, and detailed finite element models of THOR exist to support this activity. One benefit of the use of CAE is the ability to investigate many different loading scenarios as an aid to refining load case configuration and specifying instrumentation prior to physical testing. In addition, it allows measurements and observations to be carried out, including study of internal behaviour, that are not possible with a physical component. Consequently, CAE modelling can make a vital contribution to the detailed study of physical mechanical systems. However, this pre-supposes sufficient confidence in the fidelity of the CAE model. In this context, more information regarding THOR, in both the physical and the virtual domains, is required.

OBJECTIVES

This study set out with the following objectives:

To generate a set of relevant thorax component test data using a THOR-M
To observe and measure thorax response in these tests, and draw conclusions as to factors influencing its mechanical behaviour
To assess the ability of a THOR CAE model to predict the results of these tests

METHOD

In studying the behaviour of a mechanical system, including an ATD, it is essential to minimise factors that could introduce noise into the loading or contaminate response measurements. However, the loading configuration must still be sufficiently representative of in-service conditions to generate data that provides useful insight into the response of the system. Additionally, it is important to gain as much information as possible from such testing, including visual observations, in order to capture the behaviours associated with the response signals. Without an understanding of these underlying behaviours, an assessment of output signals is of limited use as it provides little information as to the likely response in other load conditions. For the same reason, in assessing the capability of a CAE model to predict a test result, a simple comparison of output signals is not adequate without a comparison of the corresponding behaviours.

To meet the requirement for low-noise but representative test conditions, CAE models were used to define a set of quasi-static and dynamic rig tests to replicate the loading characteristics and responses of the THOR-M thorax seen in an oblique vehicle crash. Using pendulum and quasi-static compression test equipment, impactor sizes, masses and velocities were chosen to match, as far as possible, the conditions experienced in a vehicle crash. The CAE simulations also allowed suitable instrumentation and camera views to be determined. Following the definition of test configurations, a fixture was designed and manufactured to allow the THOR to be fixed stiffly in a number of orientations to suit quasi-static and dynamic loadings. The fixture was designed to match the geometry of the THOR spine, and is shown in figure 4.

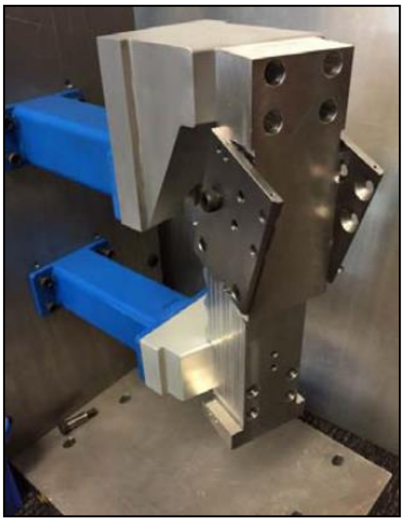


Figure 4. THOR spine fixture

The fixture was designed to allow it to be mounted vertically for dynamic pendulum testing, or horizontally in a compression loading bench for quasi-static loading. In each case it was possible to alter the angle presented by the thorax to the probe or pendulum. These two mounting conditions are shown in figure 5.

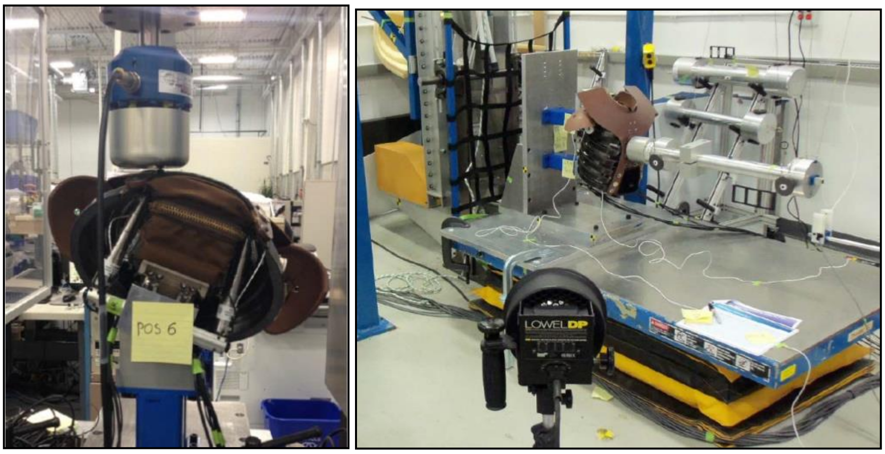


Figure 5. Horizontal and vertical fixture orientations

The thorax was fully instrumented and the previously determined camera views were installed to provide the required visual data. Following testing, a full visual and response signal analysis was completed. This was then compared to the original CAE models to confirm the validity of the models, and to help interpret the test data.

In a second set of tests, the complete THOR ATD was impacted at a number of points, and in various directions by a pendulum, whilst sitting freely on a surface. These tests were also pre-simulated to specify the masses and velocities of the pendulum impacts. The arrangement is shown in figure 6.

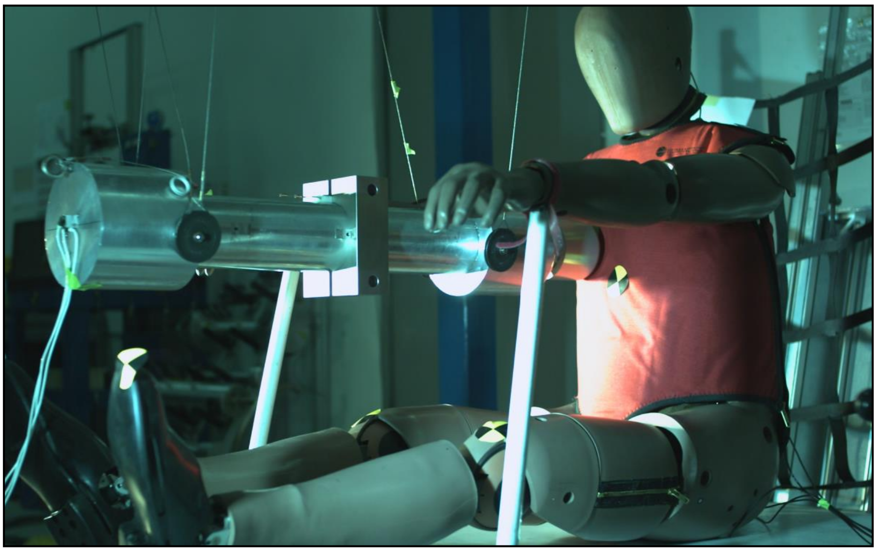


Figure 6. Complete ATD test configuration

RESULTS

Through the use of CAE it was possible to derive surrogate load configurations for quasi-static, pendulum, and full ATD tests that approximated the ATD response in vehicle crash cases. An example is shown in figure 7 where the thorax compression observed in vehicle and full ATD regimes is compared. It was considered that this degree of agreement is sufficient to make the information collected relevant to in-service conditions.

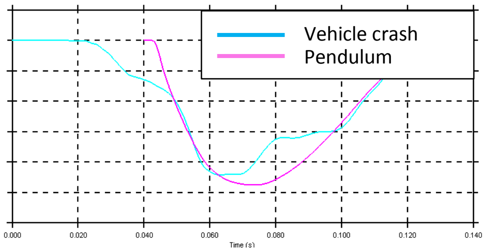


Figure 7. THOR CAE model chest deflection in vehicle and pendulum load cases

Upper thorax deflection was seen to be very sensitive to the Y location of the load form with respect to the sternum block. In figure 8 the upper chest deflections for a central and an offset pendulum impact in the fixed thorax test are shown. The upper left chest deflection in the offset impact is significantly lower than that for the central impact, showing a dramatic sensitivity to the Y location of the loading.

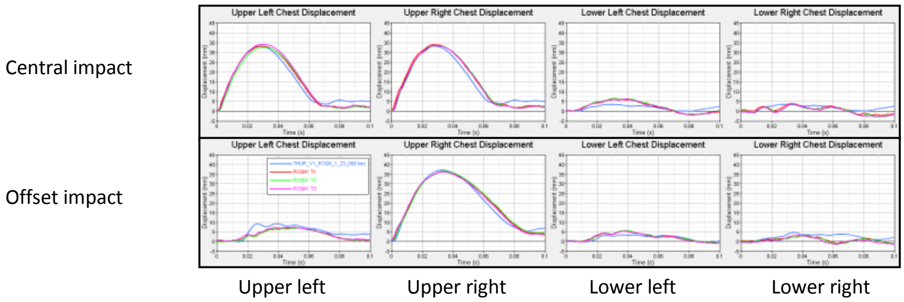


Figure 8. Upper chest deflections in central and offset pendulum fixed thorax load cases

This step change in deflection of the non-struck IRTRACC under offset pendulum impact was seen to be related to the arrangement of IRTRACC sensors and the relatively compliant connection between ribs and sternum block through the bib, as shown in figure 9.

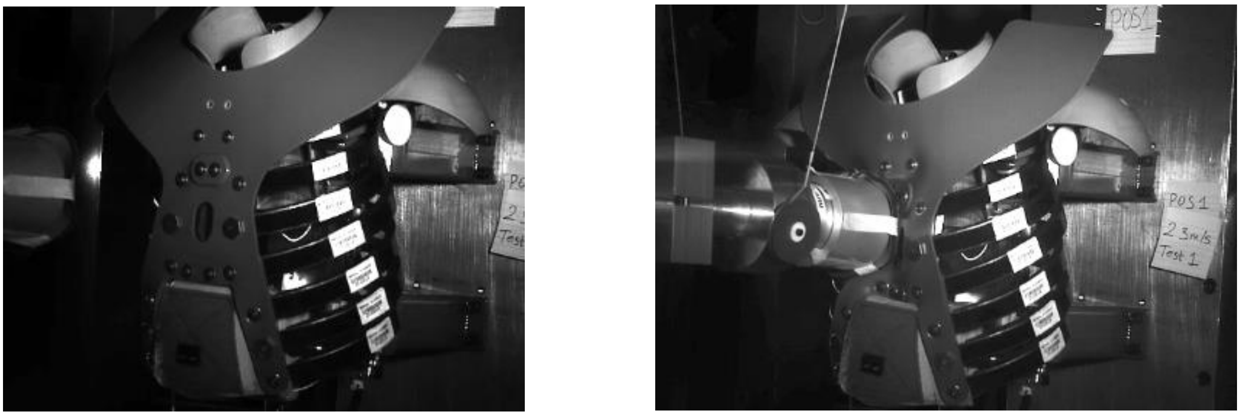


Figure 9. Local deflection of bib in the area of an offset pendulum impact

Section views through the model, shown in figure 10 illustrate how, when the impactor does not engage with the sternum block, the deflection of the IRTRACCs becomes unbalanced and the impact opposite the loading is significantly reduced, whereas the IRTRACC underneath the impactor increases. The left and right ribs are relatively weakly coupled through the bib/sternum construction, and it can be seen that the sternum block is subject to considerable rotation under off-centre loading.

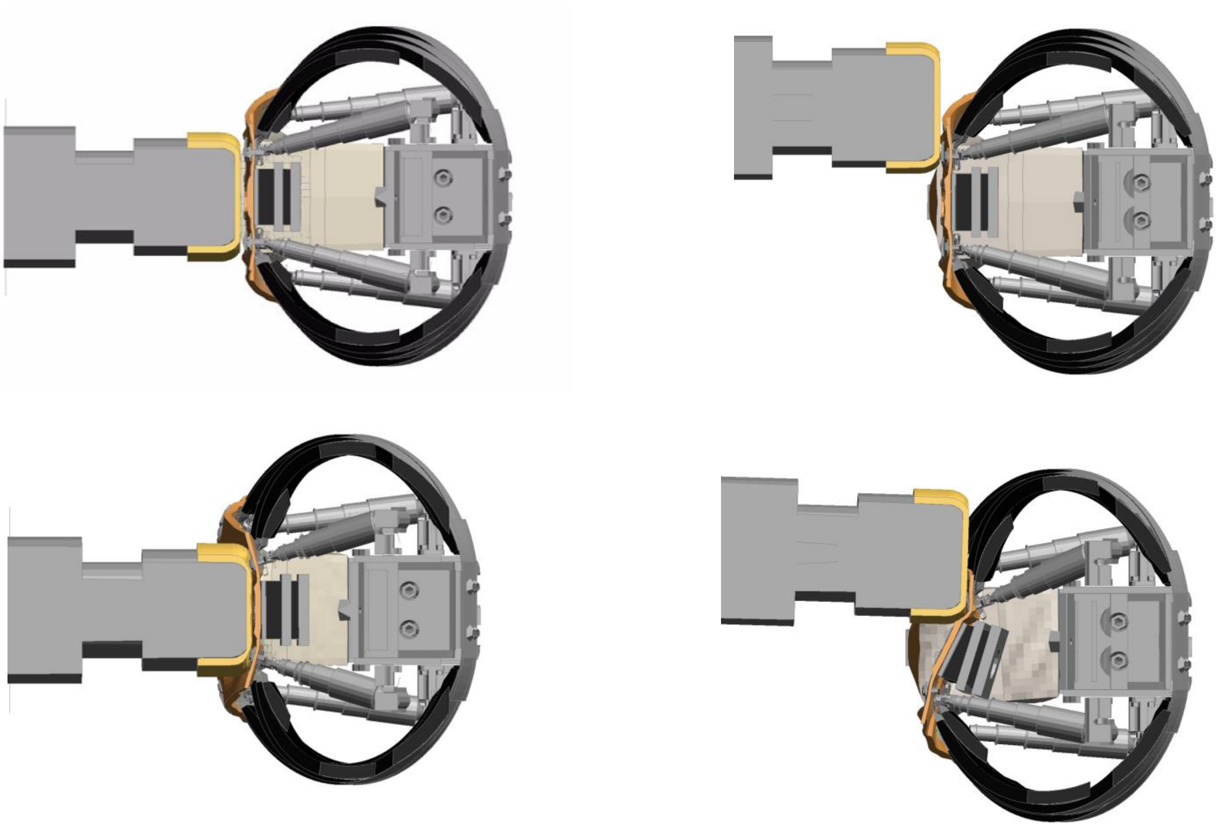


Figure 10. Local deflection of bib in the area of central and offset pendulum impacts

Although it is not possible to observe directly the internal behaviour in the full ATD physical test, section views through the corresponding CAE models allow this behavior to be inferred, and figure 11 illustrates how a similar off-centre loading response occurs in this test configuration. It can be concluded that the behaviour of the thorax in the fixed spine test is representative of the behaviour in the full THOR test. In a vehicle environment, the lateral position of a seat belt path with respect to the sternum block could significantly affect the relative thorax deflections measured between the left and right IRTRACCS, and understanding this relationship is critical to interpreting thorax deflection measurements.

Figure 11. Local deflection of bib in the area of central and offset pendulum impacts

A similar lack of vertical coupling between upper and lower IRTRACCs can be observed in figures 8, and 9, again indicating a relatively compliant bib that does not transfer load effectively in this load case.

Impact onto the sternum block in the fixed thorax pendulum test was observed to lead to an immediate compression of the rubber elements between the steel plates due to the inertia of the components. This is followed by strong oscillation of the sternum block. In figure 13, a section through the model illustrates how this compression also occurs in the full ATD mode. The level of compression of the sternum block construction can be expected to influence early chest compression measurement since the effective mass experienced by the loading is reduced due to the compliance. Strong oscillation as the sternum block rubber elements recover their original shape could lead to vibration in the output signals.

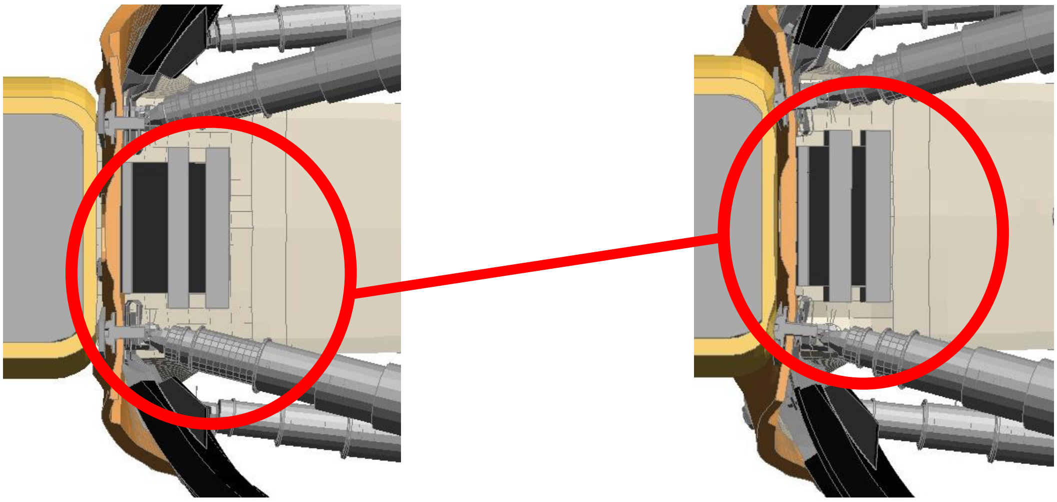


Figure 13. Compression within the sternum block under direct loading in the full ATD load case

CONCLUSION

A set of load cases was developed using a CAE model of the THOR ATD, which led to observations of behavior and corresponding signal responses that can be expected to influence the response of THOR thorax to input from vehicle systems. CAE has a vital role to play in developing relevant test specifications with reduced noise, and analyzing and interpreting results, and the ability to study behaviours not visible in the physical dummy is of particular benefit. An adequate level of confidence in the CAE model is a pre-requisite for this approach.

Three characteristic behaviours have been described here:

- A strong influence of the degree of sternum block engagement with loading system, in Y and Z directions, on upper chest deflection and distribution.
- A low level of lateral and vertical coupling between IRTRACCs.
- A highly dynamic behavior of the sternum block, which may influence the early force/displacement characteristics of the thorax deflection and introduce noise into deflection or acceleration signals.

These observations provide insight into the internal structure and behaviour of the THOR ATD under static and dynamic loading. This will lead to a more precise understanding of interactions between vehicle systems and ATD, and allow a more informed interpretation of output signals and their sensitivities to vehicle system changes. The introduction of THOR into a range of new tests requires a development in familiarity and understanding of the dummy to match that of the Hybrid 3, built up over many years, and exercises of this type are a useful addition to this knowledge base.