SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE



# Thoracic Response of the Hybrid III and THOR Small Female ATDs in Matched Frontal Sled Tests

David M. Boyle, Devon L. Albert, Warren N. Hardy, Andrew R. Kemper
Virginia Tech, Center for Injury Biomechanics

**ABSTRACT** – The THOR 5th-percentile female (THOR-05F) anthropomorphic test device (ATD) was developed to have a more-biofidelic thorax than the Hybrid III 5th-percentile female (Hybrid III-05F) ATD. The objective of this study is to compare the thoracic responses of the two ATDs during matched frontal sled tests. A 7th-generation Toyota Camry driver seat test buck was used with Camry parts (i.e., 3-point belt, modified seat, steering wheel, airbag, and column). Tests were conducted at 30 and 56 kph. The Hybrid III-05F chest potentiometer and THOR-05F IR-TRACCs were used to measure internal deflection. Upper and lower chestbands were used to measure external deflection. Chest deflections were higher in the THOR-05F tests due to the more compliant rib cage. Chestband data showed that belt location played a large role in the location and magnitude of internal deflection. Future work will include conducting matched small female PMHS sled tests.

## INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) and Humanetics have recently developed the THOR 5th-percentile female (THOR-05F), a new anthropomorphic test device (ATD) representing the 5th-percentile female. The THOR-05F was designed to have a more biofidelic thorax than the Hybrid III 5th-percentile female (Hybrid III-05F) ATD. The thorax was designed to better represent the female anatomy with slanted ribs and a more compliant rib cage compared to the Hybrid III-05F. The THOR-05F was also designed with 4 IR-TRACCs to provide more detailed chest deflection data than the single potentiometer used in the Hybrid III-05F.

While the response of the THOR-05F has been assessed using tests in the "Gold Standard" condition (Wang et al., 2021), there have been few studies directly comparing the thoracic response of the THOR-05F to the Hybrid III-05F (Carroll et al., 2021, Eggers et al., 2023) and only one study has compared the responses of the two ATDs using OEM (original equipment manufacturer) components, but tests were conducted in the rear seat (Tang et al., 2022). Therefore, the objective of this study is to compare the responses of the THOR-05F and the Hybrid III-05F in matched frontal driver seat sled tests with realistic boundary conditions and OEM components.

## METHODS

A sled buck designed to represent the driver seat environment of a 7th-generation (2012-2017) Toyota Camry was used for all sled tests. Two pulses were used: a 56-kph, 7th-generation Toyota Camry NCAP pulse and a 30 kph scaled version of the same pulse. A total of 6 sled tests were conducted using the THOR-05F (3 at 30 kph and 3 at 56 kph), and 7 sled tests were conducted using the Hybrid III-05F (3 at 30 kph and 4 at 56 kph). The 2019 version of the THOR-05F with minor design updates was used (NHTSA, 2019). A production seat back was modified to allow lines of sight to the spine. The corresponding seat bottom was not altered. Rigid polyurethane foam (65 psi) was used to represent the knee bolster (Albert et al., 2016). A Camry steering column, wheel, and airbag were used along with a 3-point belt with a 4-kN load limiter and pretensioner. The airbag and pretensioner were deployed 10 ms after the start of sled motion in the 56-kph tests. The same timing was used for the 30-kph tests except the 2nd stage of the airbag was deployed 38 ms after the start of sled motion. These timings were similar to those in the 7th-generation Camry NCAP test (56 kph) and a relevant 7th-generation Camry CISS case (30 kph) (1-13-2017-102-02).

Internal and external instrumentation were used to measure chest deflection. Hybrid III-05F internal chest deflection was measured using the standard sternum potentiometer. Resultant deflections for the THOR-05F were calculated using IR-TRACC assembly data at each location and the location with the highest peak deflection (Rmax) was reported for each test. Upper and lower chestbands were installed on both ATDs to acquire external chest deflection data. Chestbands were installed at the levels of rib 1 and ribs 4/5 on the Hybrid III-05F and at the levels of ribs 2/3 and slightly above rib 5 on the THOR-05F. These locations were chosen to approximate the locations of ribs 3/4 and the xyphoid process on a 5th-percentile human female. Maximum deflections and their locations were calculated for each chestband. Chestband deflections

Address correspondence to David Boyle, Electronic mail: dmb96@vt.edu

were also calculated at the sternum and approximate locations of the THOR IR-TRACCs for both ATDs.

## RESULTS

Internal chest deflection measurements were highest in the THOR-05F tests at both speeds (Figure 1). The Rmax location for the THOR-05F was the lower right (LR) IR-TRACC for the 30-kph tests and the upper right (UR) IR-TRACC for the 56-kph tests. The difference between the upper and lower right IR-TRACC chest deflections were not large (Table 1 & 2). Peak times were similar for all tests.

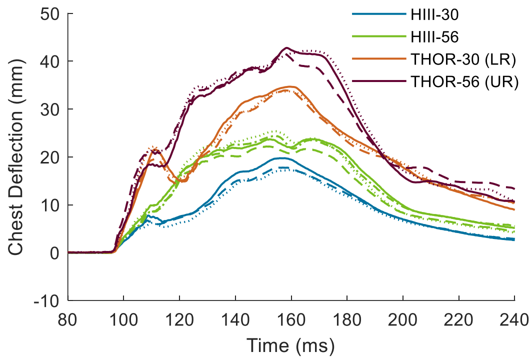


Figure 1. Chest deflection measured with internal ATD instrumentation (at the location of peak deflection (Rmax) in the THOR-05F).

The locations of maximum external deflection measured by the upper band were different between test speeds. Locations of maximum deflection recorded by both the upper and lower chestbands are shown in Figure 2. Upper band data indicated the maximum deflection for the Hybrid III occurred near the sternum at the level of rib 1. The lower band measured the maximum deflection approximately 30 mm to the right of the sternum between ribs 4 and 5. The upper band on the THOR-05F, which was slightly above the level of the upper IR-TRACCs, tended to measure the maximum deflection to the left of the sternum in the 30-kph tests, but to the right of the sternum in the 56-kph tests. Maximum lower chestband deflection for the THOR-05F occurred slightly above the location of the lower right IR-TRACC due to the placement of the chestband above the sensor.

The magnitude of the external deflections measured by the chestbands tended to be larger than what was measured by the internal instrumentation for a given location with a few exceptions (Table 1 & 2). The THOR's internal and external deflections were similar at the upper right and lower left (LL) locations. For the Hybrid III, the upper and lower chestbands both measured higher deflections at the sternum compared to the chest potentiometer, with the lower chestband being more similar.

Comparisons between ATDs were made using external deflections since none of the internal instrumentation were at comparable locations. The external deflections at the upper left (UL), lower left, and upper sternum (US) were similar between ATDs. However, deflections were larger on the right side and lower sternum (LS) for the THOR compared to the Hybrid III.

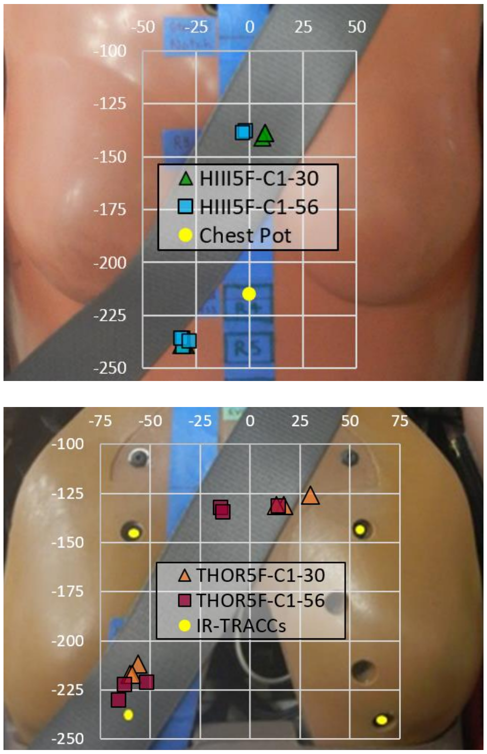


Figure 2. Locations of maximum deflections of upper and lower chestbands relative to internal deflection instrumentation for Hybrid III-05F (top) and THOR-05F (bottom) (units: mm).

Table 1. Average peak internal and external deflections in 30-kph tests

| **Upper Chest** | **UL** | **US** | **UR** |
|---|---|---|---|
| HIII Chestband | 25.0 | 35.7 | 21.5 |
| HIII Potentiometer | | 18.3 | |
| THOR Chestband | 30.0 | 36.4 | 28.9 |
| THOR IR-TRACCs | 14.9 | | 31.5 |
| **Lower Chest** | **LL** | **LS** | **LR** |
| HIII Chestband | 10.4 | 22.5 | 21.4 |
| HIII Potentiometer | | 18.3 | |
| THOR Chestband | 13.4 | 38.6 | 49.1 |
| THOR IR-TRACCs | 15.3 | | 34.1 |

Table 2. Average peak internal and external deflections in 56-kph tests

| **Upper Chest** | **UL** | **US** | **UR** |
|---|---|---|---|
| HIII Chestband | 33.0 | 44.1 | 29.5 |
| HIII Potentiometer | | 23.9 | |
| THOR Chestband | 33.8 | 44.6 | 38.0 |
| THOR IR-TRACCs | 19.4 | | 42.2 |
| **Lower Chest** | **LL** | **LS** | **LR** |
| HIII Chestband | 13.3 | 29.7 | 28.3 |
| HIII Potentiometer | | 23.9 | |
| THOR Chestband | 10.7 | 42.2 | 57.3 |
| THOR IR-TRACCs | 15.8 | | 37.8 |

## DISCUSSION

The THOR-05F has a more compliant rib cage, leading to higher chest deflections than the Hybrid III-05F, particularly along the belt path. The Rmax location in the THOR-05F tests differed based on delta-v. This is different from the results found in previous studies which reported the lower-inboard IR-TRACC as the location of peak deflection regardless of delta-v (Carroll et al., 2021, Eggers et al., 2023; Tang et al., 2022). However, airbags and knee bolsters were not used in these studies, and videos from the current study indicated substantial airbag interaction with the upper chest, potentially explaining the discrepancy. Previous studies conducted using this test buck and restraint condition on 50$^{th}$-percentile male surrogates at 56 kph always observed peak deflection on the upper chest (Albert et al. 2018). The THOR-05F tests also had more torso rotation about the z-axis in the 56-kph tests, causing the belt to move closer to the upper right IR-TRACC. This is reflected in the maximum external deflection locations of the upper band.

The chestband data in the Hybrid III-05F tests showed external deflections were higher at the upper sternum than the lower sternum. It has been shown that belt placement on the Hybrid III-05F greatly affects chest deflection measured by the potentiometer, which sits at the top of rib 4 at rest. Results presented by Eggers (2023) suggest that if the belt were placed lower on the chest, the measured potentiometer deflection would have been greater. However, a lower belt placement did not align with the natural belt routing on the surrogate following the positioning procedures.

For the THOR-05F tests, the lower right deflection measured by the chestbands was much higher than what was measured by the IR-TRACC. One reason for this is that the chestband captured the compression of the jacket and breast tissue, while the IR-TRACCs did not. This is important to consider when comparing Rmax to the chest deflection of post-mortem human surrogates (PMHS) measured by chestbands.

Chestband data showed that the location of external maximum deflection on both ATDs was within a belt's width (50.8 mm) from internal instrumentation (Figure 2). Due to this proximity and other factors such as jacket and chest plate compression, it is unclear if either ATD more effectively captured the location of maximum deflection with their respective internal instrumentation.

Future work will involve conducting matched small female PMHS sled tests. This will allow the responses of both ATDs to be directly compared to the response and post-test injury assessment of PMHS. Without matched PHMS tests to compare to, it is difficult to relate the responses of the ATDs to injury, especially in the case of the THOR-05F for which few injury risk curves are available.

## CONCLUSION

Differences were observed in the internal and external deflections of the Hybrid III-05F and THOR-05F. Chest deflections were higher in the THOR-05F tests due to the ATD's more compliant chest. The location of maximum external chest deflection was close to the sternum on the upper band for the Hybrid III-05F and close to the location of the lower right IR-TRACC on the lower band for the THOR-05F. The location of internally measured Rmax was influenced by the airbag interaction and torso rotation in the 56-kph tests. Matched small female PMHS tests will be run in the future, allowing for biofidelity and injury analyses.

## ACKNOWLEDGMENTS

Thank you to NHTSA for sponsoring this research (Contract #: 693JJ9-21-D-000023; Task Order #: 693JJ9-21-F-000174). The statements in this publication are those of the authors' and do not necessarily reflect the opinions of the sponsor.

## REFERENCES

Albert, D.L., Seeman, S.M., McNally, C., Kemper, A.R., (2016) Evalutation of rigid polyurethane foam as a surrogate material for knee bolsters and knee bolster airbags in full scale frontal sled tests. Traffic Injury Prevention 17(suppl 1): 205-208.

Albert, D.L., Beeman, S.M., Kemper, A.R., (2018) Assessment of thoracic response and injury risk using the Hybrid III, THOR-M, and post-mortem human surrogates under various restraint conditions in full-scale frontal sled tests. Stapp Car Crash Journal 62: 1-65.

Carroll, J., Kruse, D., Mishra, E., Mroz, K., Lubbe, N. (2021) Comparison of Hybrid III and THOR 5th percentile female dummies in frontal crash tests. Proc. IRCOBI, IRC-21-26.

Eggers, A., Schießler, M., Ott, J., Langner, T., Wisch, M. (2023) Sensitivity of chest deflection measurements in THOR-5F and Hybrid III small female dummies to different seat and belt settings. Proc. 27th ESV, 23-0301.

NHTSA. (2019) THOR-05F NHTSA Drawing Pkg - Sept 2019. DOT-NHTSA. https://www.regulations.gov/document/NHTSA-2019-0107-0005

Tang, K., Tylko, S., Bussières, A. (2022) Comparison of the THOR 5th to the Hybrid III 5th in full scale frontal crash tests. Proc. IRCOBI, IRC-22-63.

Wang, Z. J., Ramachandra, R., Bolte, J. H., Lee, E. (2021) THOR 5th female biofidelity evaluation in gold standard sled test condition. Proc. IRCOBI, IRC-21-24.