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# THOR-50M In-Dummy Data Acquisition System Evaluation

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**15. Supplementary Notes**

**16. Abstract**

This report describes the methods, procedures, and analysis used to evaluate the equivalence of a Test Device for Human Occupant Restraint 50th percentile male (THOR-50M) dummy with external data acquisition system (DAS) and a THOR-50M with in-dummy DAS. Qualification, sled, and crash testing were performed to investigate the differences in responses generated by the two versions of the dummy. The qualification testing began with an external DAS (cabled) dummy and then that dummy was converted to an internal DAS variant and exposed to an identical suite of tests; subsequent sled and crash testing involved comparing the responses of two different dummies of both variants. These evaluations concluded that the THOR-50M with the in-dummy DAS is functionally equivalent to its counterpart equipped with an external DAS. Consequently, NHTSA is proposing the adoption of the in-dummy DAS as a permitted optional instrumentation method for its testing procedures.

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## Objective

The proposed in-dummy data acquisition system (DAS) specifications are documented and added to the 2023 drawing package (National Highway Traffic Safety, 2023a, 2023b). Previously, instrumentation wires were bundled into an umbilical cable and connected to a DAS either in the lab or in the trunk of the vehicle in which the anthropomorphic test device (ATD) is seated. Feedback from the automotive industry as well as the European New Car Assessment Programme (Euro NCAP) suggested that users prefer an in-dummy DAS for its many usability advantages (Alliance of Automobile Manufacturers, Inc., 2016; Been & Ellway, 2018). An in-dummy DAS system has the potential to reduce vehicle weight, minimize data loss due to sliced instrumentation cables, and reduce interference between the seat back and the dummy. To investigate the in-dummy DAS system feasibility, an in-dummy DAS system was tested in a Test Device for Human Occupant Restraint 50th percentile male (THOR-50M) ATD and compared to the traditional external DAS (cabled dummy) in the same ATD.

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## Methodology

To evaluate the equivalence of the in-dummy DAS variant of the THOR-50M to the traditional external DAS variant of the dummy, the following steps were carried out. First, a full set of qualification tests was carried out on a new THOR-50M with a traditional external DAS configuration purchased from Humanetics[1] (serial number EG2595) using NHTSA's THOR-50M qualifications manual (NHTSA, 2018)

Then, a commercial items contract was awarded to Diversified Technical Systems, Inc.,[2] to implement its SLICE6 DAS in the same THOR-50M serial number EG2595. The contract included delivery of DAS components, replacement instrumentation compatible with the DAS, and replacement ATD parts to allow attachment of DAS components and preservation of inertial properties. Installation of the SLICE6 system required modifications to the parts shown in Table 1. These changes allowed attachment of the DAS hardware to the rigid components of the ATD while ensuring negligible changes to the range of motion, mass, moment of inertia, and center of gravity (CG) location of the ATD and its individual body segments. The negligible change in inertial properties has been confirmed by comparing measurements from the three-dimensional parametric model in both configurations. Additionally, the tilt sensors were replaced by DAS units that contained integrated tilt sensors that measured the same relative surfaces as the original tilt sensors. The triaxial accelerometers at the head CG, T6, and pelvis were replaced with integrated 6DX sensors (6DX-PRO, DTS, triaxial accelerometer + triaxial angular rate sensors) mounted in the same location. The 6DX at the head CG replaced the three accelerometers and the three angular rate sensors.

*Table 1. Parts Modified or Replaced to Accommodate the In-Dummy Data Acquisition System*

| Part Number | Part Name |
|---|---|
| 472-1210 | Accelerometer Mounting Plate, Head |
| 472-1212 | 7 Accelerometer Array Fixture |
| 472-3650 | Lower Thoracic Spine Assembly |
| 472-4610 | Spinal Mount Bracket Assembly |
| 472-3733 | Thoracic Spine Load Cell Flex Joint Adaptor Plate Assembly |
| 472-3691 | Lumbar Spine Pitch Change Bottom Plate |
| 472-4371 | Pelvis Accelerometer Cover |
| 472-5580-1/2 | Lower Leg Flesh, Left/Right |

After integrating the SLICE6 DAS, the mass, moment of inertia (MOI), and CG for each body segment of an in-dummy DAS ATD were measured. These measurements were then compared with data from the external DAS ATDs to ensure that there were no issues after incorporating the in-dummy DAS. The data from these measurements is tabulated in Appendix A: MASS, MOI, and CG.

[1] Humanetics Innovative Solutions, Inc., Farmington, MI.
[2] Diversified Technical Systems, Inc., Seal Beach, CA.

Then a full set of qualification tests was repeated with the in-dummy DAS installed and the results were compared to the 2018 qualification specifications. Note that the in-dummy DAS ATD was obtained in 2018. The comparison of qualification tests before and after the integration of SLICE6 was conducted according to the NHTSA (2018) version of the qualification manual. In addition to updates to the qualification corridors, the manual has also been updated with new upper leg qualification test procedures since 2018. In the 2018 version the upper leg qualification test used a 5 kg impactor traveling at a velocity of 2.6 m/s. However, the Qualification Repeatability and Reproducibility (R&R) study by Millis (2021) showed these parameters led to coefficients of variation exceeding 10 percent, particularly concerning the peak resultant acetabulum force. In response to these findings NHTSA has revised the test parameters and published a new 2023 qualification procedures manual (NHTSA, 2023c). Both the mass and velocity of the impactor have been increased and a backer plate was introduced behind the pelvis to prevent any rearward motion during the test. The proposed changes use a 12 kg impactor equipped with a 76.2 mm diameter rigid disk impact surface, moving at a speed of 3.3 ± 0.05 m/s in parallel to the femur.

To capture the changes made between the 2018 and 2023 versions of the qualification procedures manual, a second complete set of qualification tests was conducted with the in-dummy DAS and using the 2023 qualification specifications. The results of the second set of in-dummy DAS qualification testing are detailed in Appendix B: Results Using 2023 Qualification Procedure.

After the qualification test comparison was completed, additional testing was conducted using THOR-50M S/N EG2595 in two simplified sled test conditions: Gold Standard 1 and Gold Standard 2. These tests are described in more detail, along with a comparison of the in-dummy DAS configuration to the baseline THOR-50M configuration, in the NHTSA (2024) report and described in the sled tests section.

Then, two vehicle crash tests were conducted with the in-dummy DAS THOR-50M in the right front passenger seat. These crash tests were conducted in the Oblique Moving Deformable Barrier (OMDB) test mode (NHTSA, 2016). The same two vehicles were tested twice before testing external DAS THOR-50M ATDs in a similar configuration. The crash tests are briefly summarized in the oblique crash tests section, with detailed results in Saunders and Parent (2023).

Additionally, as earlier in-dummy DAS systems have caused temperature elevation concerns, NHTSA closely monitored the rib and the lumbar temperature of the THOR-50M with and without the in-dummy DAS. Both external and in-dummy DAS ATDs were used for three tests of unbelted test configurations at the regulatory speed of 40 km/hr according to Federal Motor Vehicle Safety Standard (FMVSS) No. 208, *Occupant crash protection*. The details and results of the comparisons are summarized in the temperature section.

# Qualification Results

## Head

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the head qualification procedures described in the 2018 NHTSA qualifications manual. The head qualification test is a dynamic test performed to examine the force-time and acceleration-time characteristics of the head when impacted on the forehead with a 23.36 kg rigid impactor at 2.00 ± 0.05 m/s. During these tests the probe force and the head CG resultant acceleration were measured.

### *Qualification Results*

This section gives the results of the head impact qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 2 shows the test data, followed by plot overlays comparing the two dummy configurations. Both ATD configurations passed all qualification requirements.

*Table 2. Head Impact Qualification Results for External and In-Dummy DAS ATD EG2595*

| **Parameter** | **Specification (Sep 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180322-6** | | **181114-1** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 1.95 | 2.05 | Pass | 2 | Pass | 2.01 |
| Peak Probe Force (N) | 5,022 | 6138 | Pass | 5,371 | Pass | 5,460 |
| Peak Head CG Resultant Acceleration (G) | 105.3 | 128.7 | Pass | 121.7 | Pass | 120.2 |

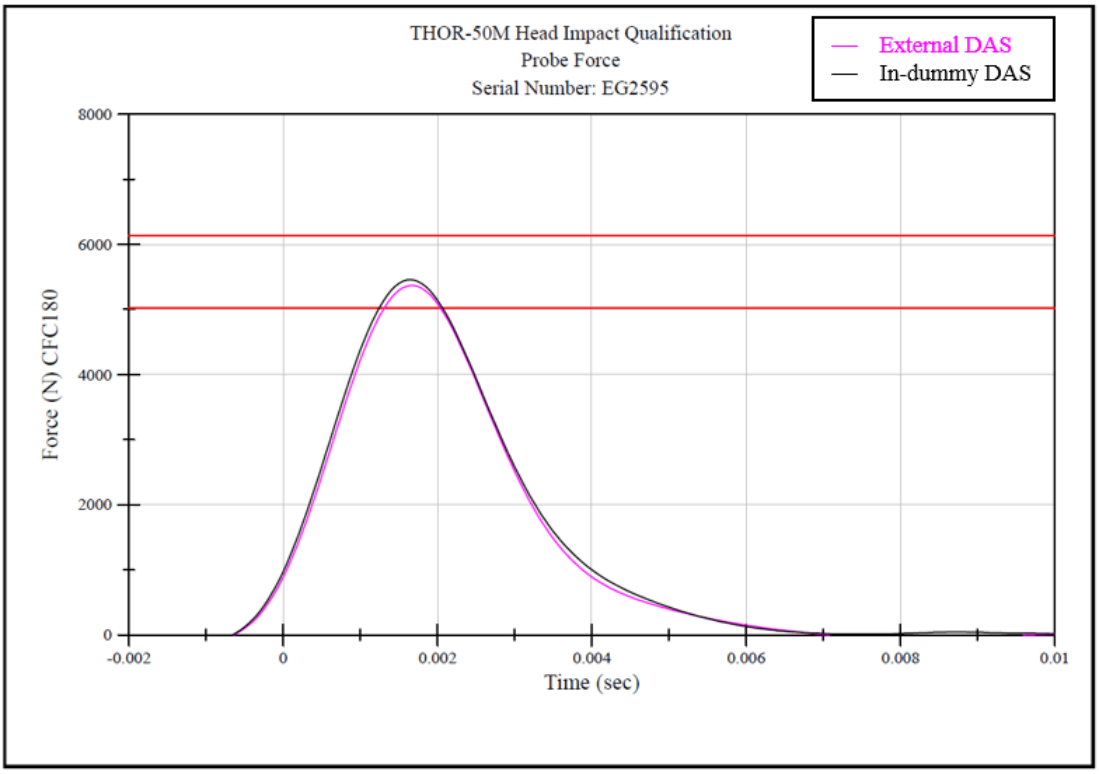


*Figure 1. Head impact: Probe force for external and in-dummy DAS EG2595*

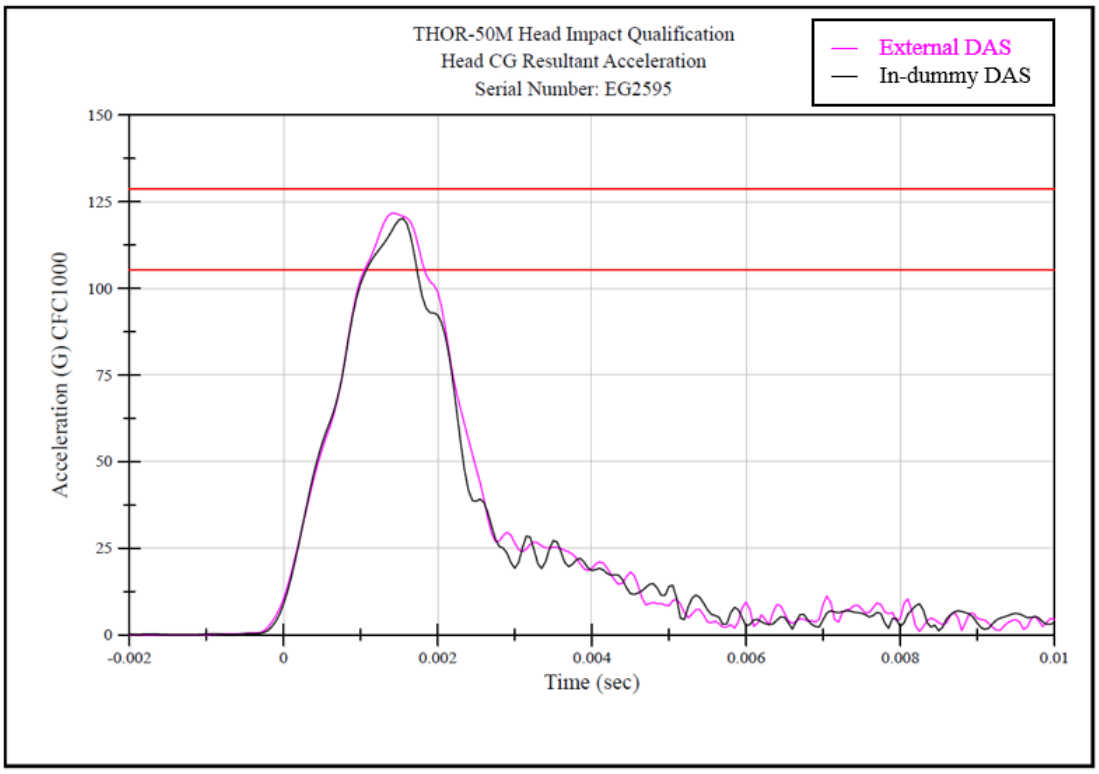


*Figure 2. Head impact: Head CG resultant acceleration for external and in-dummy DAS EG2595*

### *Discussion*

Table 2 shows the dummy passed the head qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

## Face

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the face impact qualification procedures described in the 2018 NHTSA qualifications manual. The face rigid disk qualification test examines facial impact response to loading by a rigid 152.7 mm diameter circular disk face of the 13.00 kg impactor at a velocity of 6.73 ± 0.05 m/s. During these tests the probe force and the head CG resultant acceleration were measured.

### *Qualification Results*

This section shows the results of the face impact qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 3 shows the test data, followed by plot overlays comparing the two dummy configurations. Both ATD configurations passed all qualification requirements.

*Table 3. Face Rigid Disk Impact Qualification Results for External and In-Dummy DAS ATD EG2595*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180424-11 | | 190312-7 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 6.68 | 6.78 | Pass | 6.77 | Pass | 6.68 |
| Peak Probe Force (N) | 6,378 | 7,796 | Pass | 7,191 | Pass | 7,544 |
| Peak Head CG Resultant Acceleration (G) | 124 | 152 | Pass | 145 | Pass | 145 |

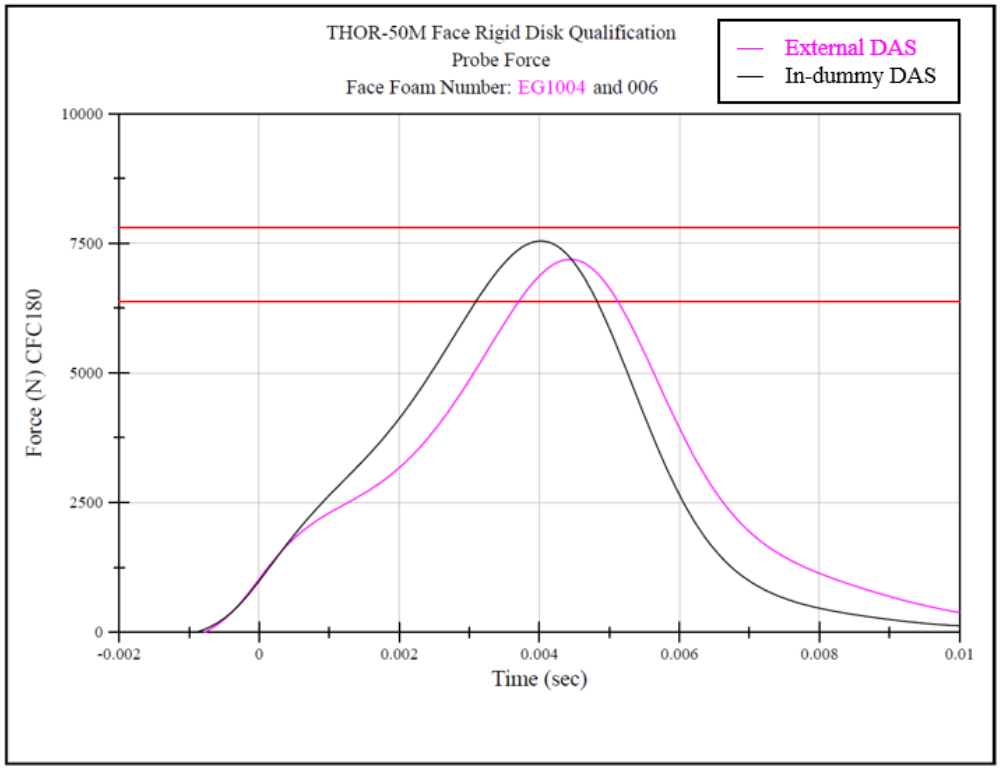


*Figure 3. Face rigid disk impact: Probe force for external and in-dummy DAS EG2595*

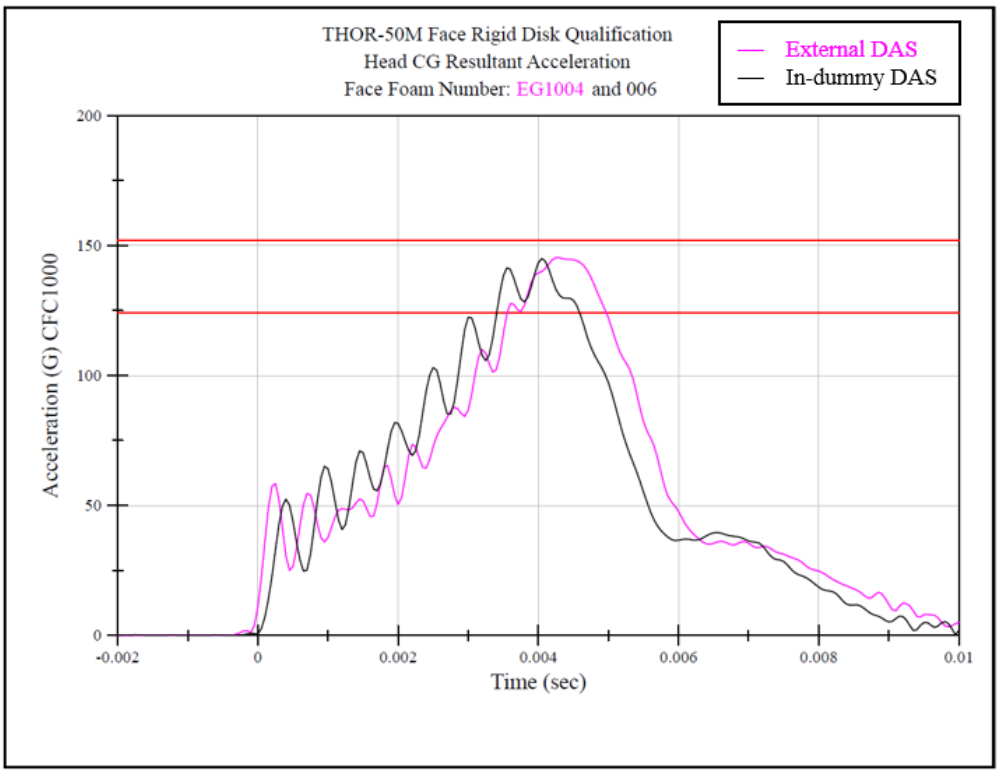


*Figure 4. Face rigid disk impact: Head CG resultant acceleration for external and in-dummy DAS EG2595*

### *Discussion*

Table 3 shows the dummy passed the face qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

It is worth noting that the face foam that was used in the external and in-dummy DAS tests was different (same part number but different serial numbers). Variations in the two face foams could have influenced the timing and/or magnitude of the results in these tests. Despite these variations, the two dummy configurations passed the face qualification testing. Both face foams were new and tested until they met the qualification requirements. The response of the face foam varies from one impact to another as indicated by the THOR-50M Repeatability and Reproducibility of Qualification Tests Report (NHTSA, 2021).

## Neck Frontal Flexion

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the neck frontal flexion qualification procedures described in the NHTSA 2018 manual. The frontal flexion tests resemble the Hybrid III head-neck pendulum test defined in CFR Title 49 Part 572 Subpart E with 152.4 mm (6 inch) aluminum honeycomb used to decelerate the pendulum from an impact velocity of 5.00 ± 0.05 m/s. During these tests the upper neck Y-axis moment (My), upper neck Z-axis force (Fz), Y-axis head angular rate ($\omega_y$), and Y-axis relative head rotation were measured. The neck serial number, EG1077, was used as an identifier instead of the dummy serial number, EG2595, because the neck frontal flexion test is a head/neck component test.

### *Qualification Results*

This section shows the results of the neck frontal flexion qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 4 and Table 5 show the test data, followed by plot overlays comparing the two dummy configurations. The external and in-dummy DAS ATDs passed all neck frontal flexion qualification requirements.

*Table 4. Neck Frontal Flexion Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180405-11 | | 180823-5 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 8 ms after T0 (m/s) | 1.57 | 1.92 | Pass | 1.68 | Pass | 1.67 |
| Pendulum velocity at 16 ms after T0 (m/s) | 3.13 | 3.82 | Pass | 3.30 | Pass | 3.26 |
| Pendulum velocity at 24 ms after T0 (m/s) | 4.42 | 5.41 | Pass | 4.63 | Pass | 4.49 |

*Table 5. Neck Frontal Flexion Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180405-11 | | 180823-5 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 1.57 | 1.92 | Pass | 1.68 | Pass | 1.67 |
| Peak Upper Neck My (Nm) | 3.13 | 3.82 | Pass | 3.30 | Pass | 3.26 |
| Peak Upper Neck Fz most positive value Prior to 40 ms (N) | 4.42 | 5.41 | Pass | 4.63 | Pass | 4.49 |
| Peak Head Angular Rate ωy relative to earth (deg/s) | -2,172 | -1,777 | Pass | -1,908 | Pass | -1,824 |
| Peak Head Rotation relative to pendulum (deg) | -71.0 | -58.1 | Pass | -64.8 | Pass | -64 |

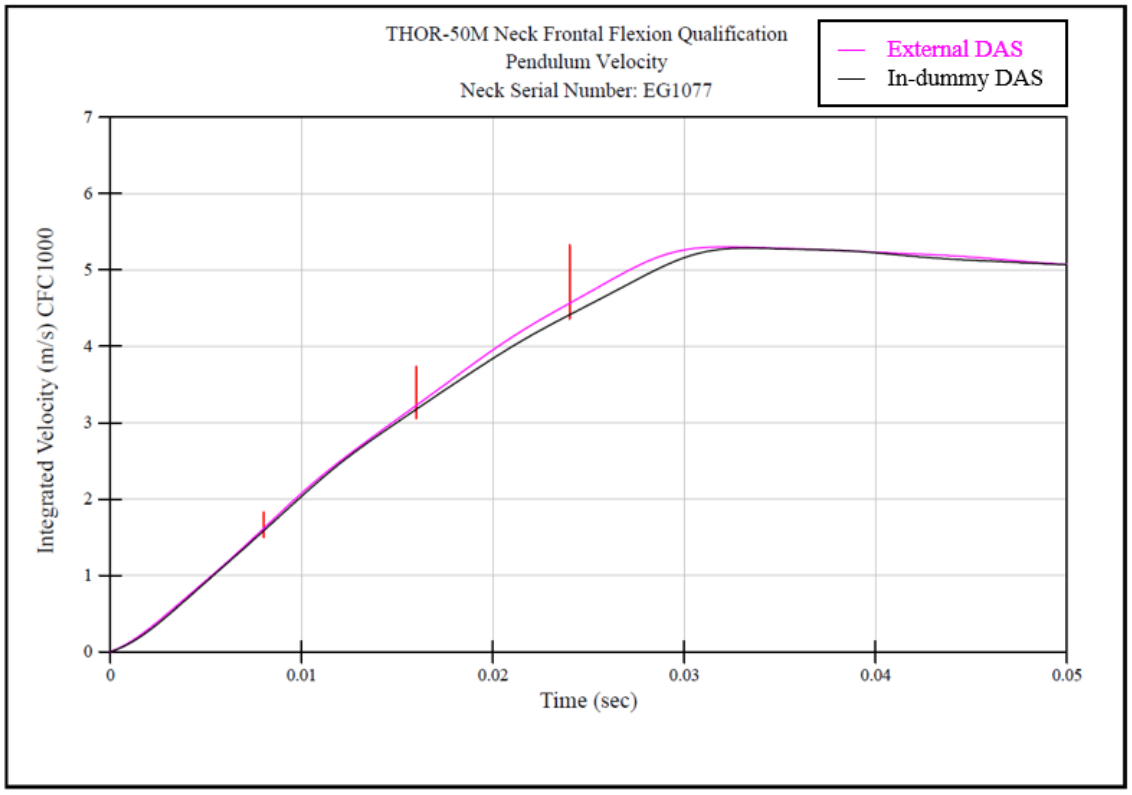


*Figure 5. Neck frontal flexion: Pendulum velocity for external and in-dummy DAS neck EG1077*

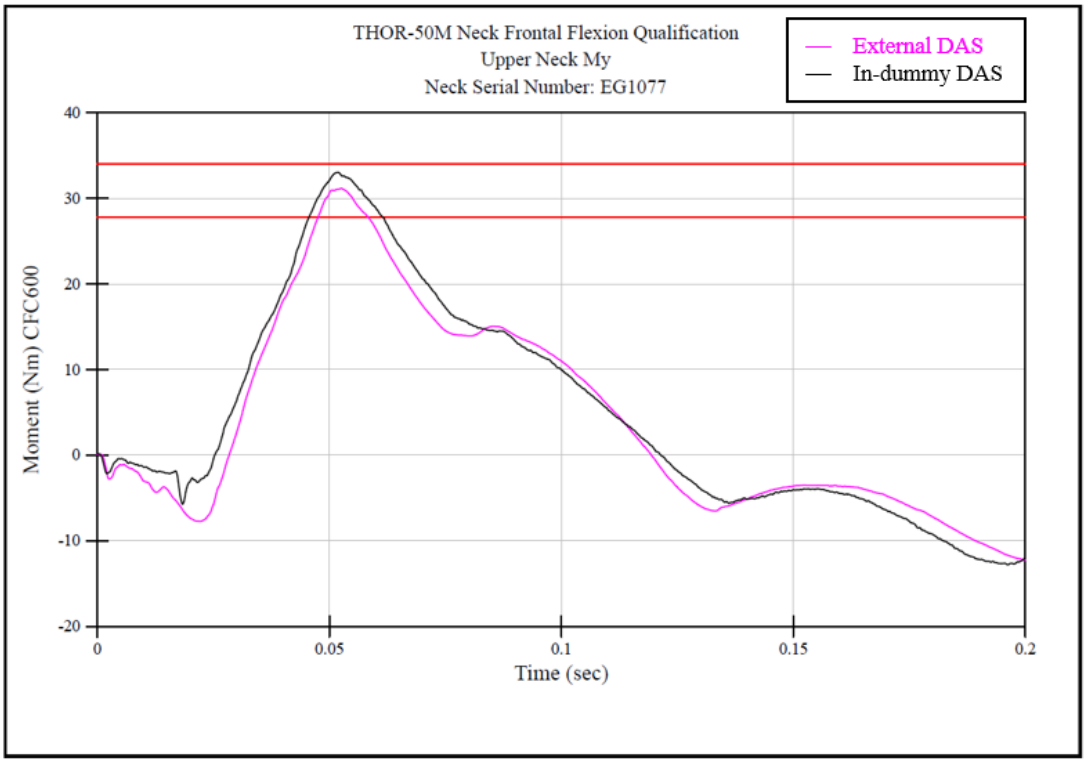


*Figure 6. Neck frontal flexion: Upper neck My for external and in-dummy DAS neck EG1077*

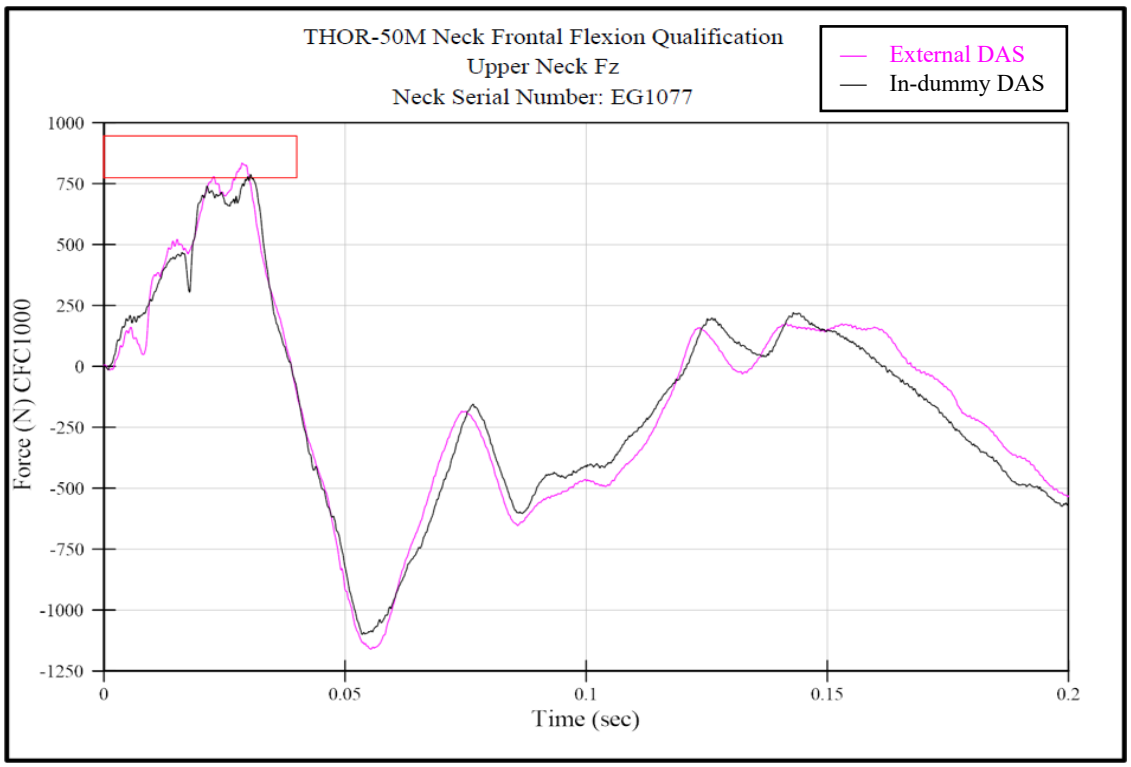


*Figure 7. Neck frontal flexion: Upper neck Fz for external and in-dummy DAS neck EG1077*

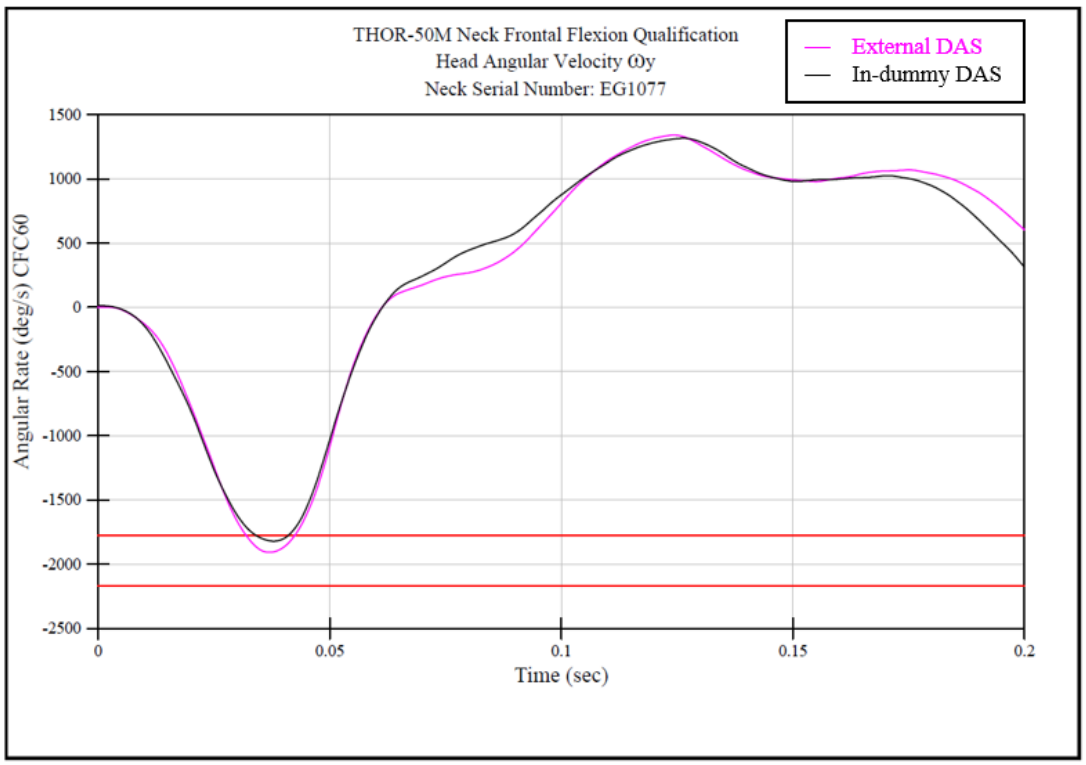


*Figure 8. Neck frontal flexion: Head angular velocity ωy for external and in-dummy DAS neck EG1077*

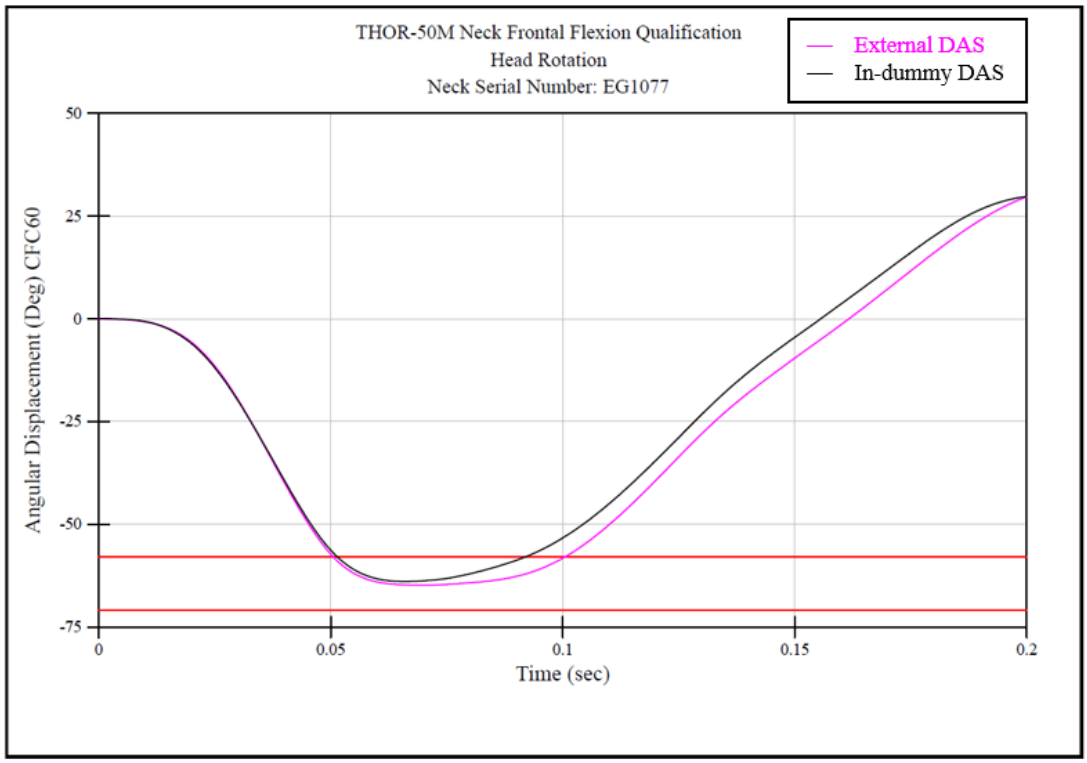


*Figure 9. Neck frontal flexion: Head rotation for external and in-dummy DAS neck EG1077*

### *Discussion*

The overall response of the neck in both configurations was in the neck frontal flexion qualification specifications (Table 4 and Table 5). Therefore, the integration does not appear to have caused undesirable effects on the response of this neck flexion qualification test.

## Neck Extension

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the neck extension qualification procedures described in the 2018 NHTSA qualifications manual. The extension tests resemble the Hybrid III head-neck pendulum test defined in 49 CFR Part 572 Subpart E with 152.4 mm (6 inch) aluminum honeycomb used to decelerate the pendulum with an impact velocity of 5.00 ± 0.05 m/s. During these tests the upper neck Y-axis moment (My), upper neck Z-axis force (Fz), Y-axis head angular rate ($\omega_y$), and Y-axis relative head rotation were measured. The neck serial number, EG1077, was used as an identifier instead of the dummy serial number, EG2595, because the neck extension test is a head/neck component test.

### *Qualification Results*

This section shows the results of the neck extension qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 6 and Table 7 show the test data, followed by plot overlays comparing the two dummy configurations. The external and in-dummy DAS ATD passed all neck extension qualification requirements.

*Table 6. Neck Extension Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180405-9 | | 180823-11 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 10 ms after T0 (m/s) | 1.74 | 2.12 | Pass | 1.99 | Pass | 1.78 |
| Pendulum velocity at 20 ms after T0 (m/s) | 3.30 | 4.04 | Pass | 3.77 | Pass | 3.41 |
| Pendulum velocity at 30 ms after T0 (m/s) | 4.53 | 5.54 | Pass | 5 | Pass | 4.69 |

*Table 7. Neck Extension Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS 180405-11 | | In-Dummy DAS 180823-5 | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.95 | 5.05 | Pass | 5 | Pass | 5 |
| Peak Upper Neck My (Nm) | -25.3 | -20.7 | Pass | -22.5 | Pass | -22.9 |
| Peak Upper Neck Fz (N) | -3210 | -2626 | Pass | -2888 | Pass | -2650 |
| Peak Head Angular Velocity ωy (deg/s) | 1850 | 2261 | Pass | 2028 | Pass | 1899 |
| Peak Head Rotation (deg) | 58.5 | 71.5 | Pass | 60.7 | Pass | 60.6 |

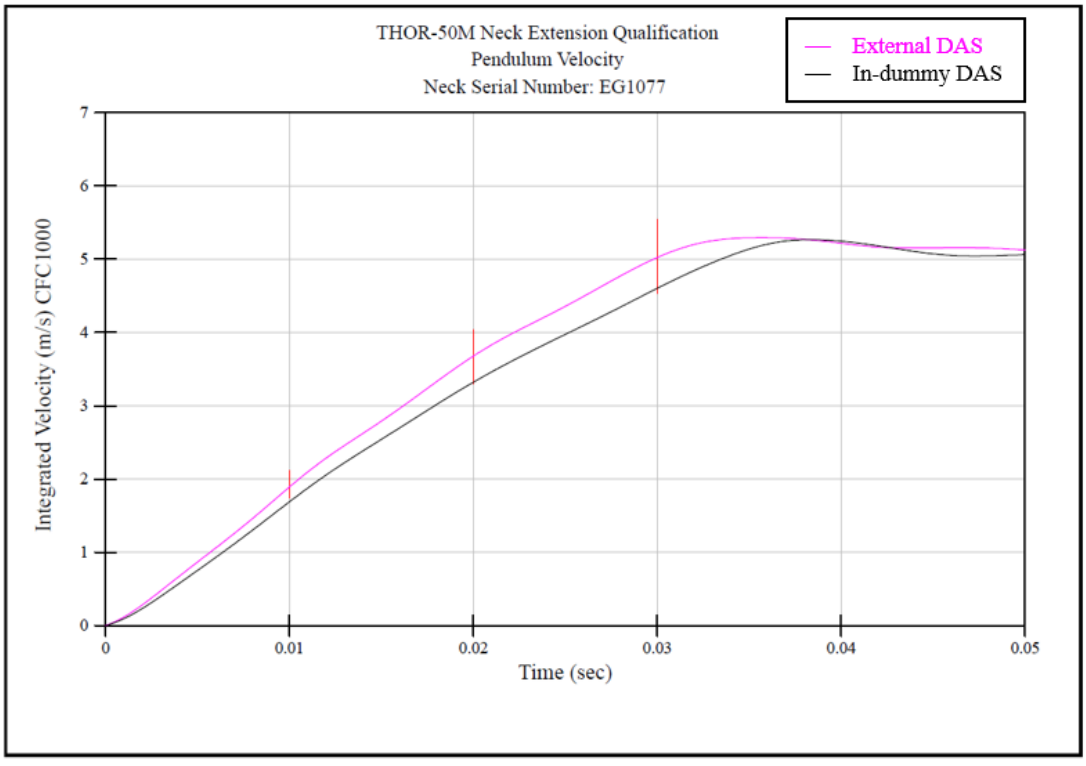


*Figure 10. Neck extension: Pendulum velocity for external and in-dummy DAS neck EG1077*

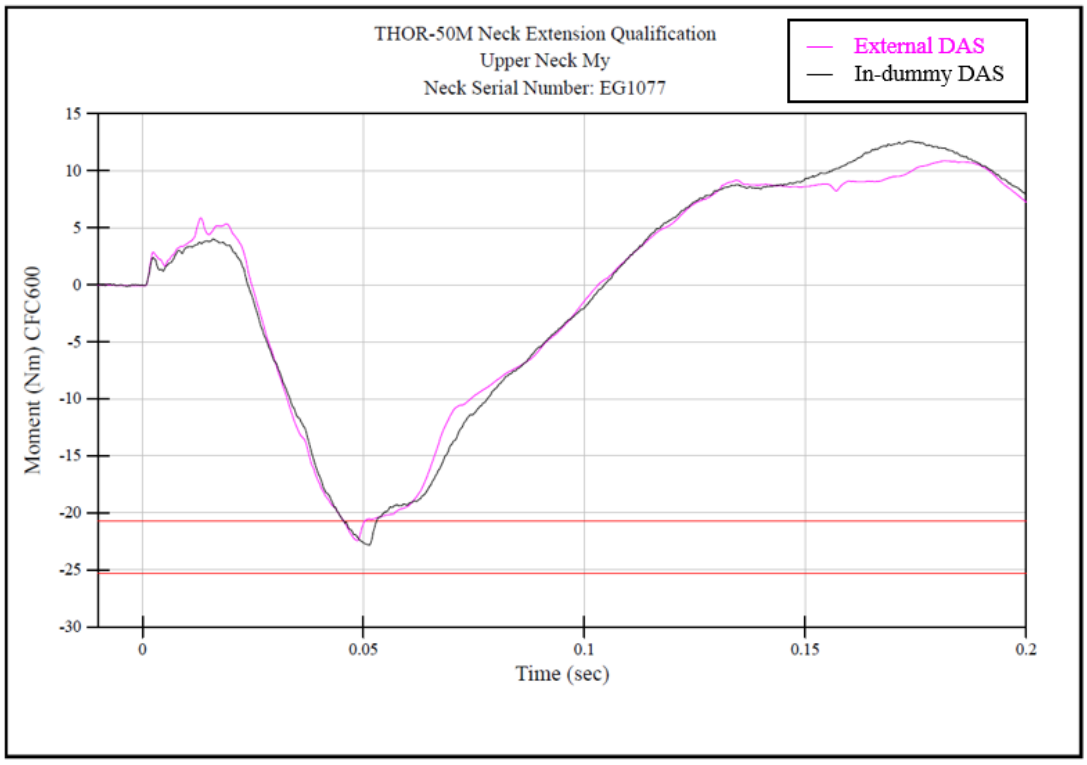


*Figure 11. Neck extension: Upper neck My for external and in-dummy DAS neck EG1077*

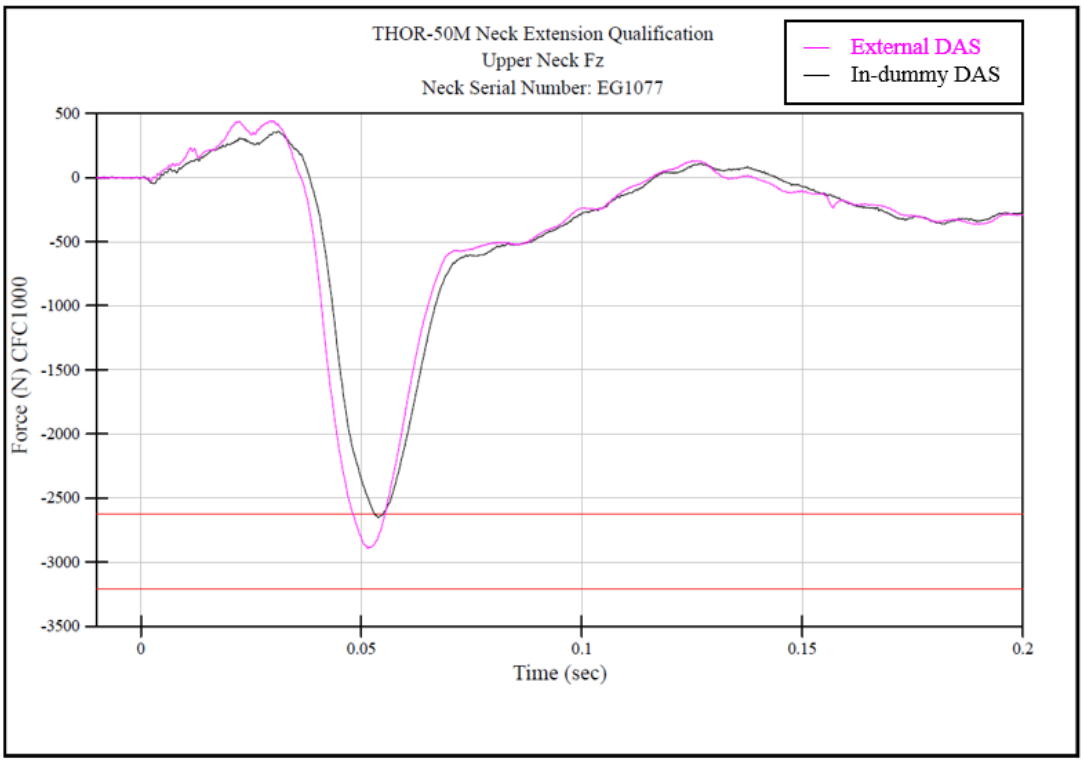


*Figure 12. Neck extension: Upper neck Fz for external and in-dummy DAS neck EG1077*

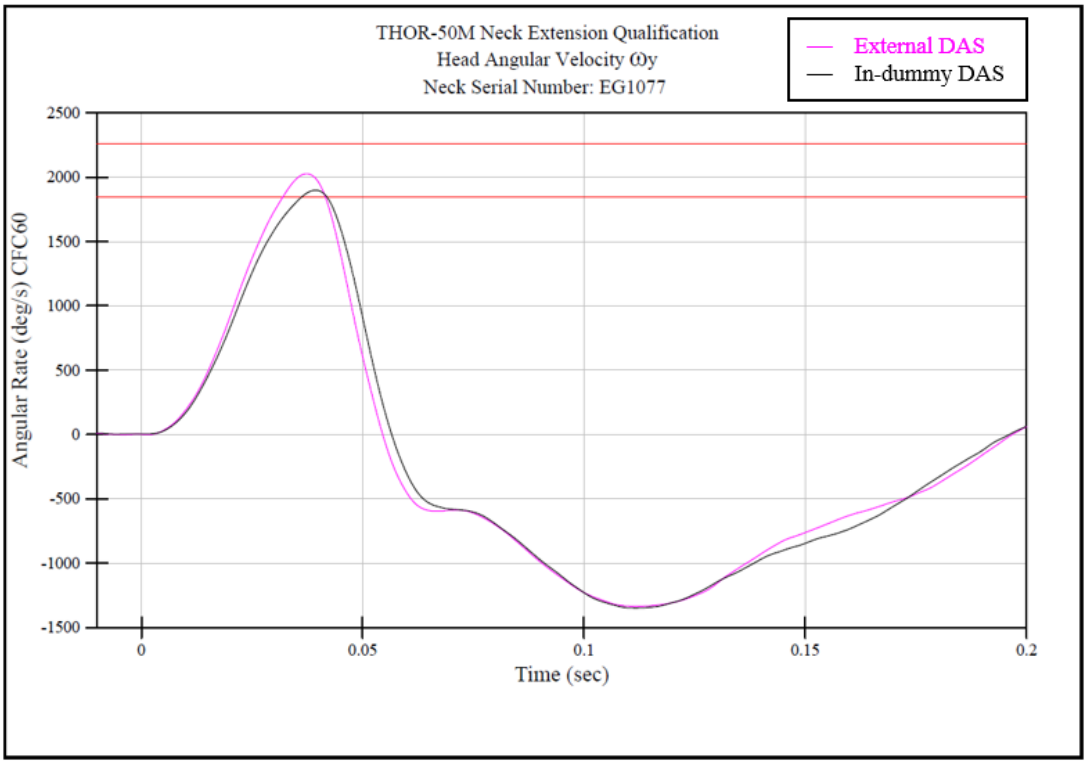


*Figure 13. Neck extension: Head angular velocity ωy for external and in-dummy DAS neck EG1077*

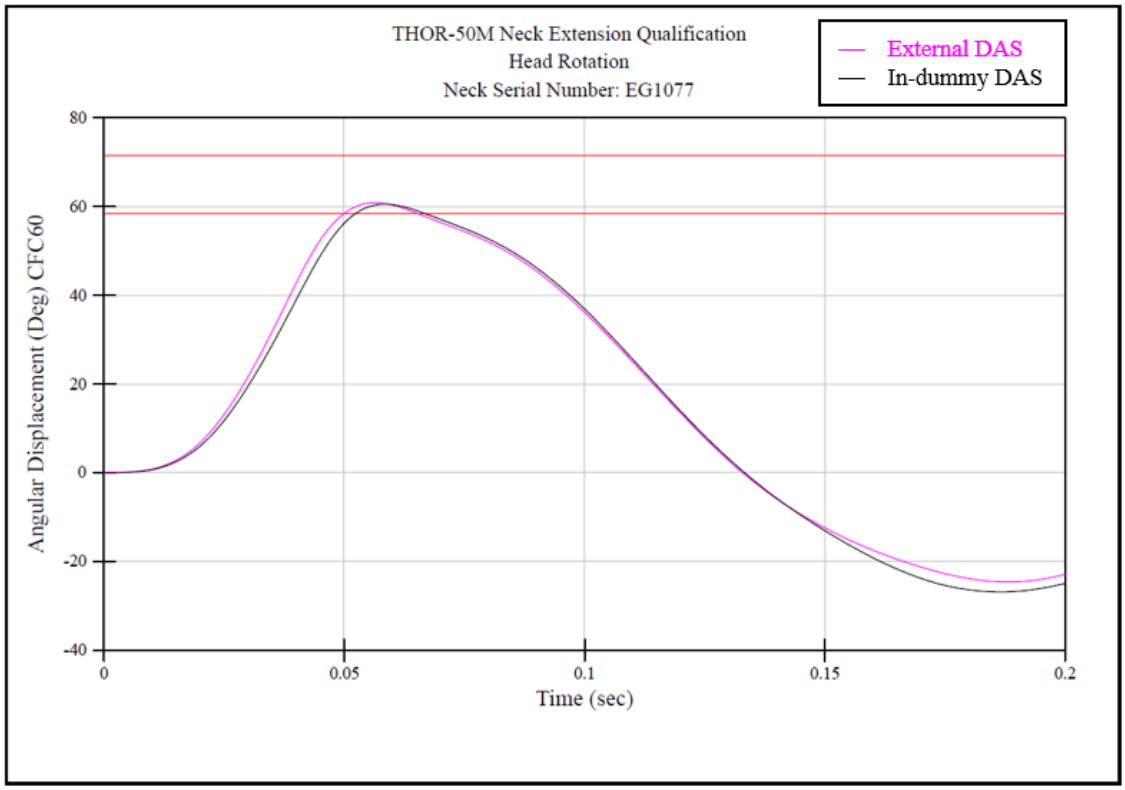


*Figure 14. Neck extension: Head rotation for external and in-dummy DAS neck EG1077*

### *Discussion*

The overall response of the neck in both configurations was in the neck extension qualification specifications (Table 6 and Table 7). Therefore, the integration does not appear to have caused undesirable effects on the response of this neck extension qualification test. The pulse for the in-dummy DAS ATD was at the lower end of the specification. This could explain the lower $\omega_y$ and upper neck Fz peaks compared to the external DAS ATD results.

## Neck Lateral Flexion

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the neck lateral flexion qualification procedures described in the 2018 NHTSA qualifications manual. The neck qualification in the lateral mode resembles the ES-2re head-neck lateral pendulum test defined in 49 CFR Part 572 Subpart U using 76.2 mm (3 inch) aluminum honeycomb for pendulum deceleration from an impact velocity of 3.40 ± 0.05 m/s. During these tests the upper neck X-axis moment (Mx), head X-axis angular rate ($\omega_x$), and X-axis relative head rotation were measured. The neck serial number, EG1077, was used as an identifier instead of the dummy serial number, EG2595, because the neck lateral flexion test is a head/neck component test.

### *Qualification Results*

This section gives the results of the neck lateral flexion qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 8 to Table 11 provide the test data, followed by plot overlays comparing the two dummy configurations. The neck was tested in left and right lateral flexion.

While the external DAS ATD passed all the neck lateral flexion qualification requirements, the in-dummy DAS ATD did not meet the pendulum velocity requirements at 8 ms.

*Table 8. Left Neck Lateral Flexion Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-1 | | 180823-13 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 4 ms after T0 (m/s) | 1.06 | 1.30 | Pass | 1.09 | Pass | 1.08 |
| Pendulum velocity at 8 ms after T0 (m/s) | 2.09 | 2.55 | Pass | 2.11 | Fail | 2.08 |
| Pendulum velocity at 12 ms after T0 (m/s) | 3.16 | 3.86 | Pass | 3.22 | Pass | 3.20 |

*Table 9. Left Neck Lateral Flexion Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-1 | | 180823-13 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 3.35 | 3.45 | Pass | 3.39 | Pass | 3.41 |
| Upper Neck Mx most positive value after 40ms (Nm) | 44.8 | 54.7 | Pass | 48.6 | Pass | 47.7 |
| First Peak Head Angular Velocity ωx (deg/s) | -1,498 | -1,226 | Pass | -1,327 | Pass | -1,300 |
| Peak Head Rotation (deg) | -45.9 | -37.6 | Pass | -40.3 | Pass | -38.8 |

*Table 10. Right Neck Lateral Flexion Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-2 | | 180827-1 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 4 ms after T0 (m/s) | 1.06 | 1.30 | Pass | 1.11 | Pass | 1.14 |
| Pendulum velocity at 8 ms after T0 (m/s) | 2.09 | 2.55 | Pass | 2.13 | Pass | 2.15 |
| Pendulum velocity at 12 ms after T0 (m/s) | 3.16 | 3.86 | Pass | 3.26 | Pass | 3.26 |

*Table 11. Right Neck Lateral Flexion Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-2 | | 180827-1 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 3.35 | 3.45 | Pass | 3.39 | Pass | 3.40 |
| Upper Neck Mx most positive value after 40ms (Nm) | -54.7 | -44.8 | Pass | -48.5 | Pass | -47.7 |
| First Peak Head Angular Velocity ωx (deg/s) | 1,226 | 1,498 | Pass | 1,362 | Pass | 1,291 |
| Peak Head Rotation (deg) | 37.6 | 45.9 | Pass | 41.9 | Pass | 38.8 |

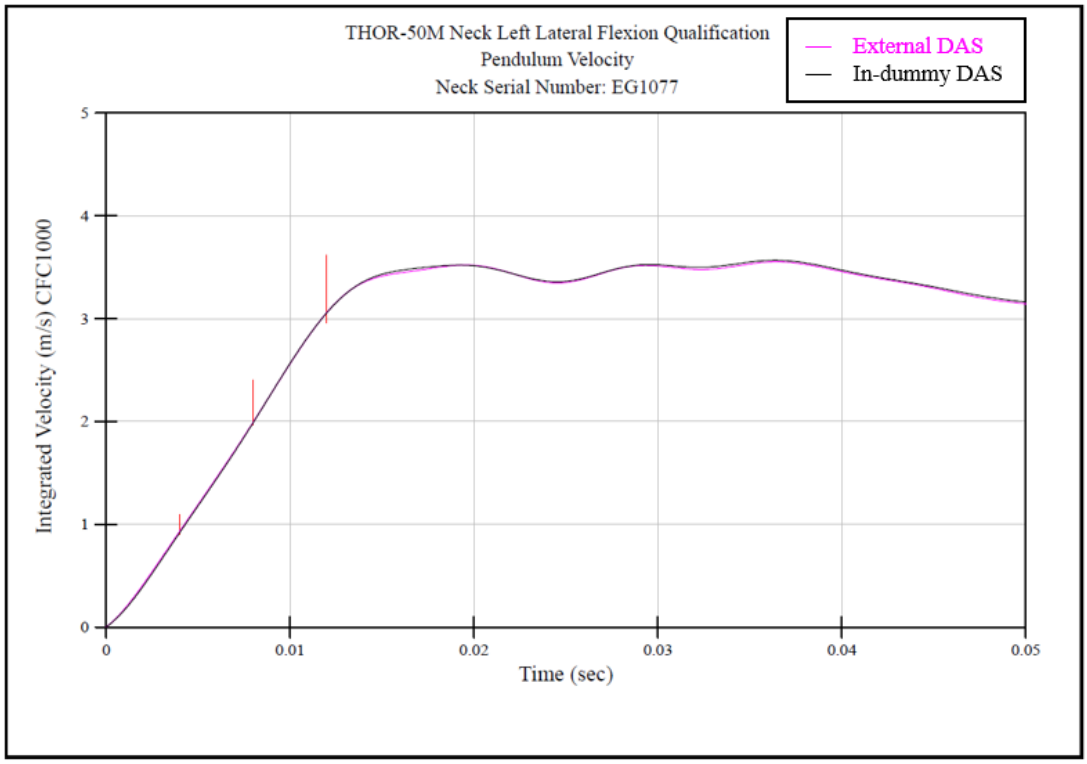


*Figure 15. Neck left lateral flexion: Pendulum velocity for external and in-dummy DAS neck EG1077*

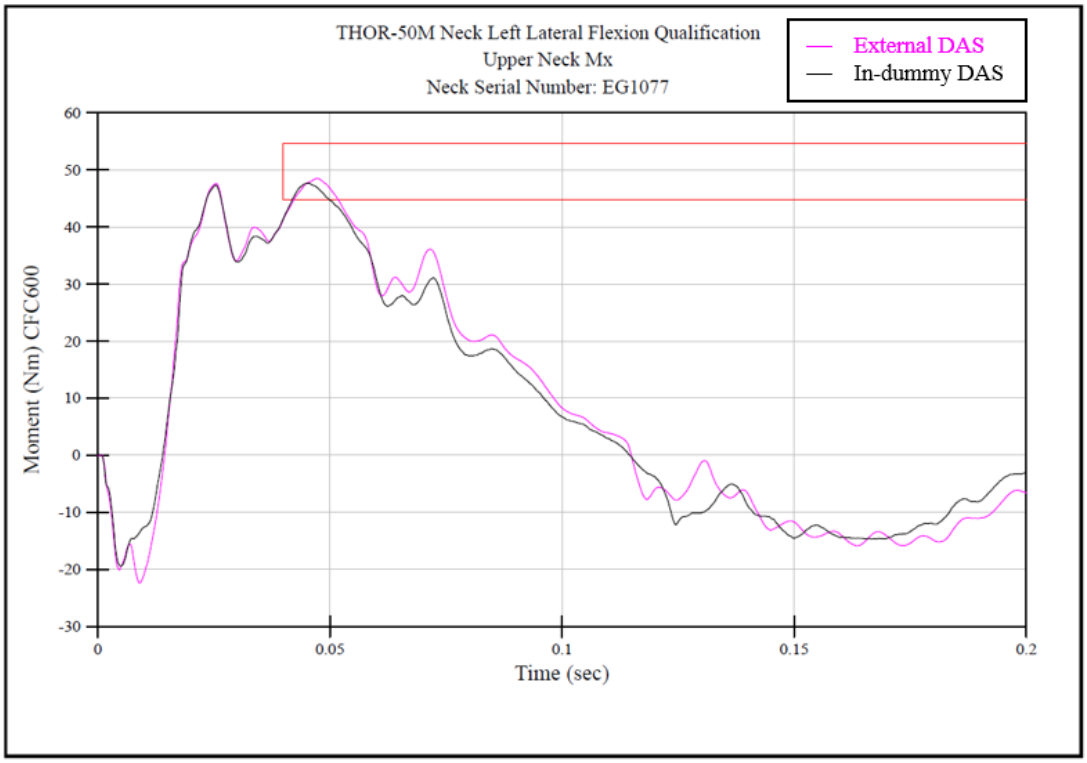


*Figure 16. Neck left lateral flexion: Upper neck Mx for external and in-dummy DAS neck EG1077*

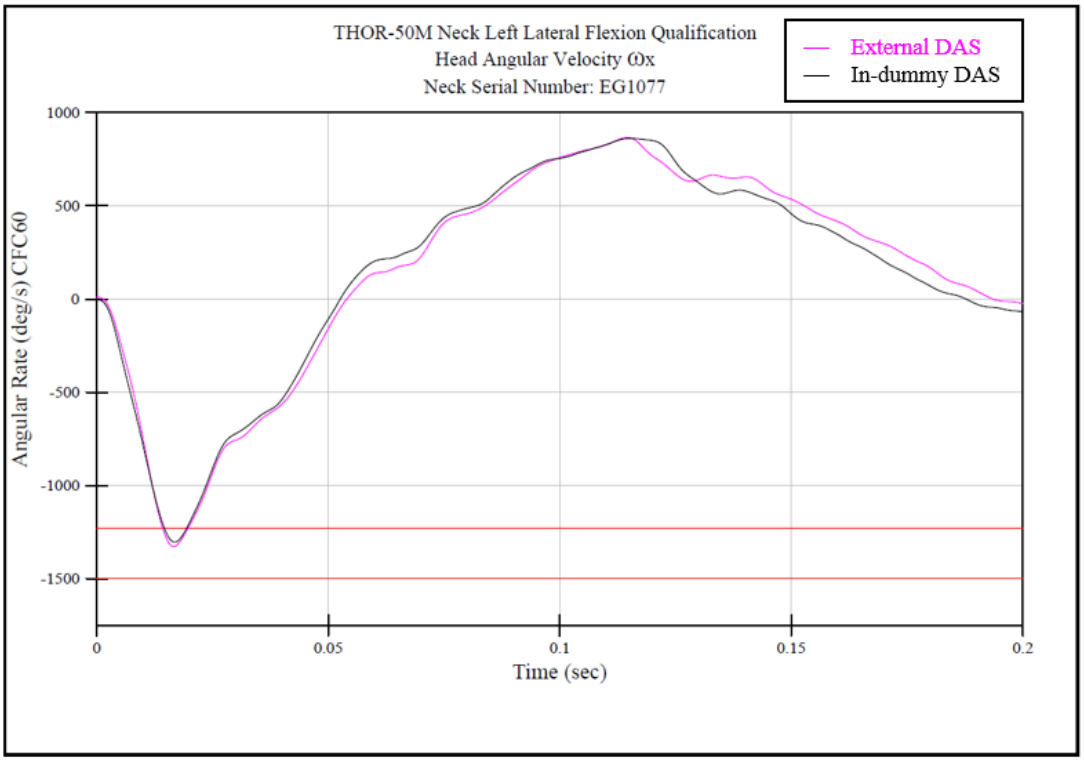


*Figure 17. Neck left lateral flexion: Head angular velocity ωx for external and in-dummy DAS neck EG1077*

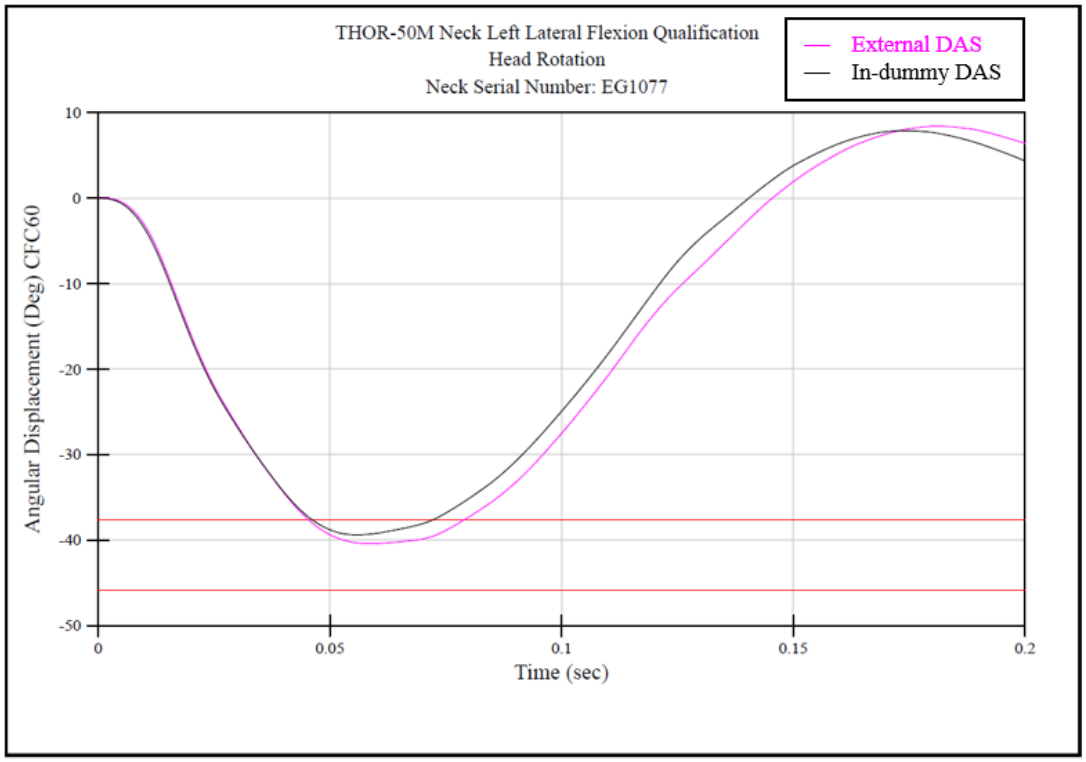


*Figure 18. Neck left lateral flexion: Head rotation for external and in-dummy DAS neck EG1077*

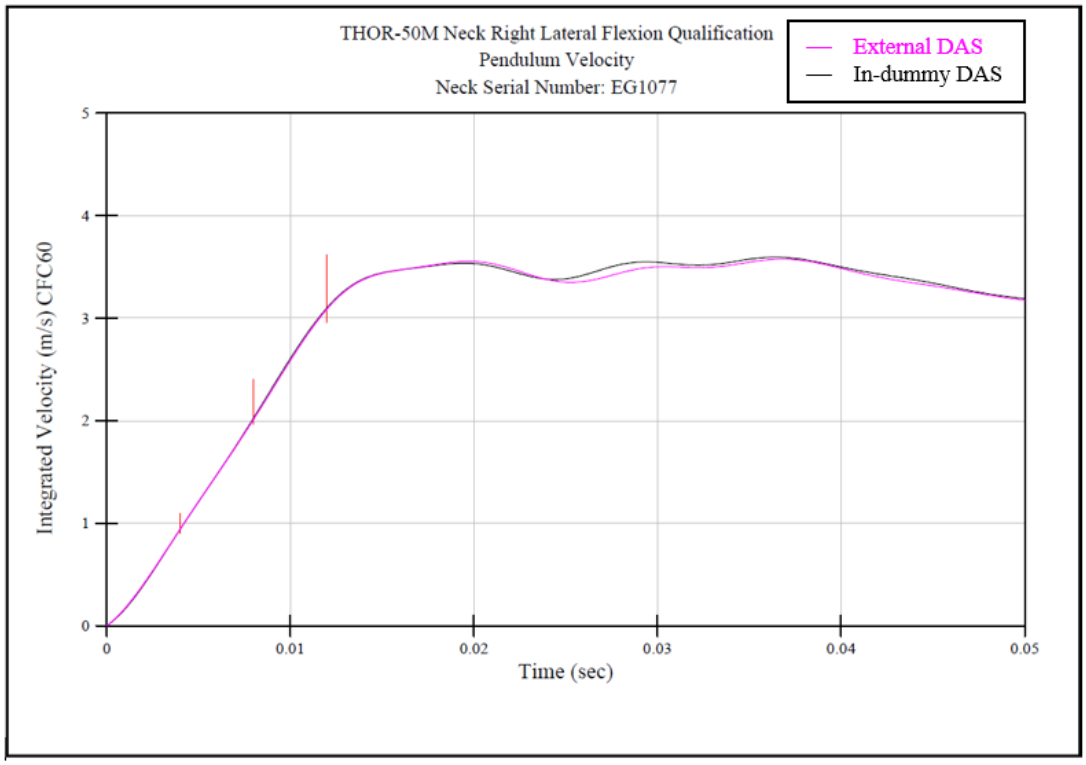


*Figure 19. Neck right lateral flexion: Pendulum velocity for external and in-dummy DAS neck EG1077*

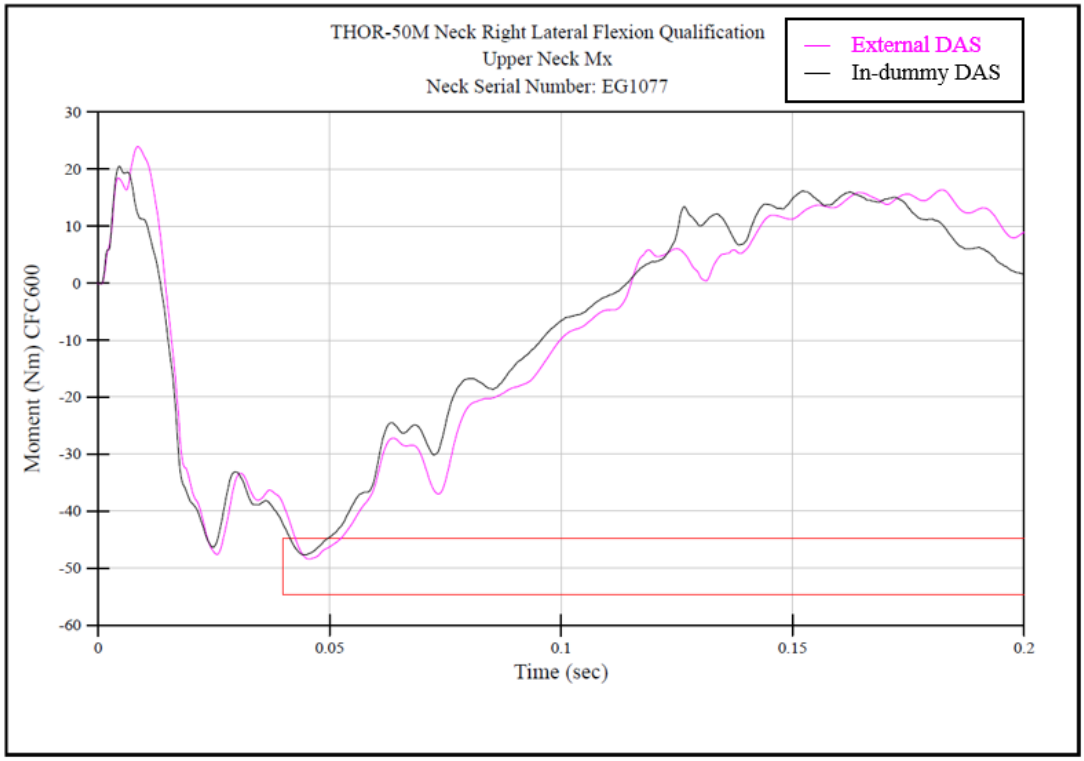


*Figure 20. Neck right lateral flexion: Upper neck Mx for external and in-dummy DAS neck EG1077*

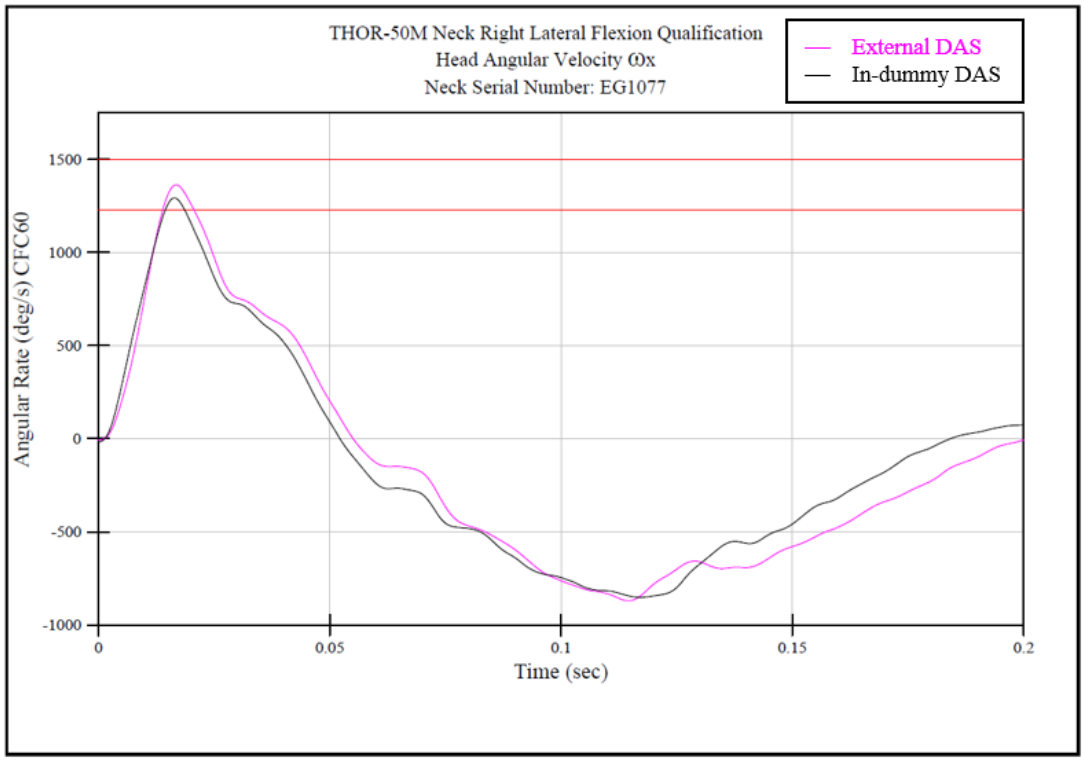


*Figure 21. Neck right lateral flexion: Head angular velocity ωx for external and in-dummy DAS neck EG1077*

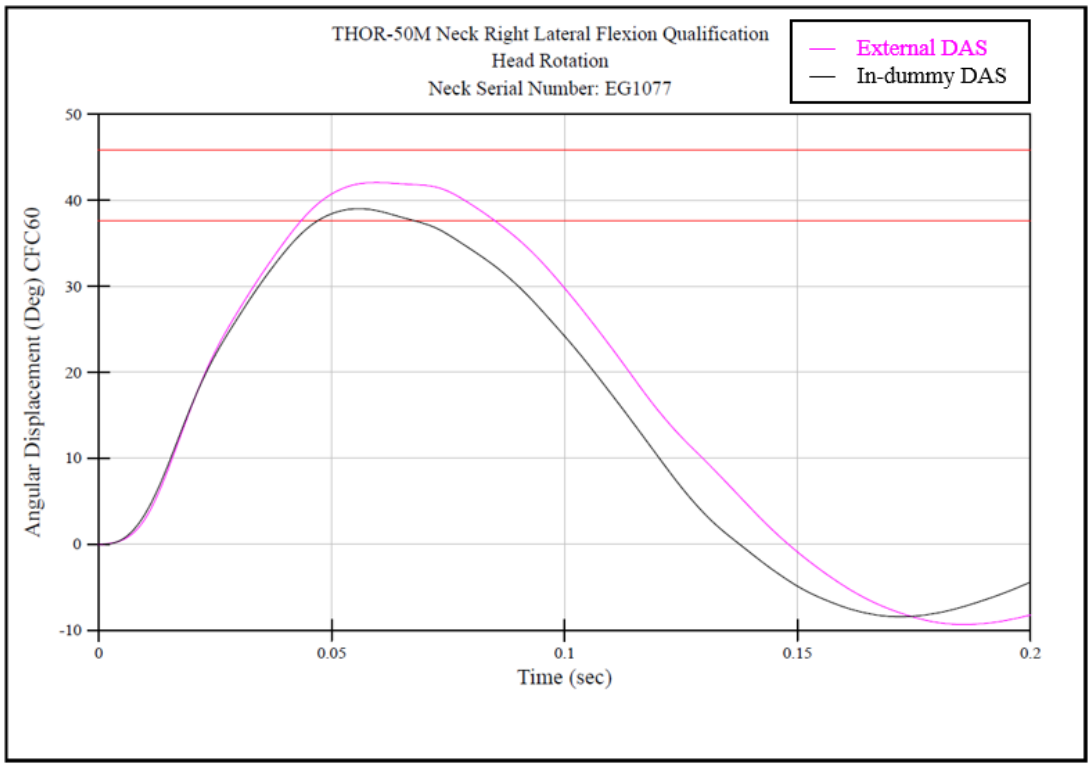


*Figure 22. Neck right lateral flexion: Head rotation for external and in-dummy DAS neck EG1077*

### *Discussion*

The external DAS ATD and in-dummy DAS ATD passed all neck lateral flexion qualification requirements (Table 8 to Table 11). The in-dummy DAS ATD did not meet the 2018 pendulum velocity requirements at 8 ms for the left lateral flexion test by 0.01 m/s. The pendulum velocity calculation method was updated after the in-dummy DAS testing resulting in the input pulse falling slightly outside the corridor. The integration does not appear to have caused undesirable effects on the response of this neck extension qualification test.

## Neck Torsion

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent qualification tests using the neck torsion qualification procedures described in the 2018 NHTSA qualifications manual. The neck qualification in the torsion mode uses 152.4 mm (6 inch) Hexcel aluminum honeycomb (or equivalent) for pendulum deceleration from an impact velocity of 5.00 ± 0.05 m/s. During these tests the upper neck Z-axis moment (Mz), Z-axis head angular rate ($\omega_z$), and Z-axis head rotation were measured. The neck serial number, EG1077, was used as an identifier instead of the dummy serial number, EG2595, because the neck lateral flexion test is a head/neck component test.

### *Qualification Results*

This section shows the results of the neck torsion qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 12 to Table 15 show the test data, followed by plot overlays comparing the two dummy configurations. The neck was tested in left and right torsion.

The external and in-dummy DAS ATD passed all neck torsion qualification requirements.

*Table 12. Left Neck Torsion Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-3 | | 180827-3 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 10 ms after T0 (m/s) | 1.71 | 2.09 | Pass | 1.78 | Pass | 1.86 |
| Pendulum velocity at 15 ms after T0 (m/s) | 2.57 | 3.14 | Pass | 2.66 | Pass | 2.82 |
| Pendulum velocity at 20 ms after T0 (m/s) | 3.46 | 4.23 | Pass | 3.60 | Pass | 3.80 |
| Pendulum velocity at 25 ms after T0 (m/s) | 4.27 | 5.22 | Pass | 4.39 | Pass | 4.72 |

*Table 13. Left Neck Torsion Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-3 | | 180827-3 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.95 | 5.05 | Pass | 5.04 | Pass | 5.01 |
| Peak Upper Neck Mz (Nm) | 37.3 | 45.6 | Pass | 41.4 | Pass | 43.1 |
| First Peak Upper Neck Angular Velocity ωz (relative to earth) (deg/s) | -1,529 | -1,251 | Pass | -1,307 | Pass | -1,364 |
| Peak Neck Fixture Rotation (deg) | -52.7 | -43.1 | Pass | -45.3 | Pass | -45.4 |

*Table 14. Right Neck Torsion Input Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-5 | | 180827-4 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Pendulum velocity at 10 ms after T0 (m/s) | 1.71 | 2.09 | Pass | 1.78 | Pass | 1.91 |
| Pendulum velocity at 15 ms after T0 (m/s) | 2.57 | 3.14 | Pass | 2.67 | Pass | 2.80 |
| Pendulum velocity at 20 ms after T0 (m/s) | 3.46 | 4.23 | Pass | 3.58 | Pass | 3.77 |
| Pendulum velocity at 25 ms after T0 (m/s) | 4.27 | 5.22 | Pass | 4.40 | Pass | 4.70 |

*Table 15. Right Neck Torsion Qualification Results for External and In-Dummy DAS Neck EG1077*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180409-5 | | 180827-4 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.95 | 5.05 | Pass | 5.04 | Pass | 5.01 |
| Peak Upper Neck Mz (Nm) | -45.6 | -37.3 | Pass | -40.0 | Pass | -43.5 |
| First Peak Upper Neck Angular Velocity ωz (relative to earth) (deg/s) | 1251 | 1529 | Pass | 1336 | Pass | 1344 |
| Peak Neck Fixture Rotation (deg) | 43.1 | 52.7 | Pass | 47.4 | Pass | 46.0 |

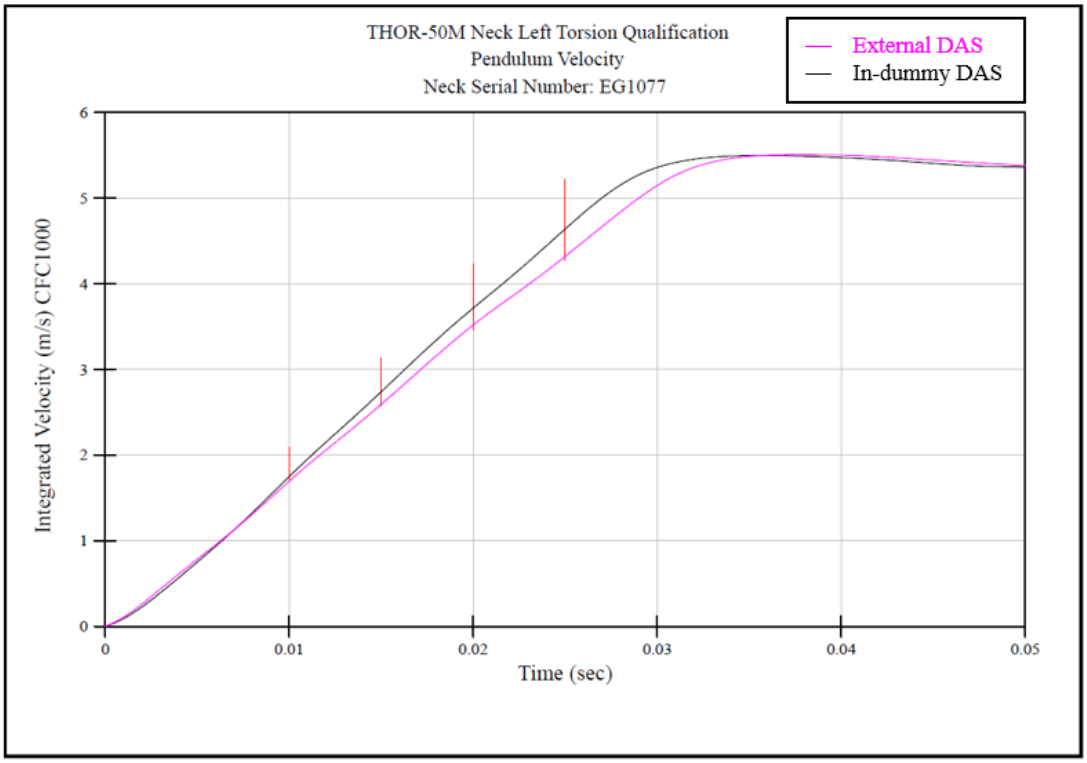


*Figure 23. Neck left torsion: Pendulum velocity for external and in-dummy DAS neck EG1077*

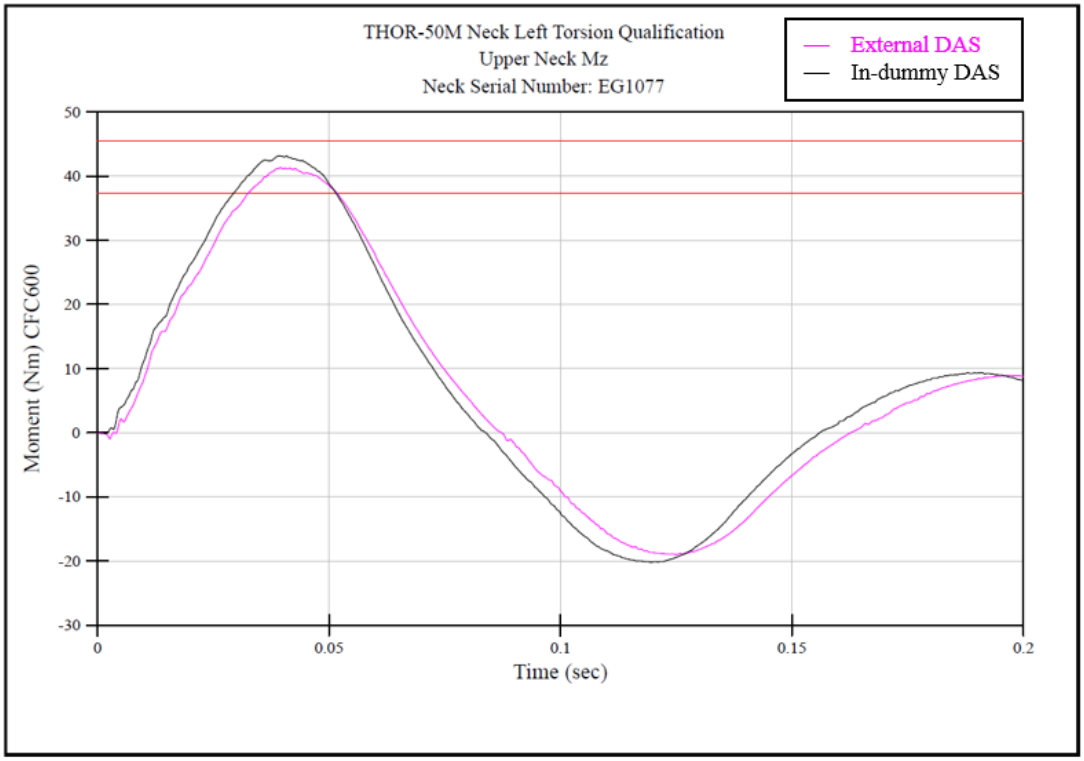


*Figure 24. Neck left torsion: Upper neck Mz for external and in-dummy DAS neck EG1077*

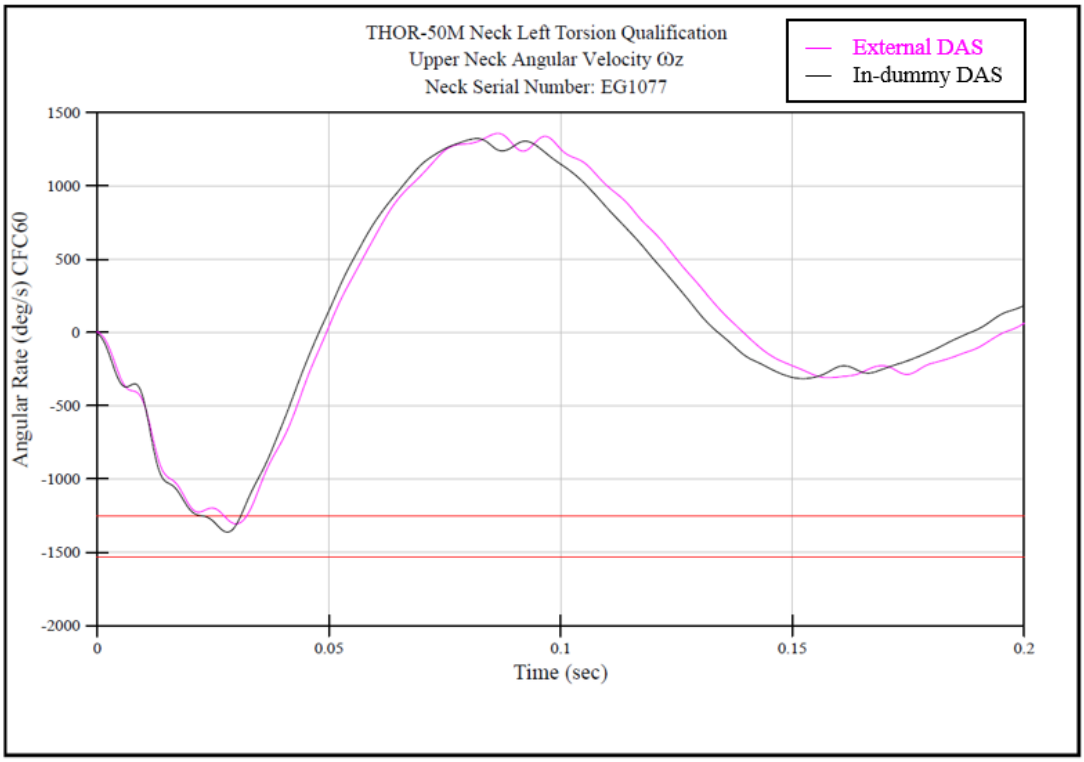


*Figure 25. Neck left torsion: Upper neck angular velocity ωz for external and in-dummy DAS neck EG1077*

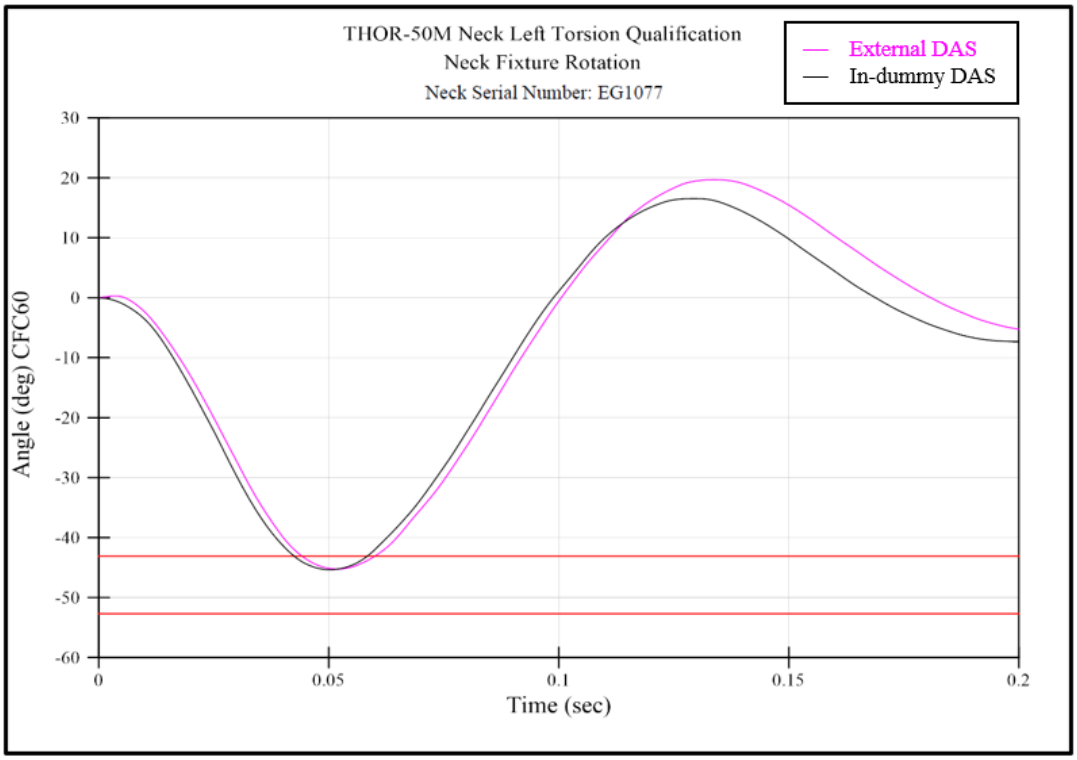


*Figure 26. Neck left torsion: Neck fixture rotation for external and in-dummy DAS neck EG1077*

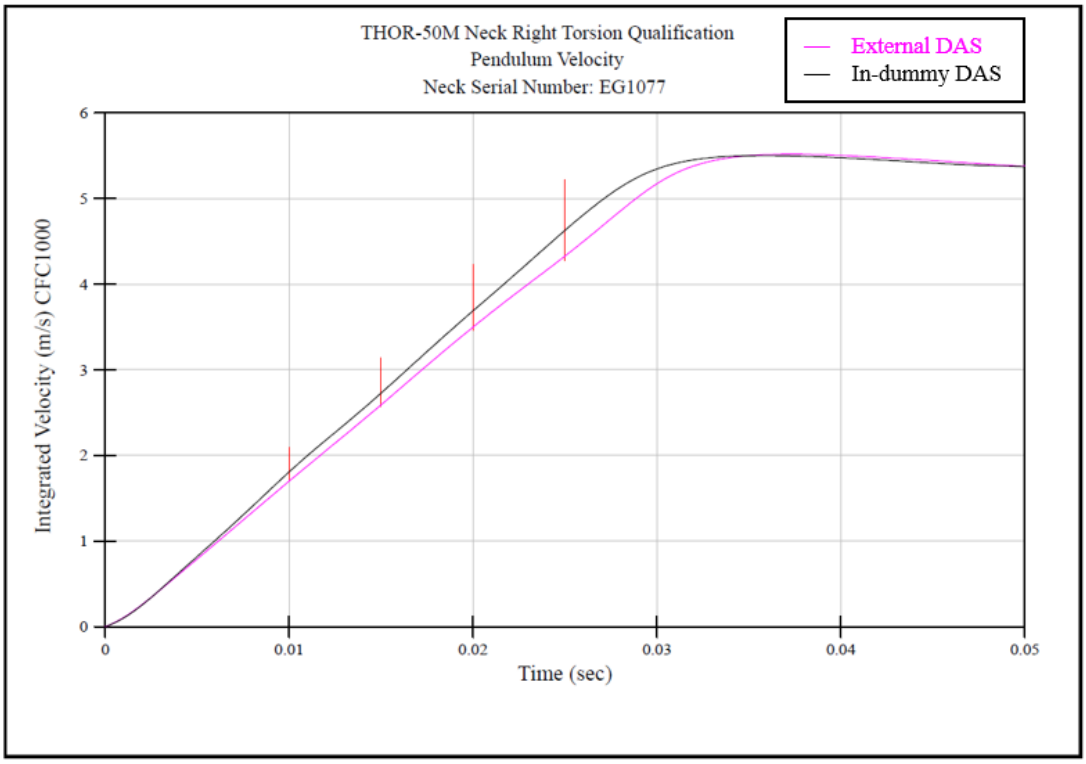


*Figure 27. Neck right torsion: Pendulum velocity for external and in-dummy DAS neck EG1077*

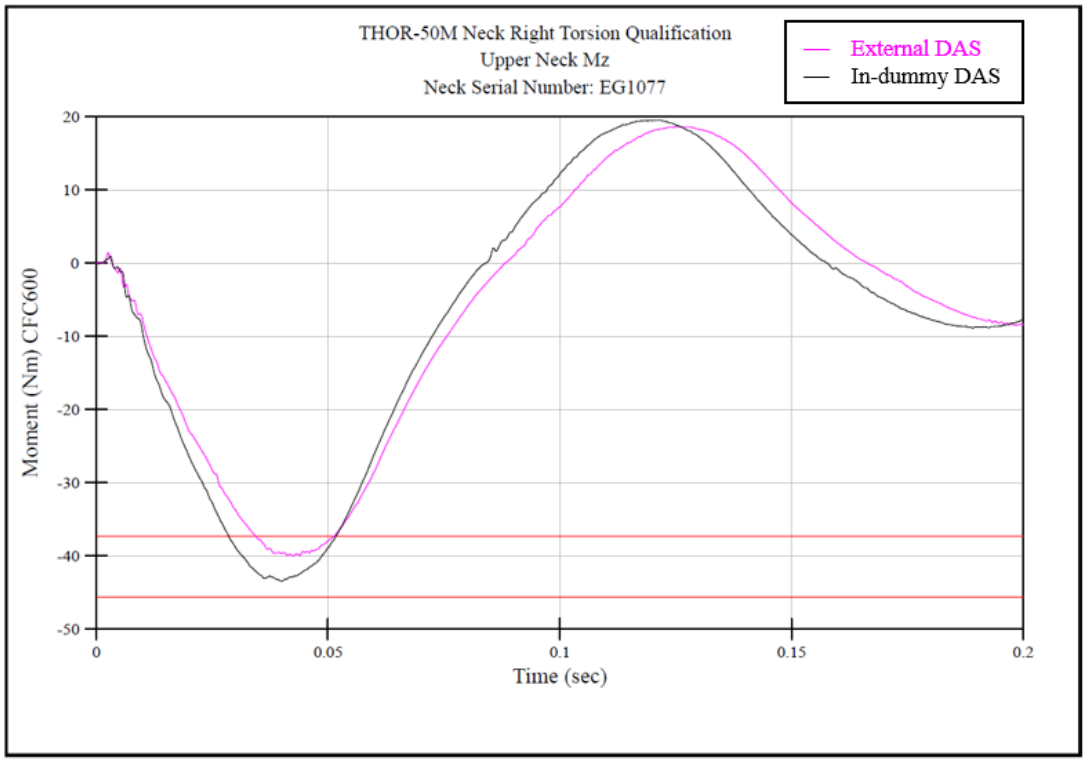


*Figure 28. Neck right torsion: Upper neck Mz for external and in-dummy DAS neck EG1077*

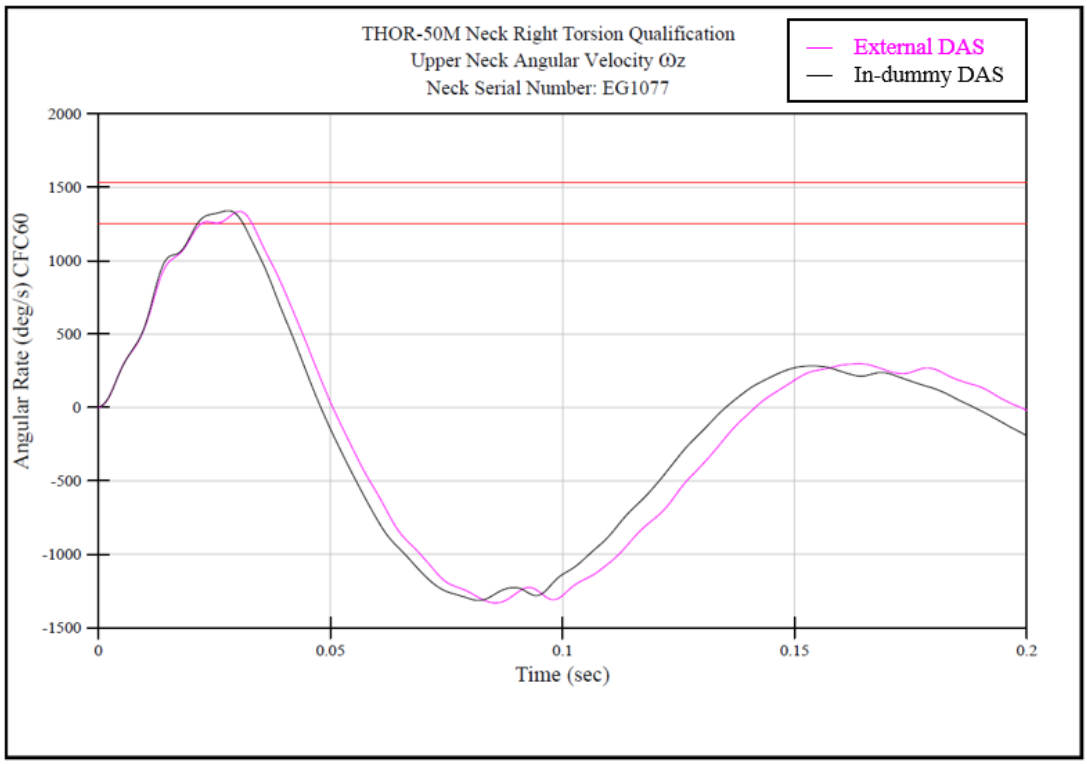


*Figure 29. Neck right torsion: Upper neck angular velocity ωz for external and in-dummy DAS neck EG1077*

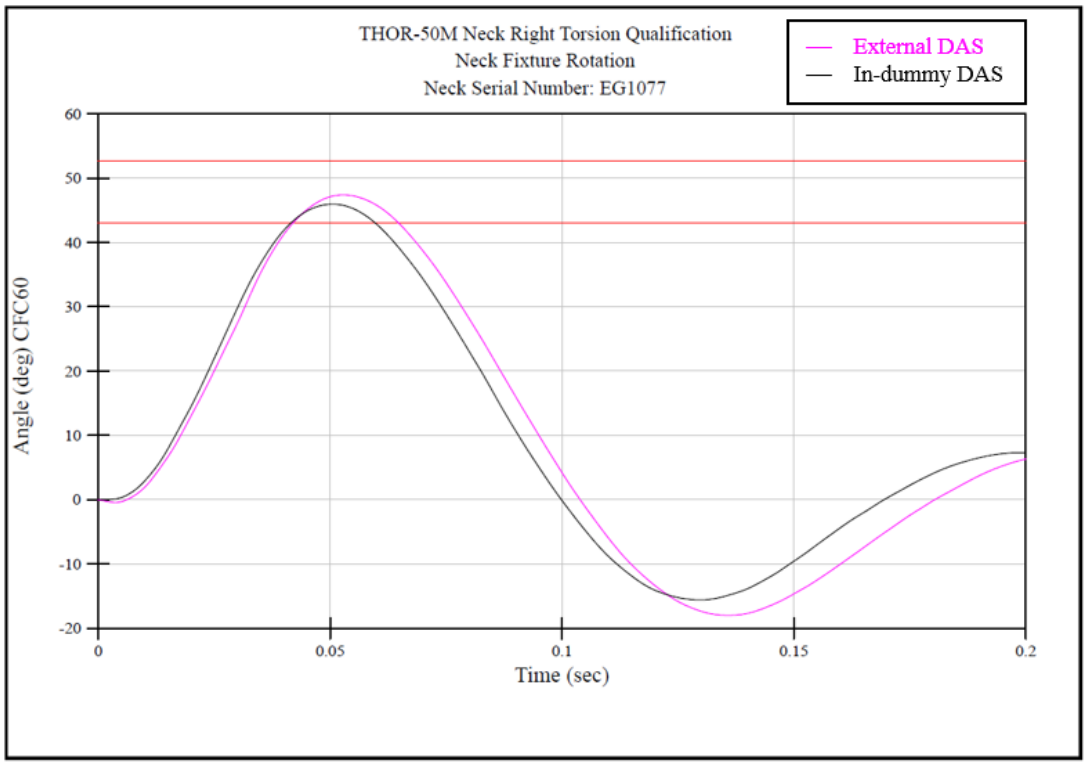


*Figure 30. Neck right torsion: Neck fixture rotation for external and in-dummy DAS neck EG1077*

### *Discussion*

The external DAS ATD and in-dummy DAS ATD passed all neck torsion qualification requirements (Table 14 and Table 15). The integration of internal DAS does not appear to have caused undesirable effects on the response of this qualification test.

## Upper Thorax

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent upper thorax qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test requires a blunt thoracic impact to the sternum, like the Hybrid III 50th percentile male qualification test, but at a lower speed of 4.30 ± 0.05 m/s. During these tests the resultant deflections of the left and right upper ribs and probe force at the time of maximum resultant deflection were measured.

### *Qualification Results*

This section shows the results of the upper thorax qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 16 shows the test data, followed by plot overlays comparing the two dummy configurations.

The external and in-dummy DAS ATDs passed all upper thorax qualification requirements.

*Table 16. Upper Thorax Qualification Results for External and In-Dummy DAS EG2595*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180524-3 | | 190404-6 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.25 | 4.35 | Pass | 4.31 | Pass | 4.27 |
| Peak Probe Force (N) | | < 3039 | Pass | 2858 | Pass | 2960 |
| Peak Upper Left Resultant Deflection (mm) | 48.3 | 59 | Pass | 55 | Pass | 54.3 |
| Peak Upper Right Resultant Deflection (mm) | 48.3 | 59 | Pass | 54.6 | Pass | 53.7 |
| Difference Between Peak Left & Right Resultant Deflections (mm) | | < 5 | Pass | 0.43 | Pass | 0.61 |
| Force at Left Peak Resultant Deflection (N) | 2409 | 2944 | Pass | 2836 | Pass | 2936 |
| Force at Right Peak Resultant Deflection (N) | 2409 | 2944 | Pass | 2802 | Pass | 2816 |

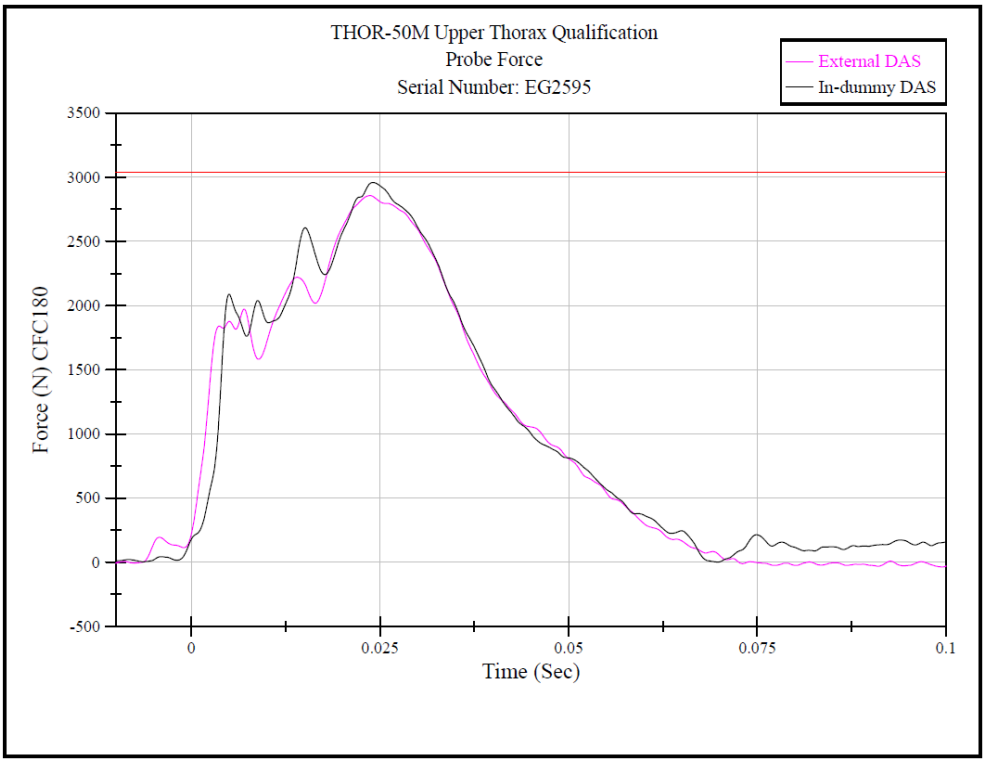


*Figure 31. Upper thorax impact: Probe force for external and in-dummy DAS EG2595*

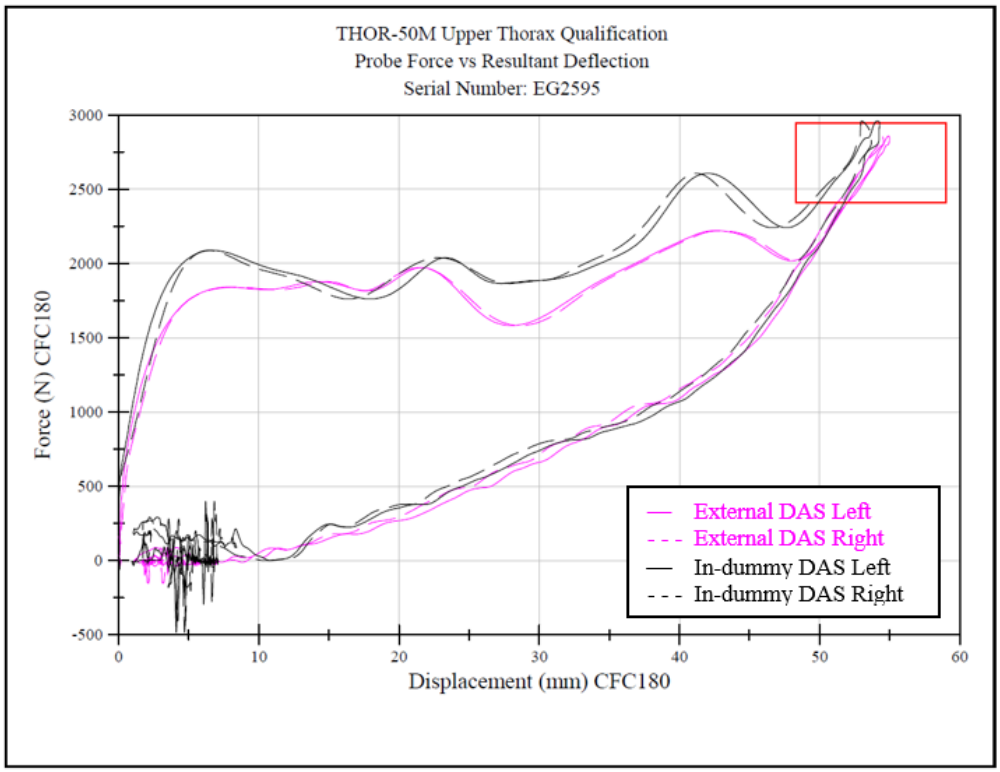


*Figure 32. Upper thorax impact: Probe force vs resultant deflection for external and in-dummy DAS EG2595*

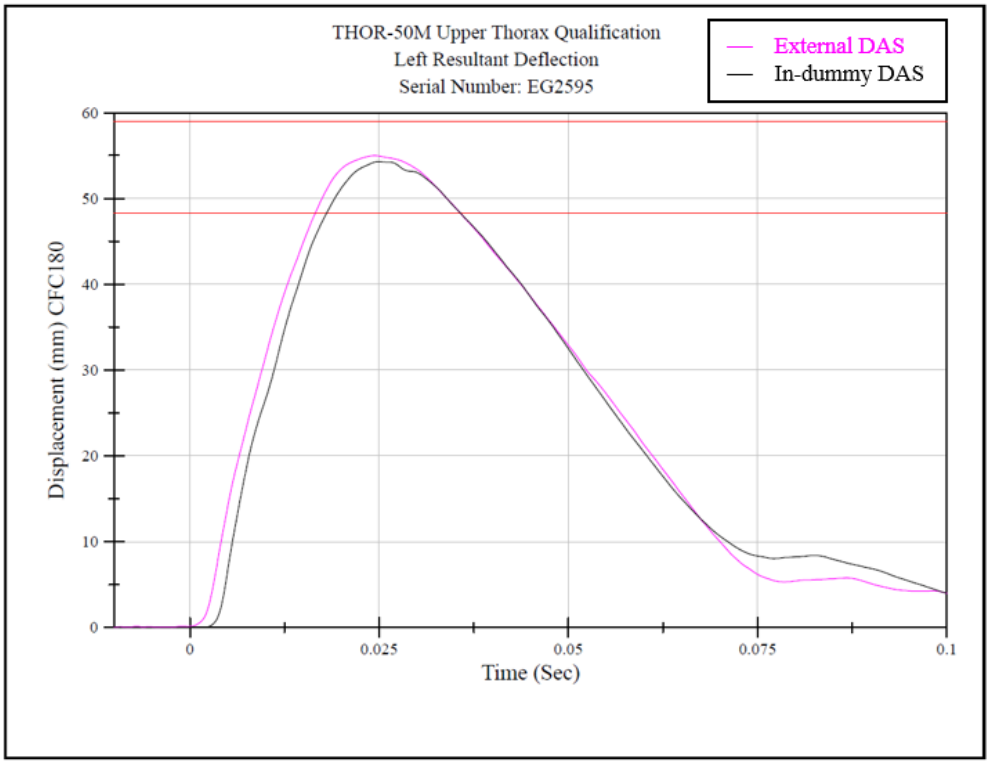


*Figure 33. Upper thorax impact: Left resultant deflection for external and in-dummy DAS EG2595*

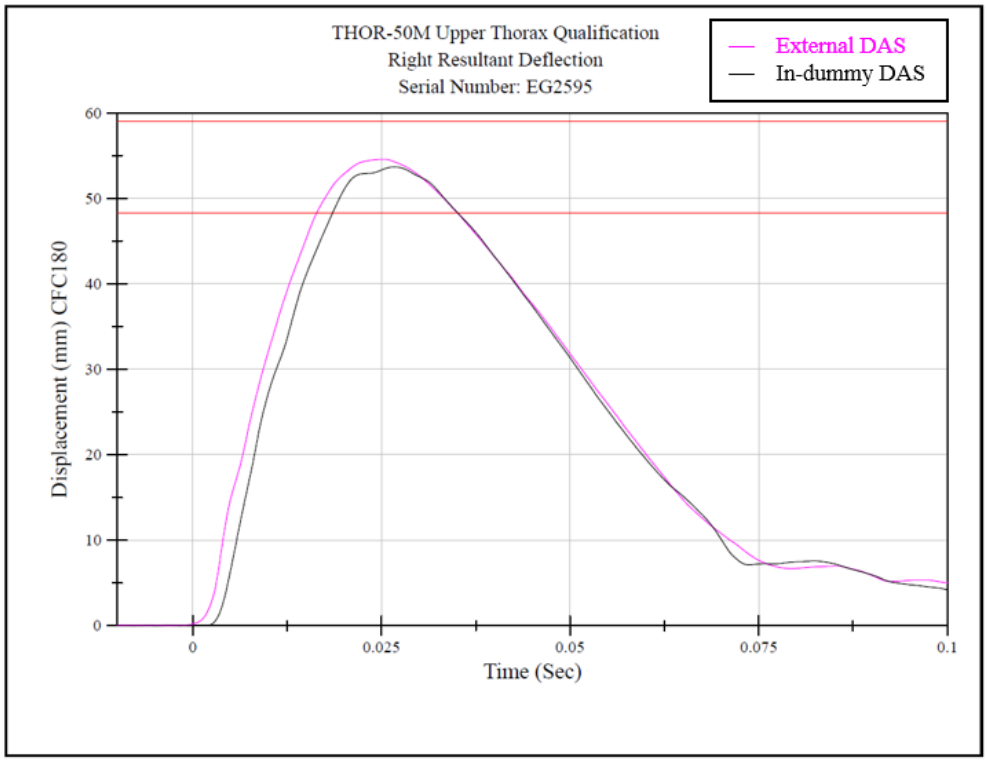


*Figure 34. Upper thorax impact: Right resultant deflection for external and in-dummy DAS EG2595*

### *Discussion*

Table 16 shows the dummy passed the upper thorax qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

The definition of T0 was revised between the external and in-dummy DAS ATD tests to be a force threshold instead of a contact switch. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 31, Figure 33, and Figure 34 as the jacket compression causes some variability.

## Lower Thorax

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent lower thorax qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test mode impacts the lower ribcage on either the right or left sides of the thorax. The lower ribcage impact qualification tests use the same impactor as the upper ribcage central impact test. This impactor has a mass of 23.36 kg and a 152.40 mm diameter rigid disk impact surface that contacts the THOR-50M at 4.30 ± 0.05 m/s. During these tests, the probe force and resultant deflections at the time of maximum probe force were measured.

#### *Qualification Results*

This section shows the results of the lower thorax qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 17 and Table 18 show the test data, followed by plot overlays comparing the two dummy configurations. The lower thorax was impacted on the left and right sides.

The external and in-dummy DAS ATDs passed all lower thorax qualification requirements.

*Table 17. Left Lower Thorax Qualification Results for External and In-Dummy DAS EG2595*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180524-4 | | 190404-1 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.25 | 4.35 | Pass | 4.31 | Pass | 4.31 |
| Peak Probe Force (N) | 3136 | 3832 | Pass | 3483 | Pass | 3469 |
| Left Resultant Deflection at Peak Force (mm) | 45.8 | 56 | Pass | 49.6 | Pass | 46 |

*Table 18. Right Lower Thorax Qualification Results for External and In-Dummy DAS EG2595*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180524-5 | | 190404-5 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.25 | 4.35 | Pass | 4.31 | Pass | 4.34 |
| Peak Probe Force (N) | 3,136 | 3,832 | Pass | 3,362 | Pass | 3,656 |
| Left Resultant Deflection at Peak Force (mm) | 45.8 | 56 | Pass | 45.8 | Pass | 48 |

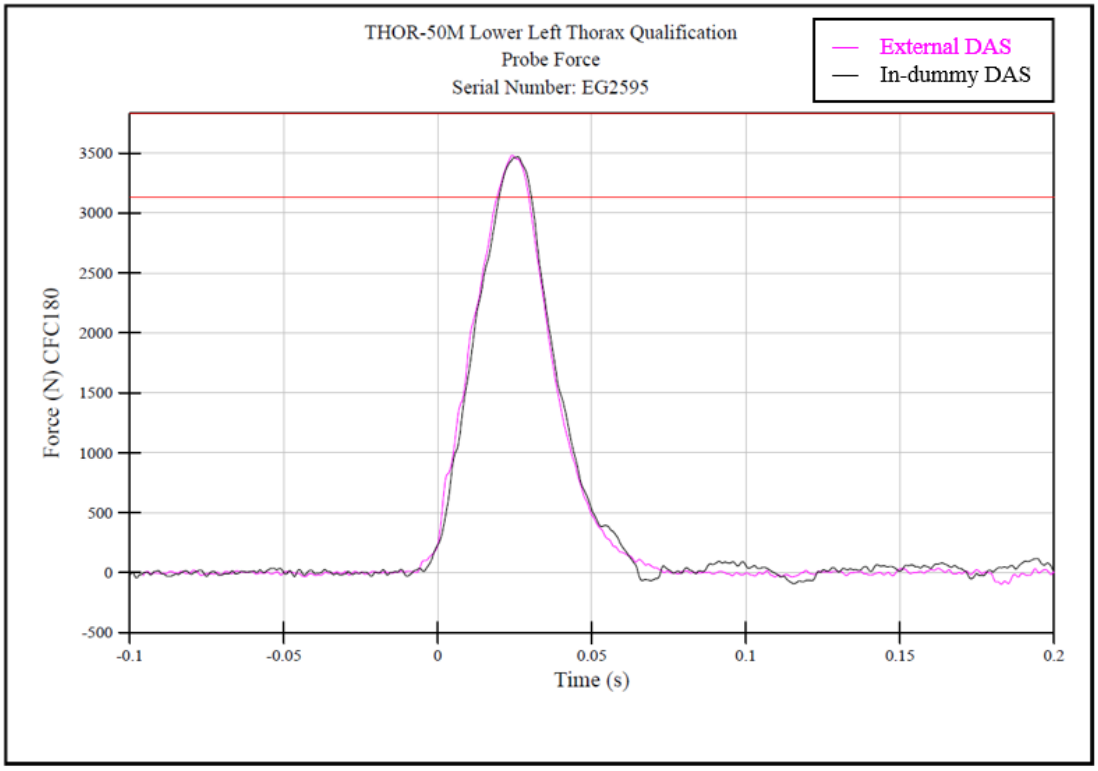


*Figure 35. Lower left thorax: Probe force for external and in-dummy DAS EG2595*

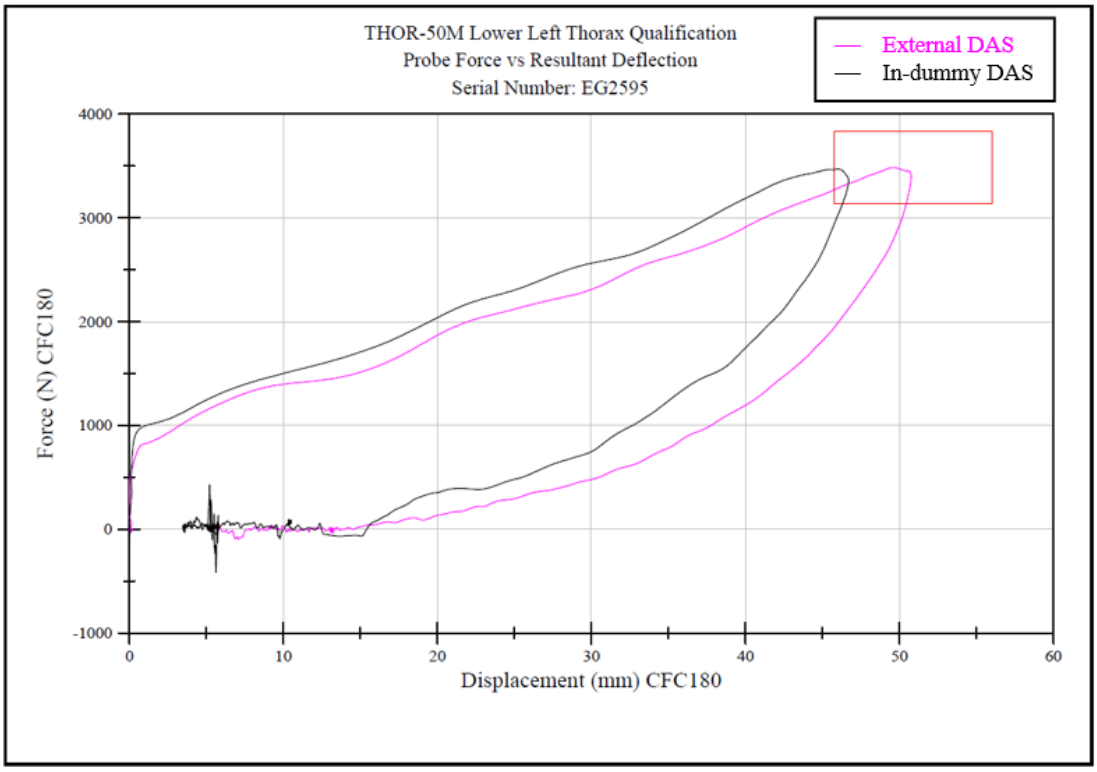


*Figure 36. Lower left thorax: Probe force versus resultant deflection for external and in-dummy DAS EG2595*

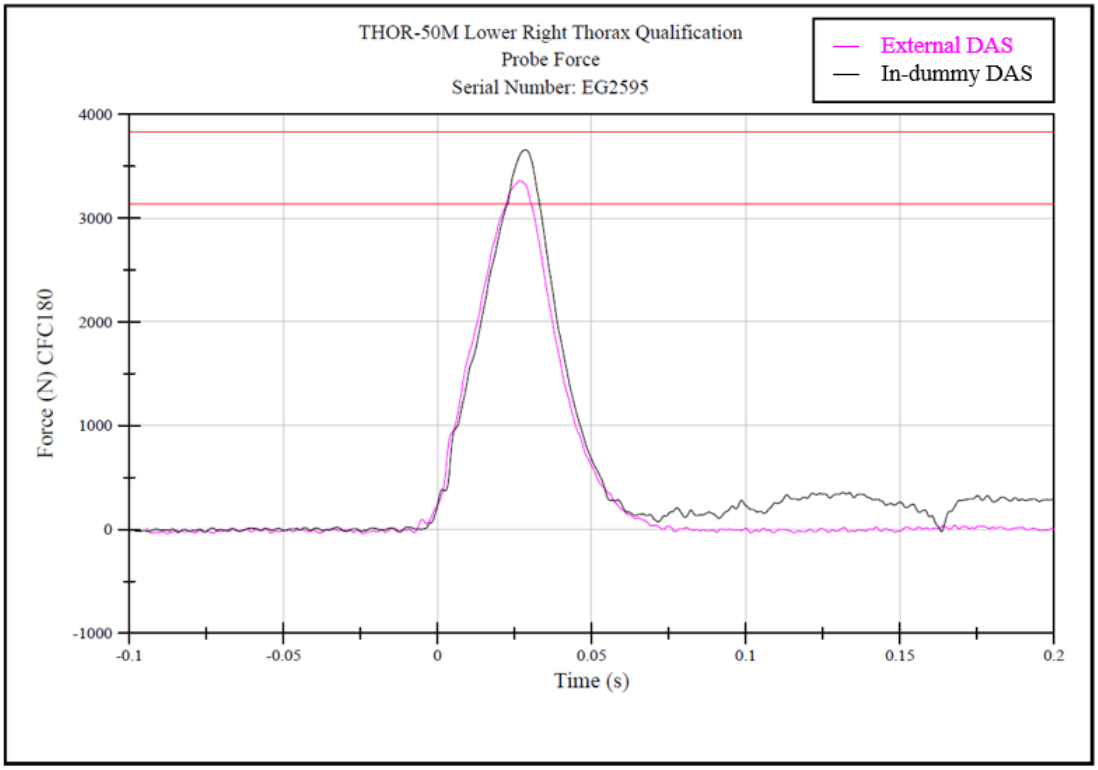


*Figure 37. Lower right thorax: Probe force for external and in-dummy DAS EG2595*

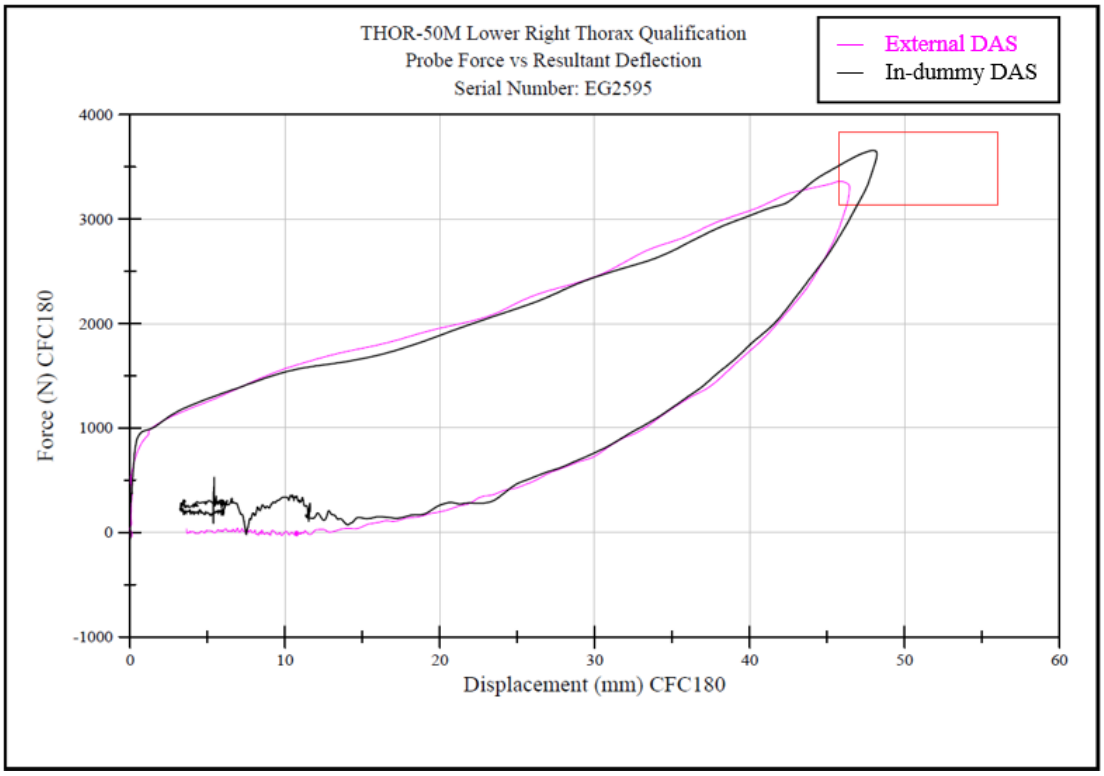


*Figure 38. Lower right thorax: Probe force versus resultant deflection for external and in-dummy DAS EG2595*

### *Discussion*

The external and in-dummy DAS ATDs passed all lower thorax qualification requirements (Table 17 and Table 18). As demonstrated in the THOR-50M R&R report (NHTSA, 2021), variations in testing can lead to slight differences in ATD response.

## Abdomen

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent abdomen qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. The abdomen qualification test is a dynamic test performed to examine the deflection and corresponding force of the abdomen when impacted with a 32 kg rigid impactor (using a horizontally oriented rigid bar impactor face) at 3.30 m/s. During these tests the X-axis deflection (for both left and right sides) at the time of maximum probe force, and probe force were measured.

### *Qualification Results*

This section shows the results of the abdomen qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 19 provides the test data, followed by plot overlays comparing the two dummy configurations.

The external and in-dummy DAS ATDs passed all abdomen qualification requirements.

*Table 19. Abdomen Qualification Results for External and In-Dummy DAS EG2595*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180524-8 | | 181108-1 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 3.25 | 3.35 | Pass | 3.30 | Pass | 3.32 |
| Peak Probe Force (N) | 2,626 | 3,210 | Pass | 2,753 | Pass | 2,733 |
| Left Abdomen X-axis Deflection at Time of Peak Force (mm) | -91.3 | -74.7 | Pass | -91.1 | Pass | -79.3 |
| Right Abdomen X-axis Deflection at Time of Peak Force (mm) | -91.3 | -74.7 | Pass | -85.5 | Pass | -77.2 |
| Difference Between Peak Left & Right X-axis Deflections (mm) | | < 8.0 | Pass | 5.6 | Pass | 2.1 |

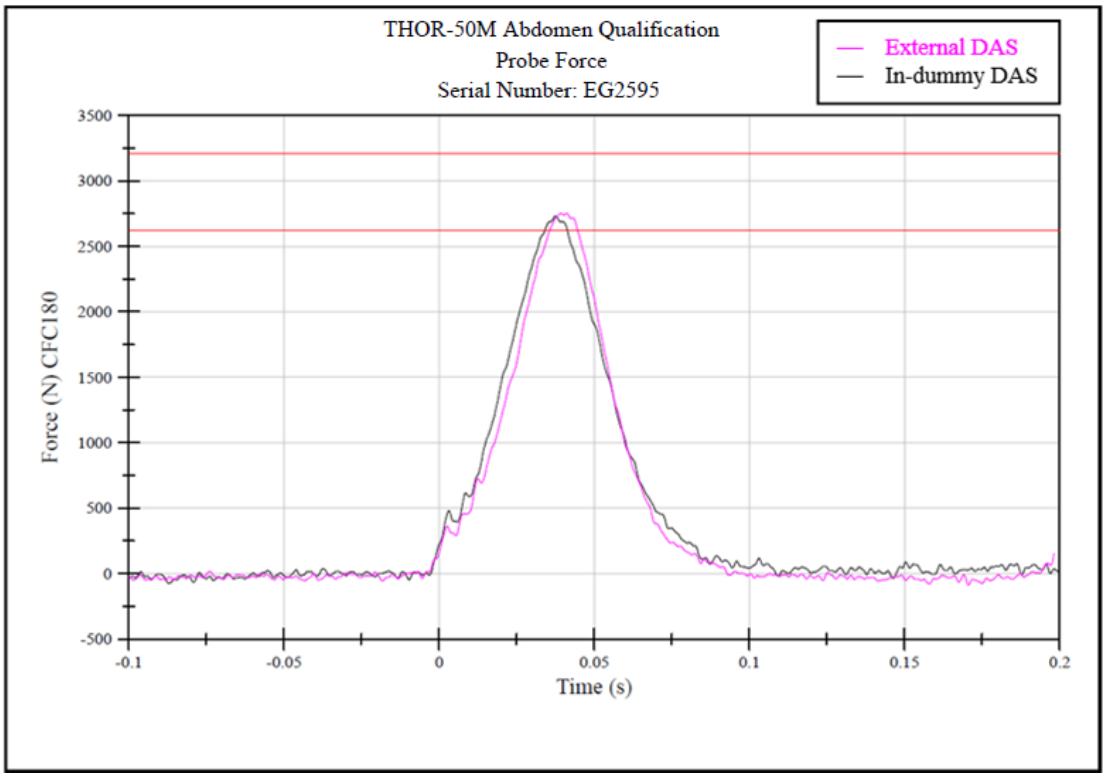


*Figure 39. Abdomen: Probe force for external and in-dummy DAS EG2595*

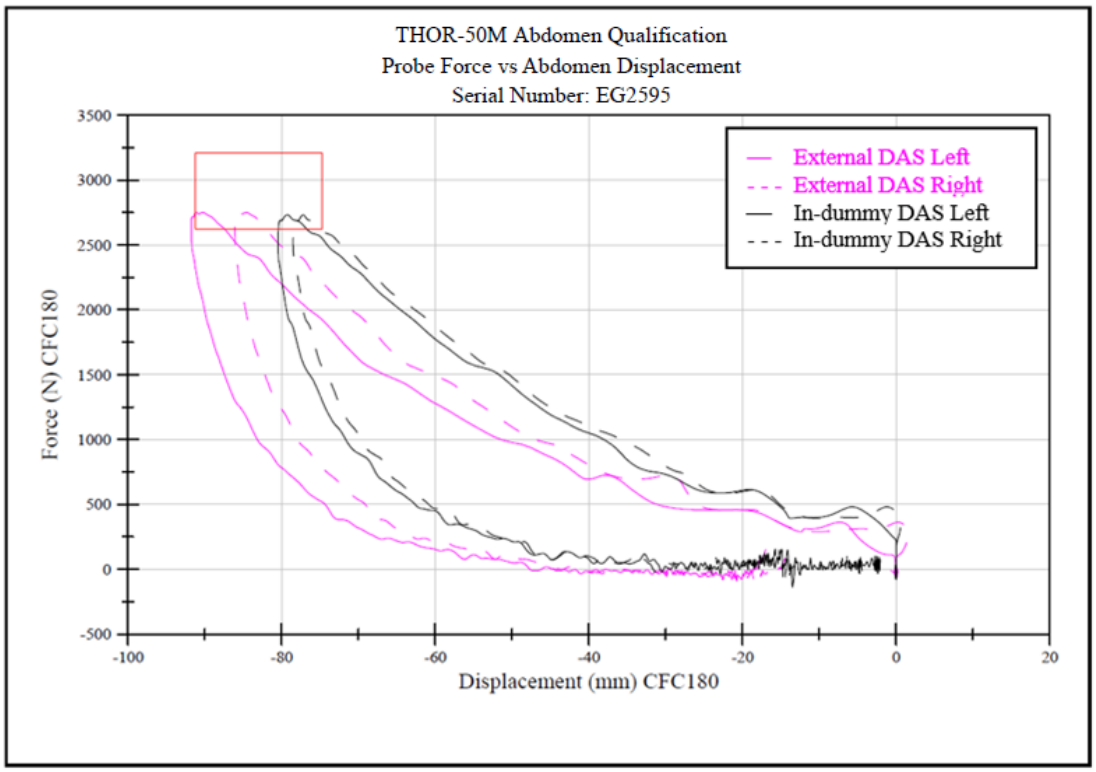


*Figure 40. Abdomen: Probe force versus abdomen deflection for external and in-dummy DAS EG2595*

### *Discussion*

The external DAS and in-dummy DAS ATDs passed all abdomen qualification requirements (Table 19). As explained in the THOR-50M R&R report (NHTSA 2021) the abdomen test is particularly sensitive to the dummy's rotation about the z-axis that could explain the left to right deflection difference in the external DAS test. The range of responses from external and in-dummy DAS ATD was observed during R&R tests.

## Upper Leg

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent upper leg qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test examines the response of the femur to axial impacts at the knee using a 12 kg impactor with a 76.2 mm diameter rigid disk impact surface at 3.30 ± 0.05 m/s. During these tests the probe force, femur force, and resultant acetabulum force were measured.

### *Qualification Results*

This section shows the results of the upper leg qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 20 and Table 21 show the test data, followed by plot overlays comparing the two dummy configurations. The left and right legs were tested for each ATD configuration.

The external and in-dummy DAS ATDs passed all upper leg qualification requirements except for the maximum resultant acetabulum force for the right in-dummy DAS upper leg.

*Table 20. Left Upper Leg Qualification Results for External and In-Dummy DAS EG2595*

| **Parameter** | **Specification (Sep 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180329-2** | | **190422-4** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 2.55 | 2.65 | Pass | 2.63 | Pass | 2.57 |
| Peak Probe Force (N) | 4221 | 5158 | Pass | 4603 | Pass | 4804 |
| Peak Femur Force, Fz (N) | -3314 | -2712 | Pass | -3156 | Pass | -3279 |
| Peak Resultant Acetabulum Force (N) | 1478 | 1806 | Pass | 1590 | Pass | 1553 |

*Table 21. Right Upper Leg Qualification Results for External and In-Dummy DAS EG2595*

| Parameter | Specification (Sep 2018) | | External DAS 180329-3 | | In-Dummy DAS 181119-1 | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 2.55 | 2.65 | Pass | 2.61 | Pass | 2.61 |
| Peak Probe Force (N) | 4221 | 5158 | Pass | 4454 | Pass | 4769 |
| Peak Femur Force, Fz (N) | -3314 | -2712 | Pass | -2765 | Pass | -3192 |
| Peak Resultant Acetabulum Force (N) | 1478 | 1806 | Pass | 1630 | Fail | 1445 |

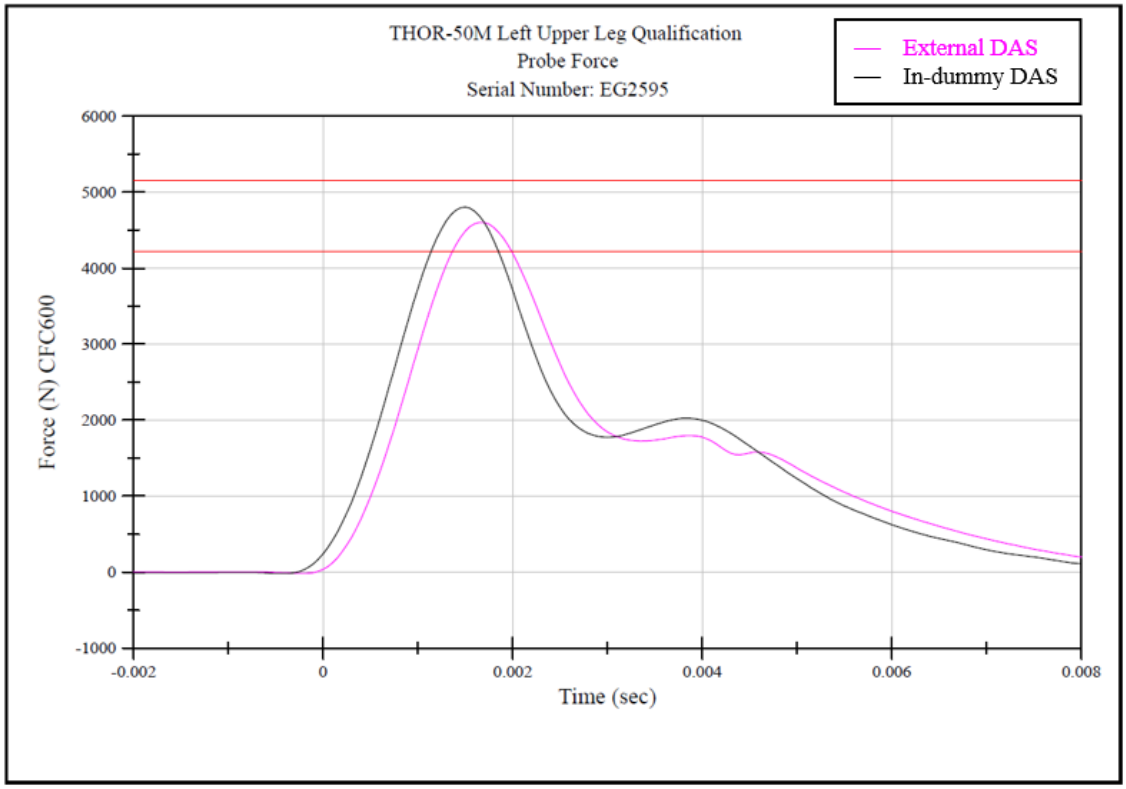


*Figure 41. Left upper leg: Probe force for external and in-dummy DAS EG2595*

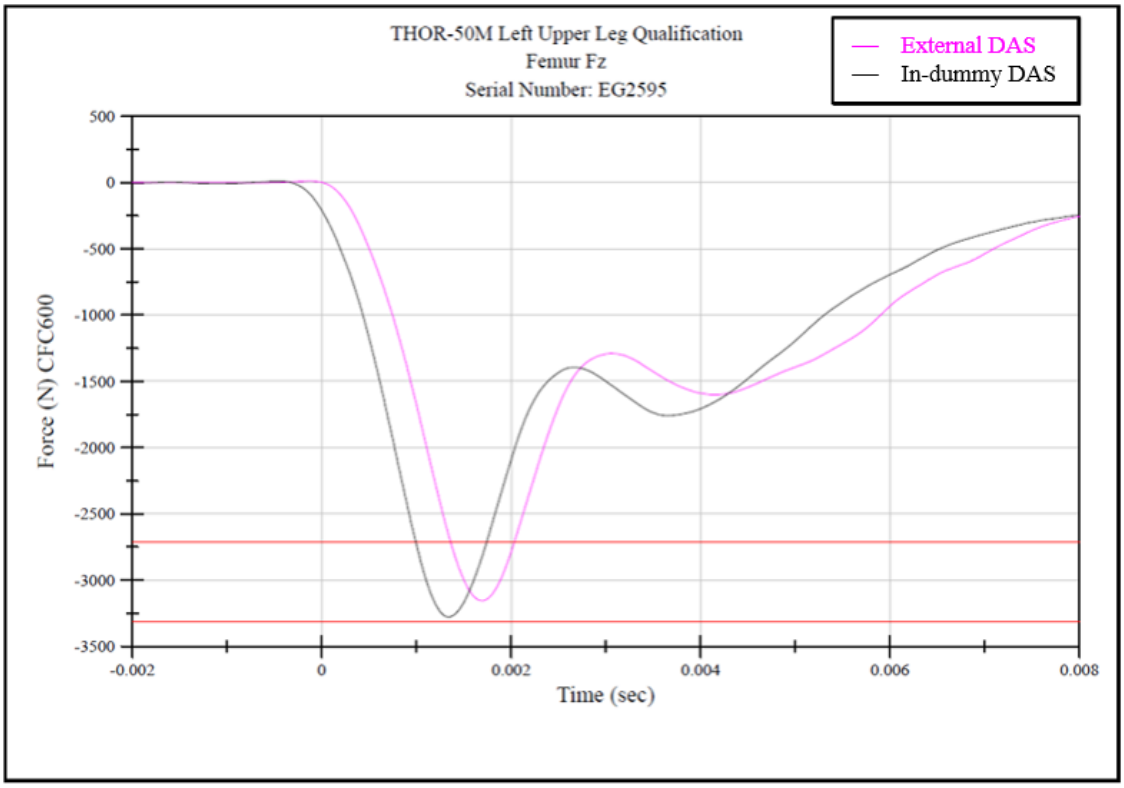


*Figure 42. Left upper leg: Femur Fz for external and in-dummy DAS EG2595*

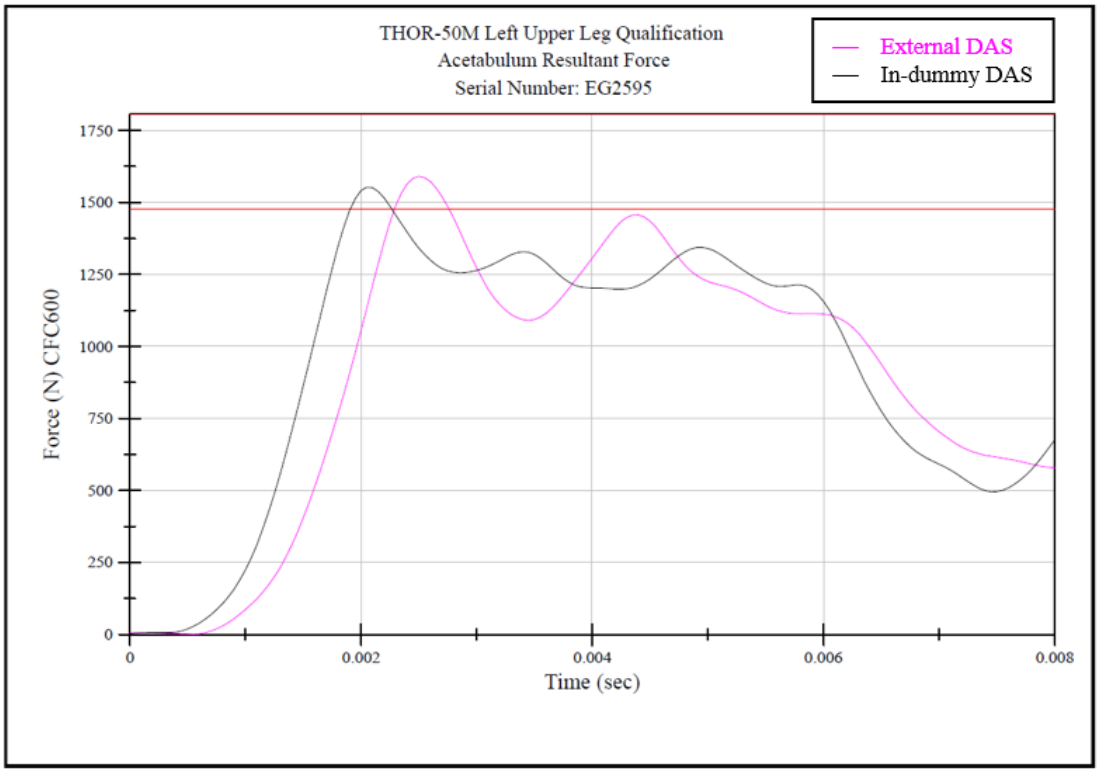


*Figure 43. Left upper leg: Acetabulum resultant force for external and in-dummy DAS EG2595*

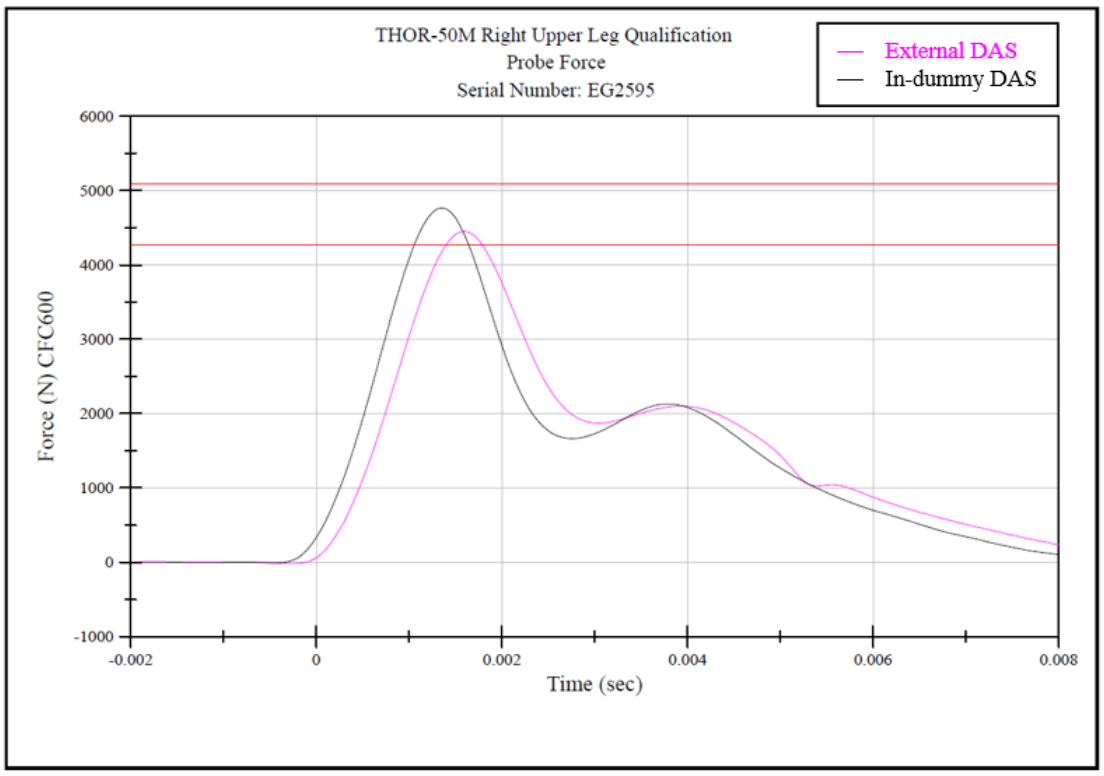


*Figure 44. Right upper leg: Probe force for external and in-dummy DAS EG2595*

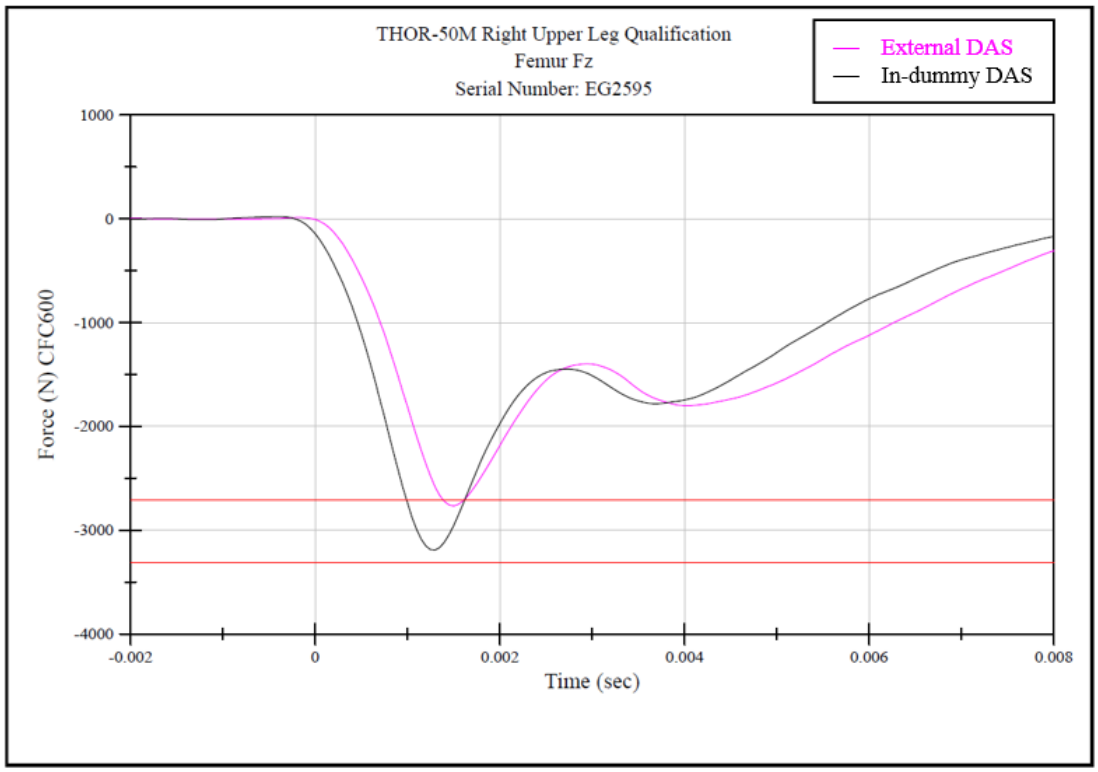


*Figure 45. Right upper leg: Femur Fz for external and in-dummy DAS EG2595*

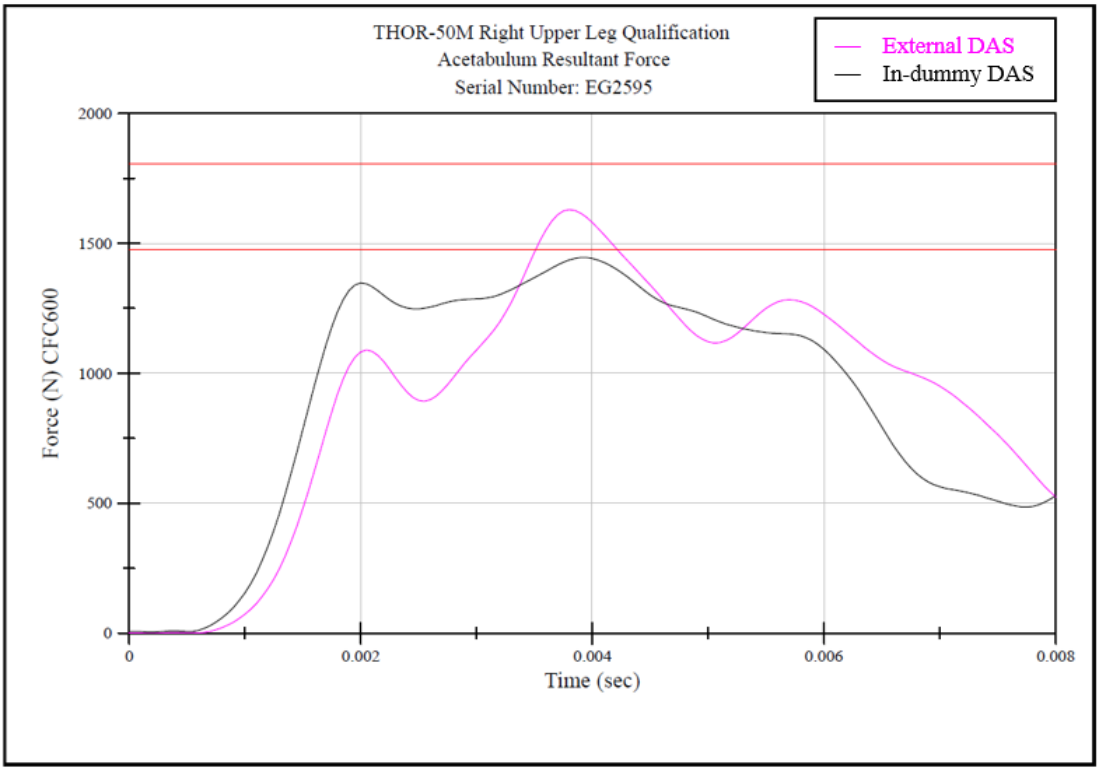


*Figure 46. Right upper leg: Acetabulum resultant force for external and in-dummy DAS EG2595*

### *Discussion*

The left external and in-dummy DAS ATDs passed all upper leg qualification requirements (Table 20). The results for the in-dummy DAS ATD right upper leg acetabulum force did not meet the qualification requirements (Table 21).

The test failures can be due to poor test reproducibility and are not likely due to the differences between the external and in-dummy DAS configurations. The upper leg qualification procedure has since been updated to address test reproducibility inconsistencies and both ATDs pass the new requirements. Appendix B includes results from the in-dummy DAS THOR-50M being tested using the NHTSA (2023c) manual.

The definition of T0 was revised between the external and in-dummy DAS ATD tests to be a force threshold instead of a contact switch. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 41 to Figure 46.

## Knee

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent knee qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test examines the response of the anterior-posterior translation of the tibia with respect to the femur at the knee joint. A 12.00 kg impactor with a 76.2 mm diameter rigid disk impact surface impacts a load distribution bracket attached at the knee joint at 2.20 ± 0.05 m/s. During these tests, the femur Z-axis force and knee deflection at peak femur force were measured.

### *Qualification Results*

This section shows the results of the knee qualification tests for the external ATD and in-dummy DAS ATD. Table 22 and Table 23 provide the test data, followed by plot overlays comparing the two dummy types. The left and right legs were tested for each ATD.

The external and in-dummy DAS ATDs passed all knee qualification requirements.

*Table 22. Left Knee Qualification Results for External and In-Dummy DAS EG2595*

| **Parameter** | **Specification (Sep 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180329-4** | | **181211-6** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 2.15 | 2.25 | Pass | 2.22 | Pass | 2.21 |
| Peak Femur Force, Fz (N) | -7,156 | -5,855 | Pass | -6,405 | Pass | -6,660 |
| Knee Deflection at Peak Femur Force (mm) | -22.2 | -18.2 | Pass | -20.1 | Pass | -19.8 |

*Table 23. Right Knee Qualification Results for External and In-Dummy DAS EG2595*

| **Parameter** | **Specification (Sep 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180402-1** | | **190423-3** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 2.15 | 2.25 | Pass | 2.22 | Pass | 2.19 |
| Peak Femur Force, Fz (N) | -7,156 | -5,855 | Pass | -6,421 | Pass | -7,087 |
| Knee Deflection at Peak Femur Force (mm) | -22.2 | -18.2 | Pass | -20.1 | Pass | -21.2 |

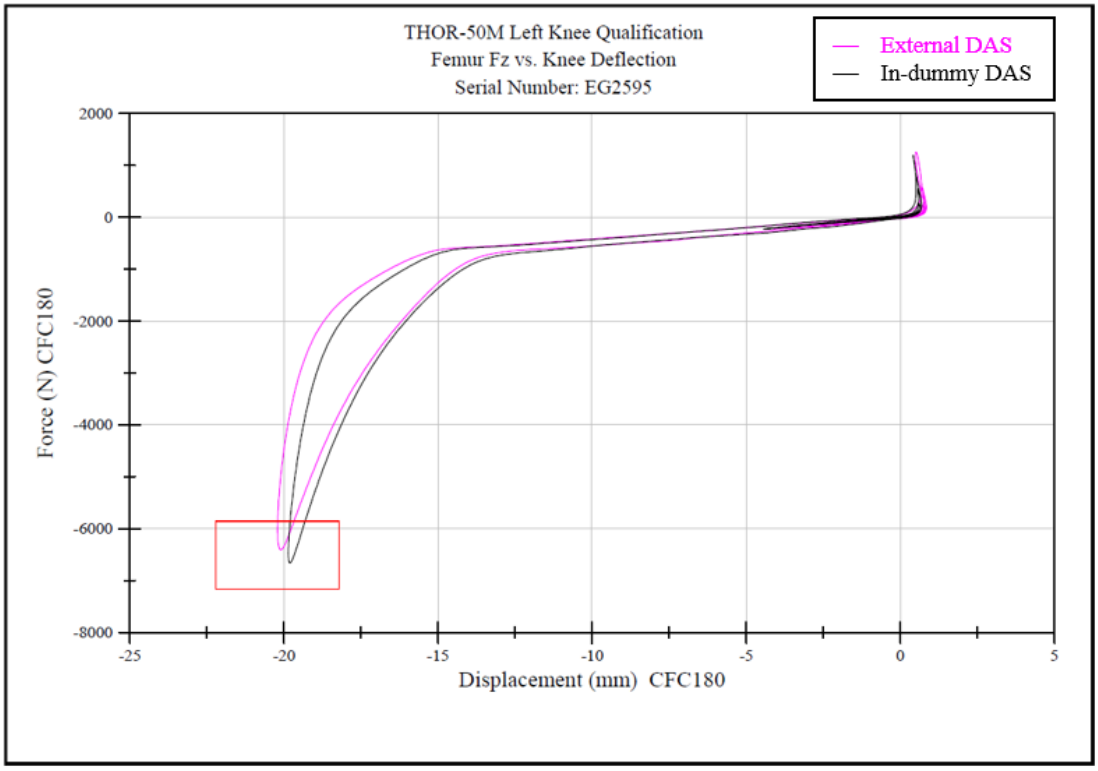


*Figure 47. Left knee: Femur force Fz vs. X-axis knee deflection for external and in-dummy DAS EG2595*

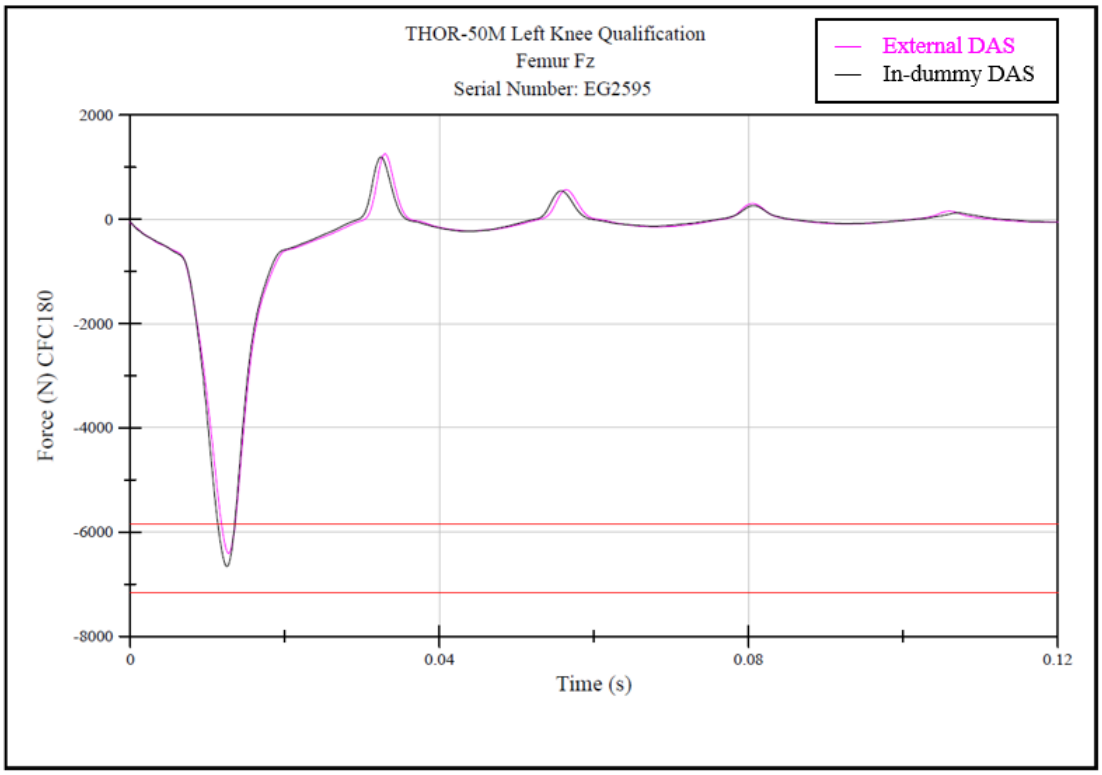


*Figure 48. Left knee: Femur Fz for external and in-dummy DAS EG2595*

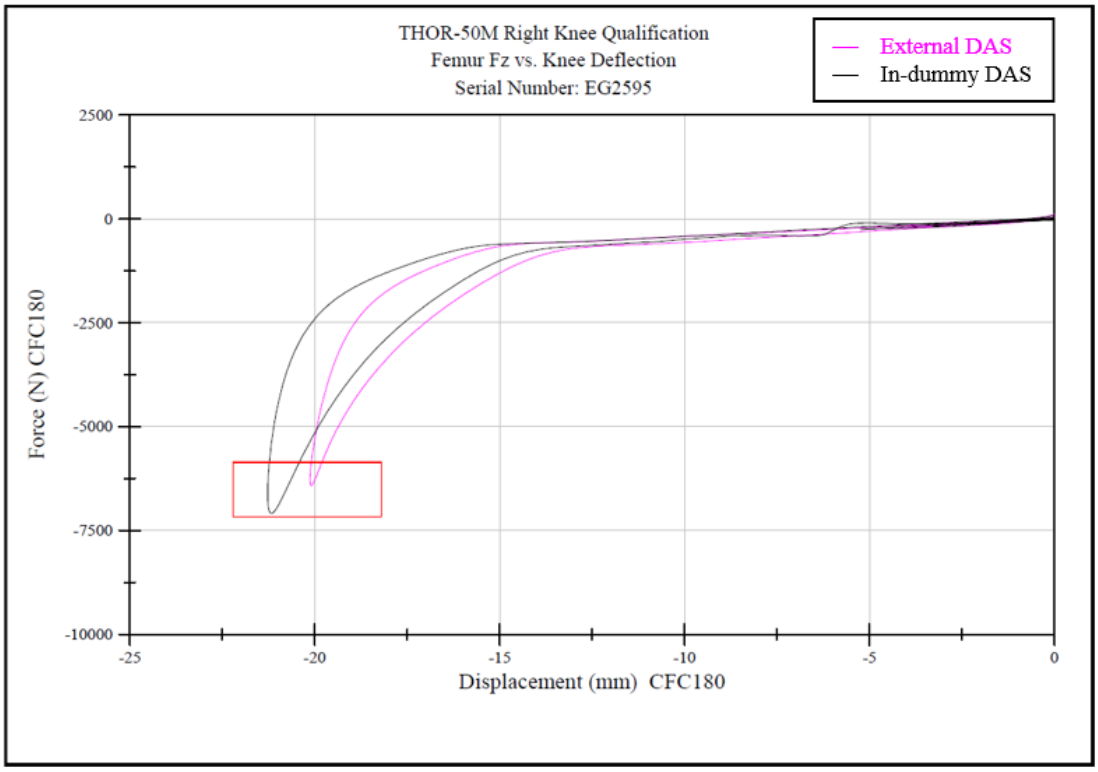


*Figure 49. Right knee: Femur Fz vs. X-axis knee deflection for external and in-dummy DAS EG2595*

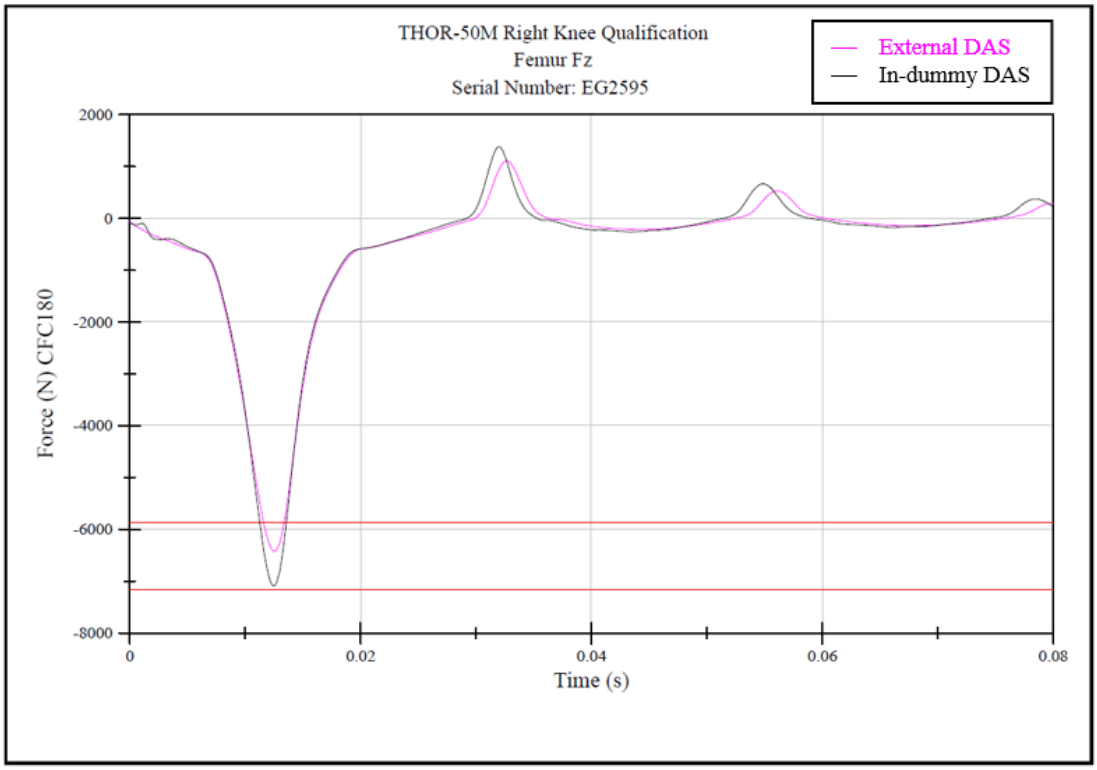


*Figure 50. Right knee: Femur Fz for external and in-dummy DAS EG2595*

### *Discussion*

Table 22 and Table 23 show the dummy passed the knee qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

## Ankle Inversion

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent ankle inversion qualification tests following the qualification procedures described in NHTSA (2018). The leg is held rigidly where the X-Z plane of the foot and lower leg are horizontal. The test uses the NHTSA Dynamic Impactor (TLX-9000-013) described in the THOR-50M drawing package (NHTSA, 2023a, 2023b), with an effective mass of 5.00 ± 0.02 kg (11.02 ± 0.04 lb.). The pendulum impacts the inversion bracket at a velocity of 2.00 ± 0.05 m/s. During these tests the lower tibia force (Fz), and X-axis rotation were measured; the ankle resistive moment about X, was calculated from Fy and Mx.

### *Qualification Results*

This section discusses the results of the ankle inversion qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 24 and Table 25 show the test data, followed by plot overlays comparing the two dummy configurations. The left (LX EG3060) and right (LX EG3120) legs were tested.

The external and in-dummy DAS ATDs passed all ankle inversion qualification requirements.

*Table 24. Left Ankle Inversion Qualification Results for External and In-Dummy DAS EG2595 LX EG3060*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180404-11 | | 181210-3 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 1.95 | 2.05 | Pass | 2.02 | Pass | 2 |
| Peak Lower Tibia, Fz (N) | -555 | -454 | Pass | -485 | Pass | -462 |
| Peak Ankle Resistive Moment (Nm) | -43 | -35.2 | Pass | -38.1 | Pass | -35.7 |
| Peak Ankle X-axis Rotation (deg) | -37.9 | -31 | Pass | -36.6 | Pass | -35.4 |

*Table 25. Right Ankle Inversion Qualification Results for External and In-Dummy DAS EG2595 LX EG3120*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180403-4 | | 181203-14 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 1.95 | 2.05 | Pass | 2.02 | Pass | 2.01 |
| Peak Lower Tibia, Fz (N) | -555 | -454 | Pass | -476 | Pass | -515 |
| Peak Ankle Resistive Moment (Nm) | 35.2 | 43 | Pass | 38.6 | Pass | 36.7 |
| Peak Ankle X-axis Rotation (deg) | 31.0 | 37.9 | Pass | 35.7 | Pass | 37 |

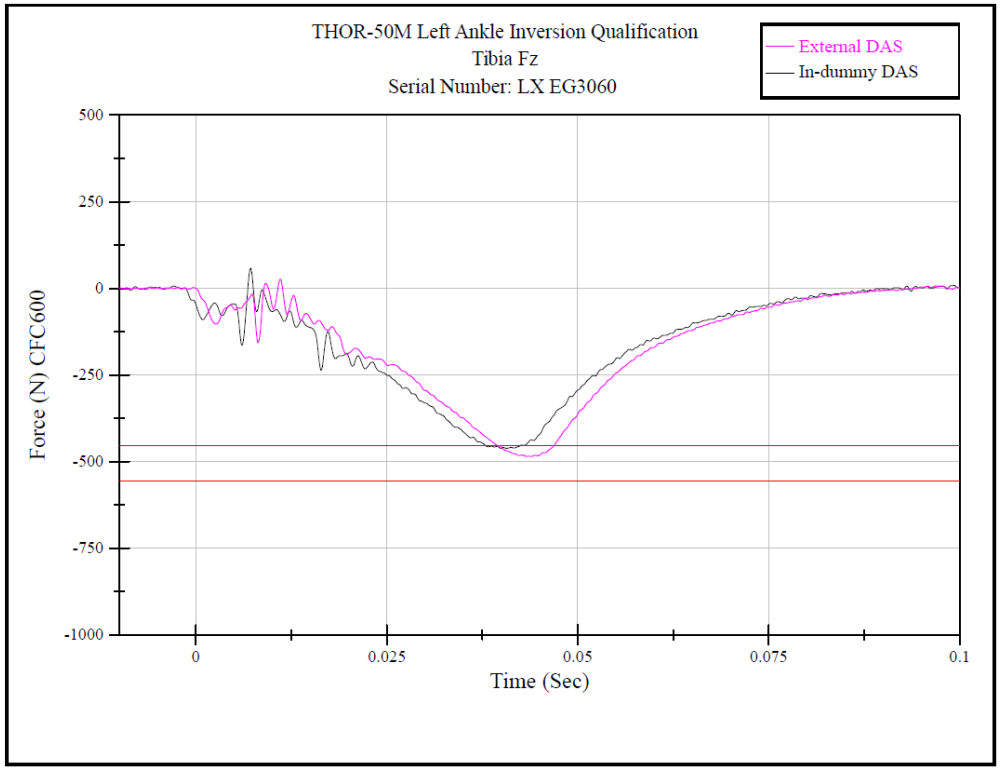


*Figure 51. Left ankle inversion: Tibia Fz for external and in-dummy DAS EG2595 LX EG3060*

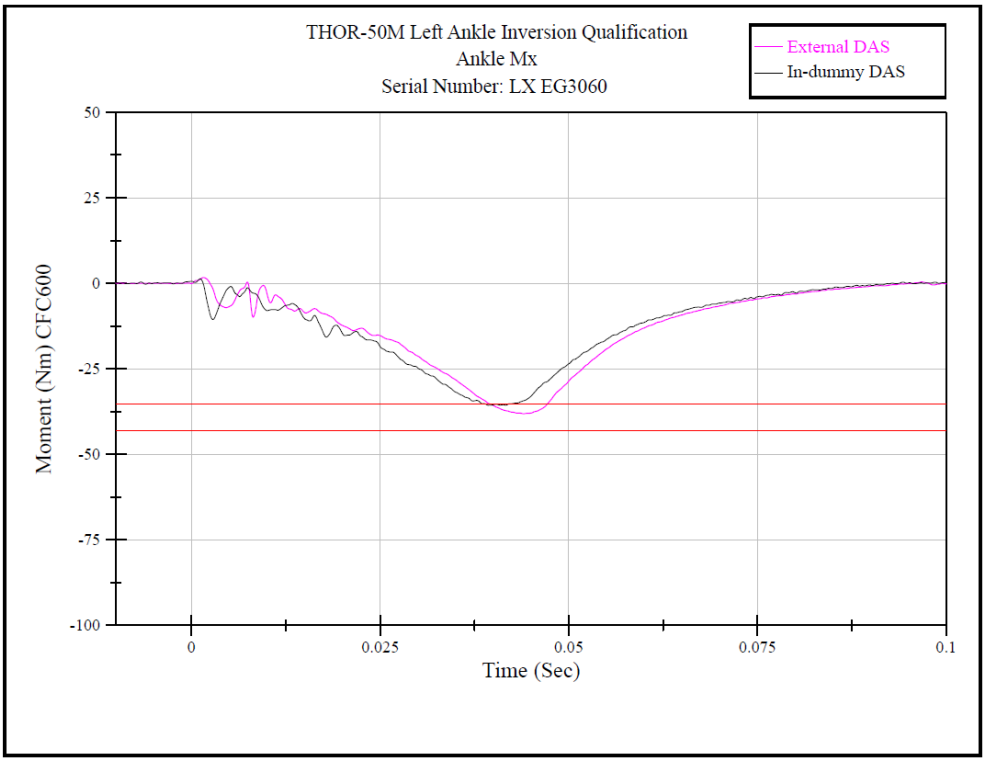


*Figure 52. Left ankle inversion: Ankle Mx for external and in-dummy DAS EG2595 LX EG3060*

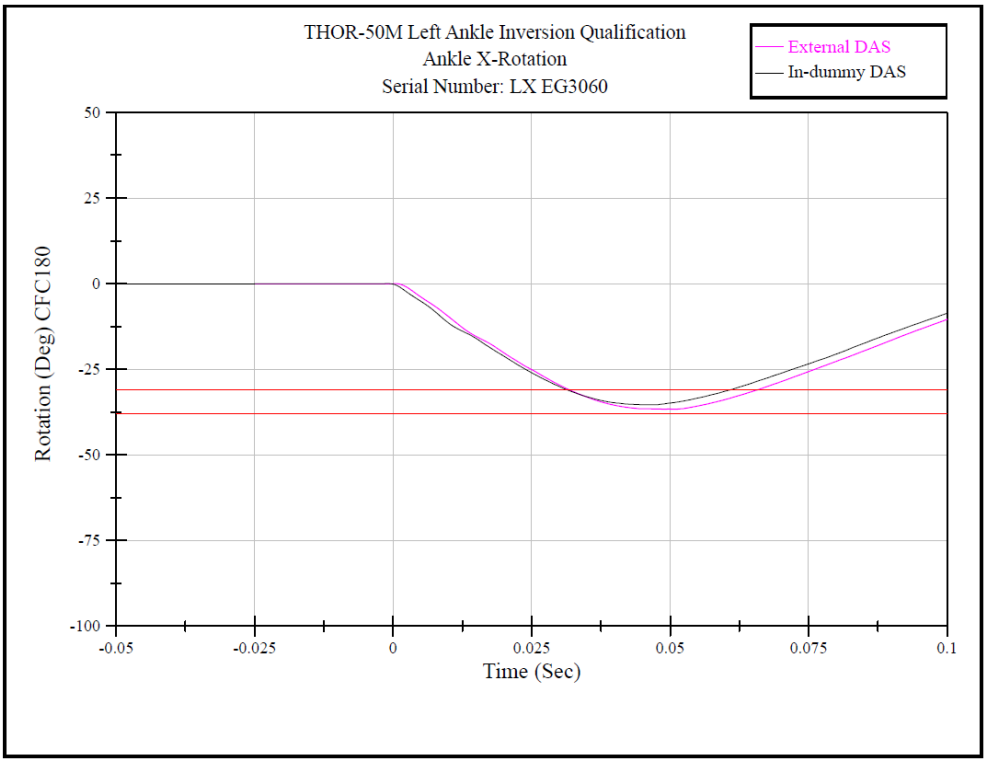


*Figure 53. Left ankle inversion: Ankle X-axis rotation for external and in-dummy DAS EG2595 LX EG3060*

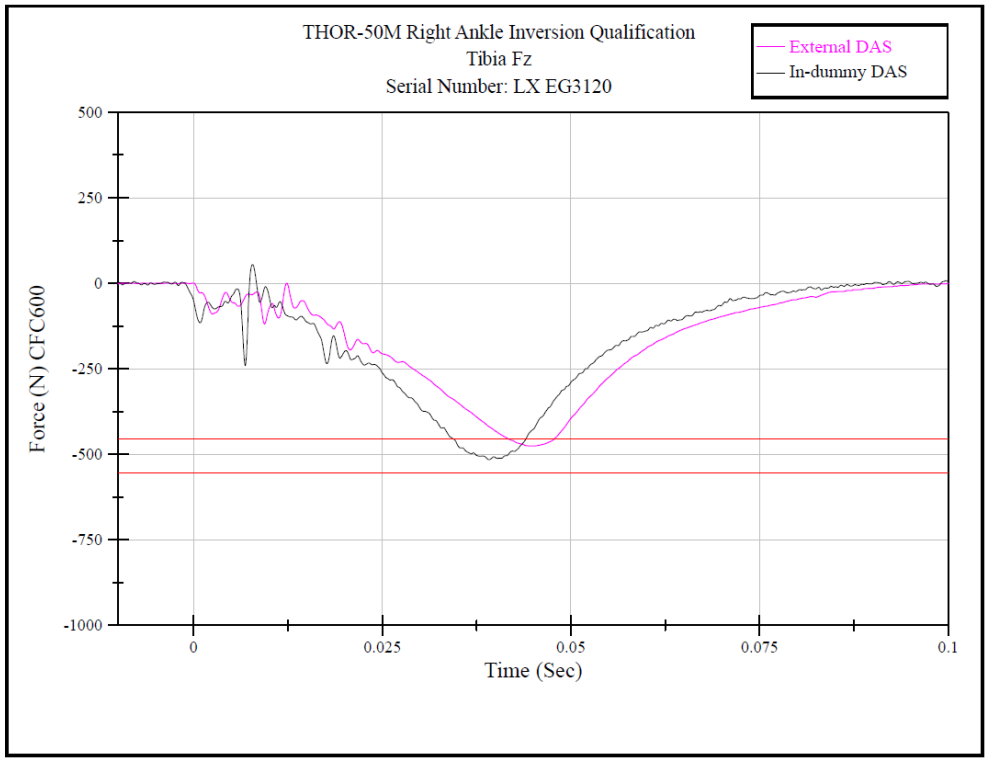


*Figure 54. Right ankle inversion: Tibia Fz for external and in-dummy DAS EG2595 LX EG3120*

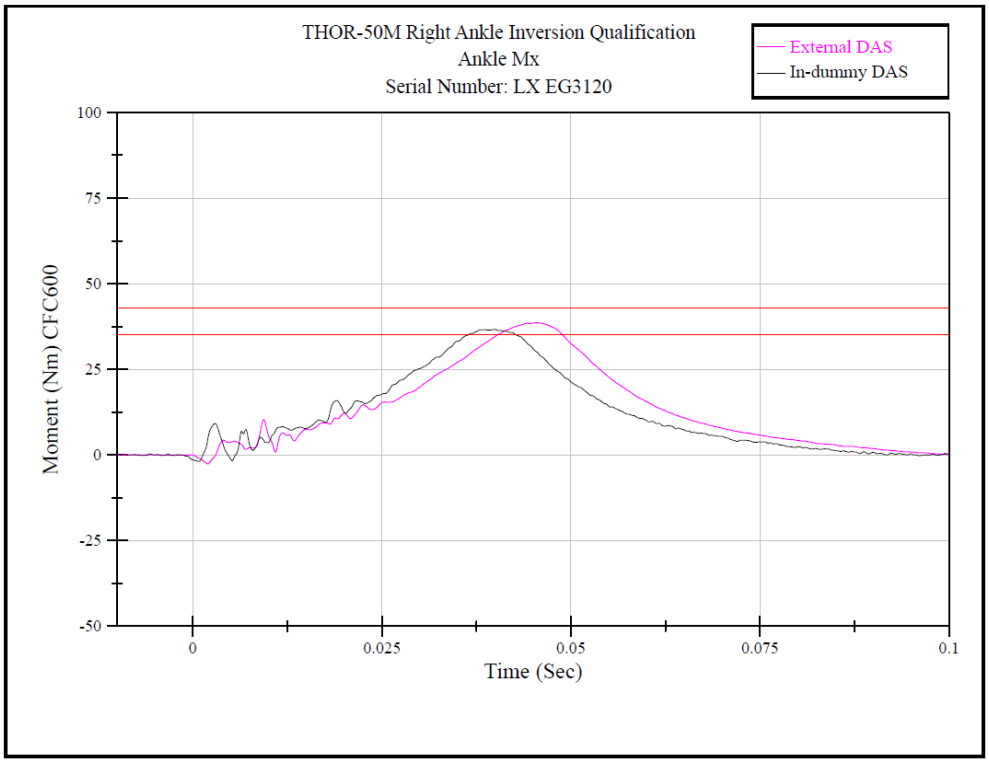


*Figure 55. Right ankle inversion: Ankle Mx for external and in-dummy DAS EG2595 LX EG3120*

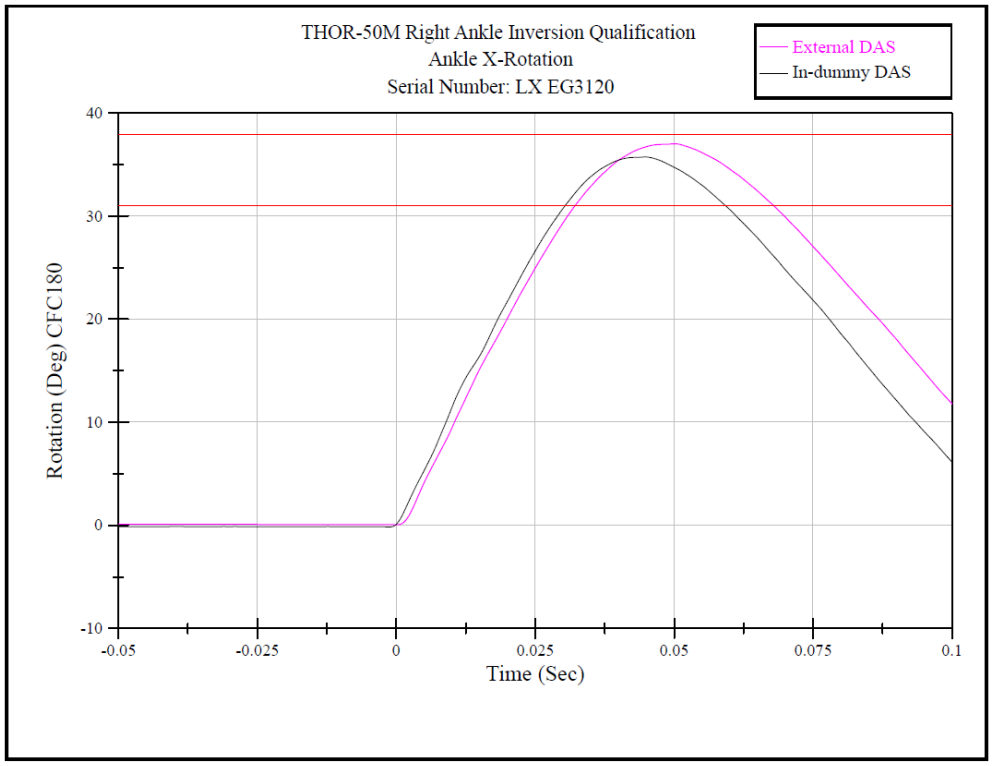


*Figure 56. Right ankle inversion: Ankle X-axis rotation for external and in-dummy DAS EG2595 LX EG3120*

### *Discussion*

Table 24 and Table 25 show the dummy passed the ankle inversion qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

The definition of T0 was revised between the external and in-dummy DAS ATD tests. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 51 to Figure 56.

## Ankle Eversion

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent ankle eversion qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. The leg is held rigidly such that the X-Z plane of the foot and lower leg are horizontal. The test uses the NHTSA Dynamic Impactor (TLX-9000-013) (NHTSA, 2023a, 2023b) with an effective mass of 5.00 ± 0.02 kg (11.02 ± 0.04 lb.). The pendulum impacts the eversion bracket at a velocity of 2.00 ± 0.05 m/s. During these tests the lower tibia force (Fz), and X-axis rotation were measured; the ankle resistive moment about X, was calculated from Fy and Mx.

### *Qualification Results*

This section gives the results of the ankle eversion qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 26 and Table 27 show the test data, followed by plot overlays comparing the two dummy configurations. The left (LX EG3060) and right (LX EG3120) legs were tested for each ATD.

The external and in-dummy DAS ATDs passed all ankle eversion qualification requirements.

*Table 26. Left Ankle Eversion Qualification Results for External and In-Dummy DAS EG2595 LX EG3060*

| Parameter | Specification (Sep 2018) | | External DAS 180404-9 | | In-Dummy DAS 181210-4 | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 1.95 | 2.05 | Pass | 2.02 | Pass | 2.03 |
| Peak Lower Tibia, Fz (N) | -629 | -514 | Pass | -574 | Pass | -582 |
| Peak Ankle Resistive Moment (Nm) | 38.7 | 47.3 | Pass | 45.5 | Pass | 43.5 |
| Peak Ankle X-axis Rotation (deg) | 26.6 | 32.5 | Pass | 28.6 | Pass | 27.6 |

*Table 27. Right Ankle Eversion Qualification Results for External and In-Dummy DAS EG2595 LX EG3120*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180403-5 | | 181204-6 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 1.95 | 2.05 | Pass | 2.02 | Pass | 2.02 |
| Peak Lower Tibia, Fz (N) | -629 | -514 | Pass | -538 | Pass | -600 |
| Peak Ankle Resistive Moment (Nm) | -47.3 | -38.7 | Pass | -41.1 | Pass | -42.3 |
| Peak Ankle X-axis Rotation (deg) | -32.5 | -26.6 | Pass | 28.6 | Pass | 27.6 |

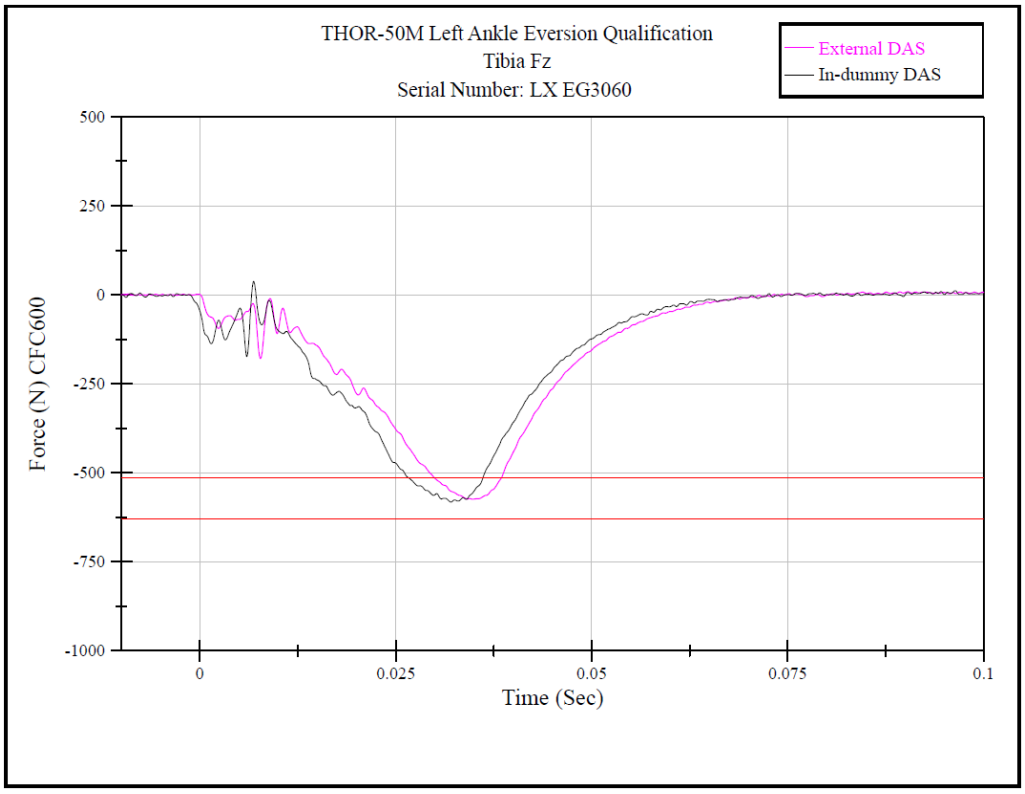


*Figure 57. Left ankle eversion: Tibia Fz for external and in-dummy DAS EG2595 LX EG3060*

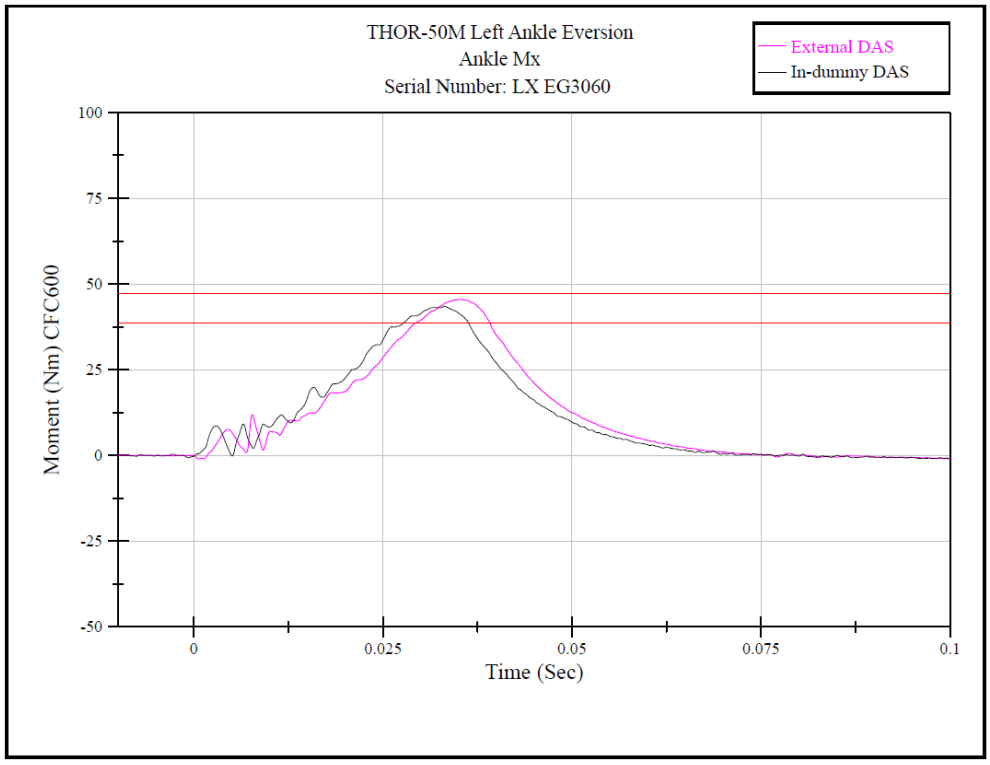


*Figure 58. Left ankle eversion: Ankle Mx for external and in-dummy DAS EG2595 LX EG3060*

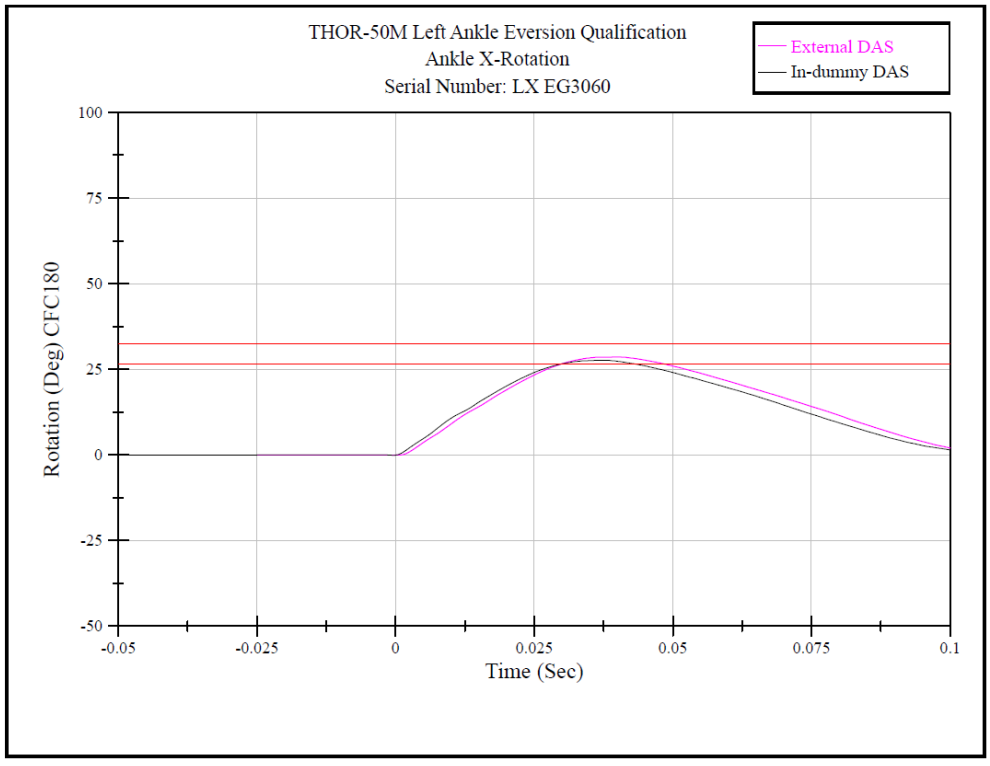


*Figure 59. Left ankle eversion: Ankle X-axis rotation for external and in-dummy DAS EG2595 LX EG3060*

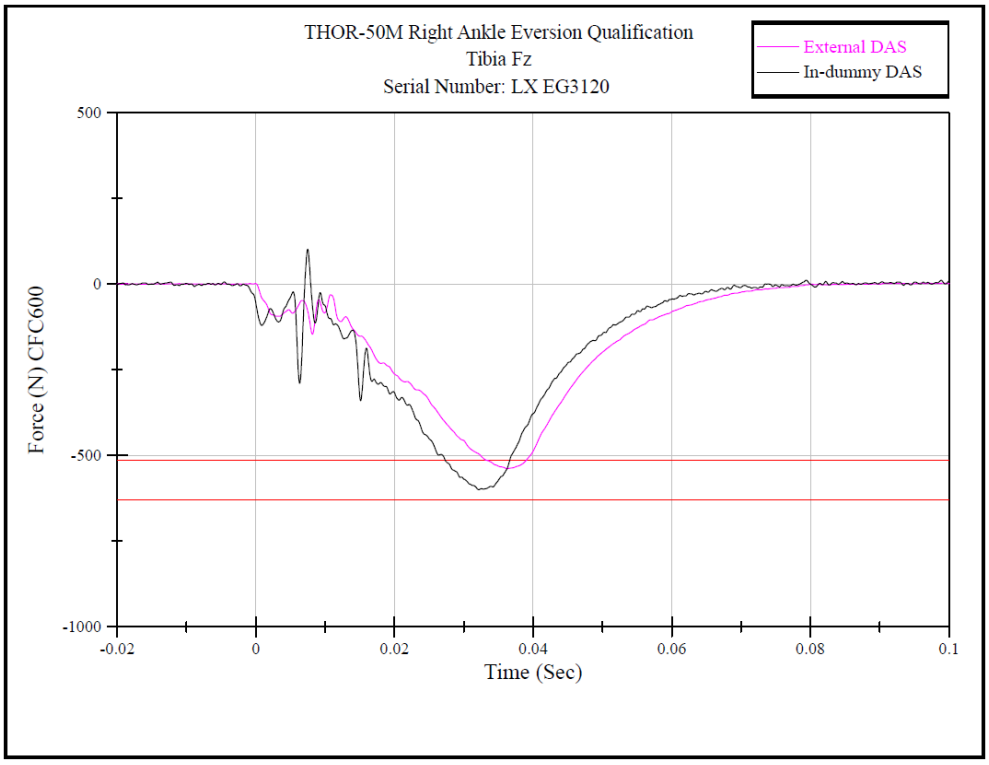


*Figure 60. Right ankle eversion: Tibia force Fz for external and in-dummy DAS EG2595 LX EG3120*

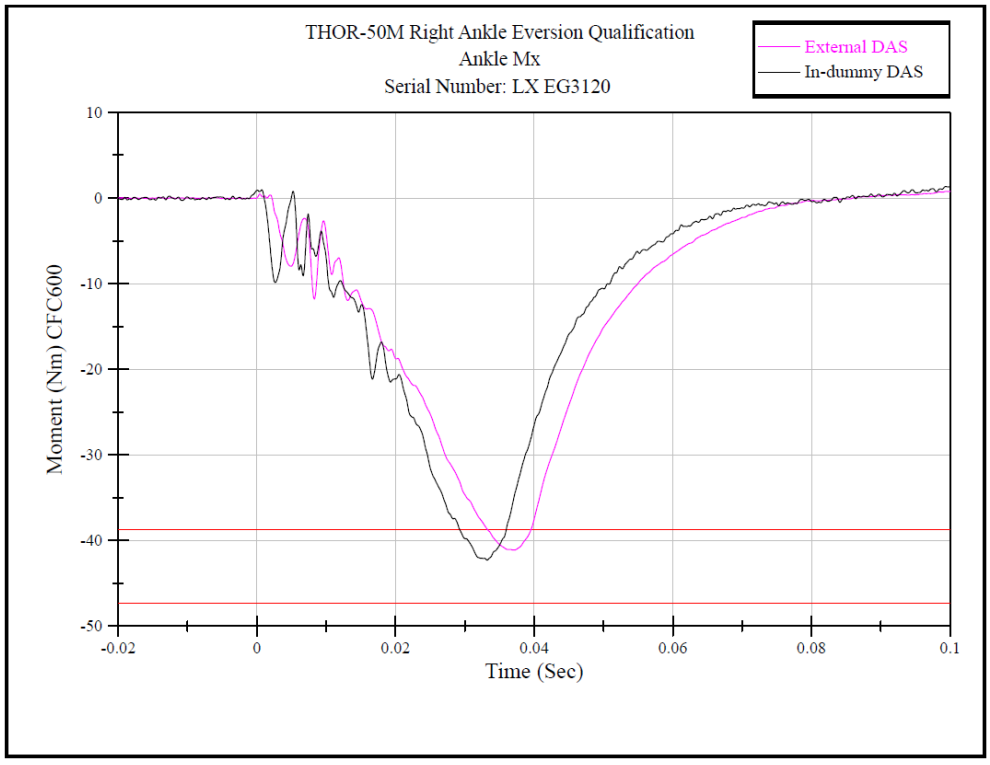


*Figure 61. Right ankle eversion: Ankle Mx for external and in-dummy DAS EG2595 LX EG3120*

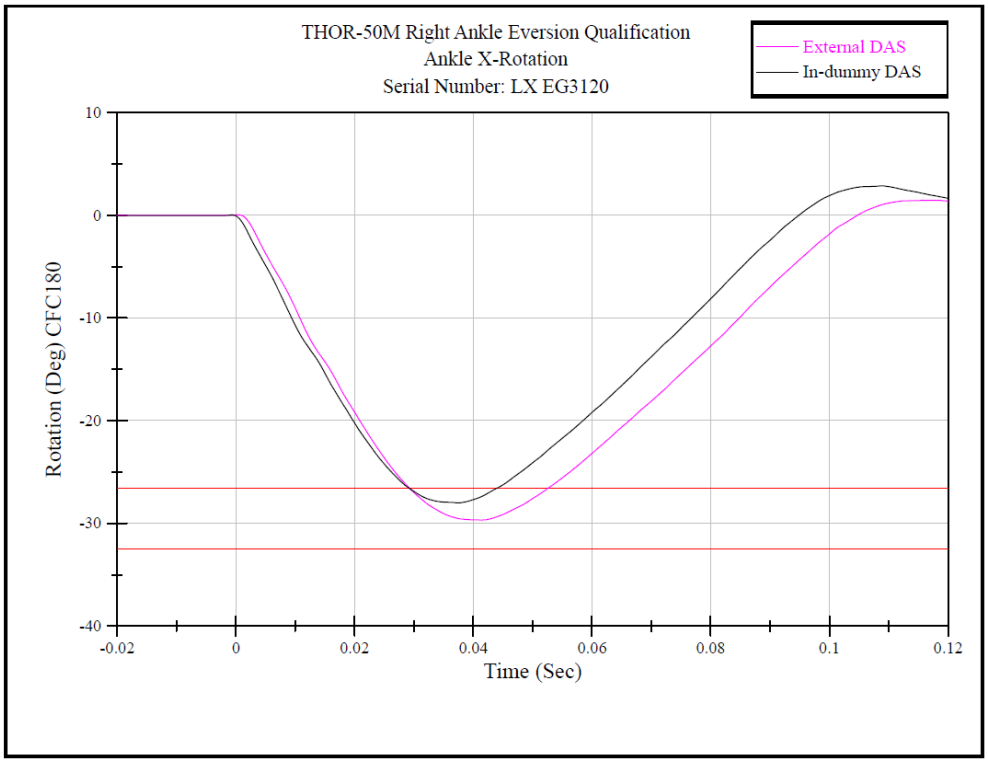


*Figure 62. Right ankle eversion: Ankle X-axis rotation for external and in-dummy DAS EG2595 LX EG3120*

### *Discussion*

Table 26 and Table 27 shows the dummy passed the ankle eversion qualification testing both with the external DAS and after the integration of the in-dummy DAS. Therefore, the integration does not appear to have caused undesirable effects on the response of this qualification test.

The definition of T0 was revised between the external and in-dummy DAS ATD tests. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 57 through Figure 62.

## Ball of Foot

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent ball of foot qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test examines the dynamic impact response of the ball of the foot. In these tests, the molded shoe was used (NHTSA, 2023a, 2023b), while the leg is held rigidly with the tibia horizontal. The pendulum impacts the ball of the foot at a velocity of 5.00 ± 0.05 m/s. During these tests, the lower tibia force (Fz) and Y-axis rotation were measured; the ankle resistive moment about Y was calculated from Fx and My.

### *Qualification Results*

This section shows the results of the ball of foot qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 28 and Table 29 show the test data, followed by plot overlays comparing the two dummy configurations. The left and right legs were tested. The in-dummy DAS ATD did not pass all ball of foot qualification requirements.

*Table 28. Left Ball of Foot Qualification Results for External and In-Dummy DAS EG2595 LX EG3060*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180404-7 | | 181211-1 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.95 | 5.05 | Pass | 5.03 | Pass | 4.98 |
| Peak Lower Tibia, Fz (N) | -3,490 | -2,855 | Pass | -2,952 | Fail | -2,771 |
| Peak Ankle Resistive Moment (Nm) | 49.8 | 60.9 | Pass | 60.6 | Fail | 62.9 |
| Peak Ankle Y-axis Rotation (deg) | 30.4 | 37.2 | Pass | 35.6 | Pass | 33.4 |

*Table 29. Right Ball of Foot Qualification Results for External and In-Dummy DAS EG2595 LX EG3120*

| Parameter | Specification (Sep 2018) | | External DAS | | In-Dummy DAS | |
|---|---|---|---|---|---|---|
| | | | 180403-6 | | 181204-11 | |
| | Min. | Max. | Pass/Fail | Value | Pass/Fail | Value |
| Impact Velocity (m/s) | 4.95 | 5.05 | Pass | 4.98 | Pass | 5.03 |
| Peak Lower Tibia, Fz (N) | -3,490 | -2,855 | Pass | -2,861 | Pass | -2,867 |
| Peak Ankle Resistive Moment (Nm) | 49.8 | 60.9 | Pass | 60.6 | Fail | 65.2 |
| Peak Ankle Y-axis Rotation (deg) | 30.4 | 37.2 | Pass | 34.1 | Pass | 31.8 |

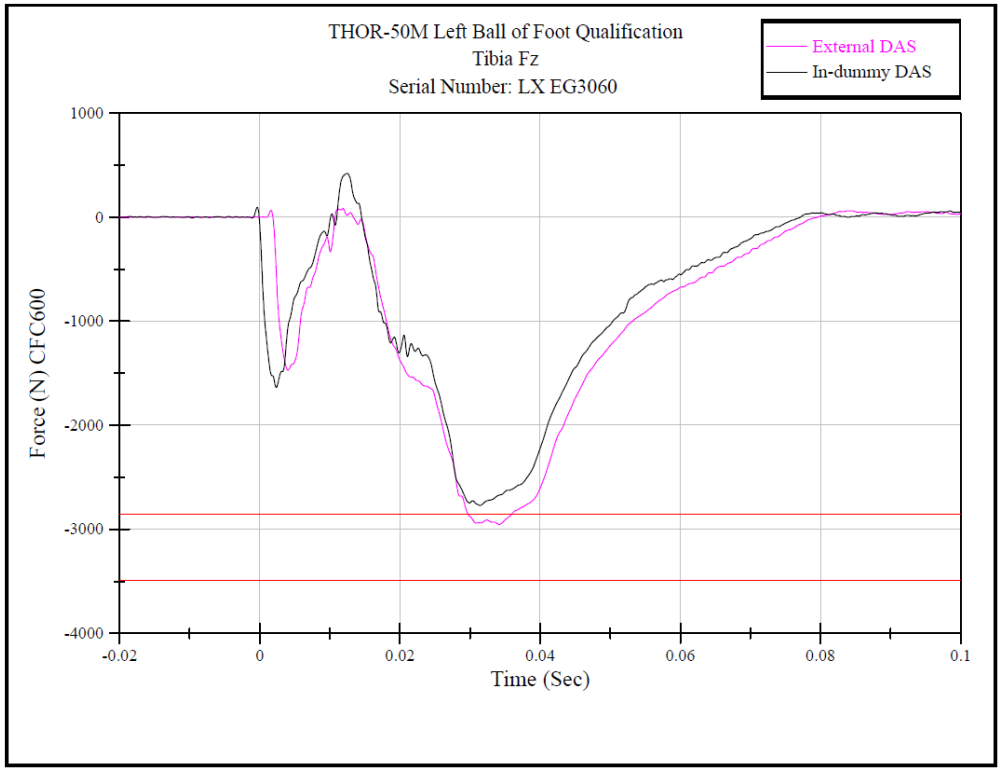


*Figure 63. Left ball of foot: Tibia Fz for external and in-dummy DAS EG2595 LX EG3060*

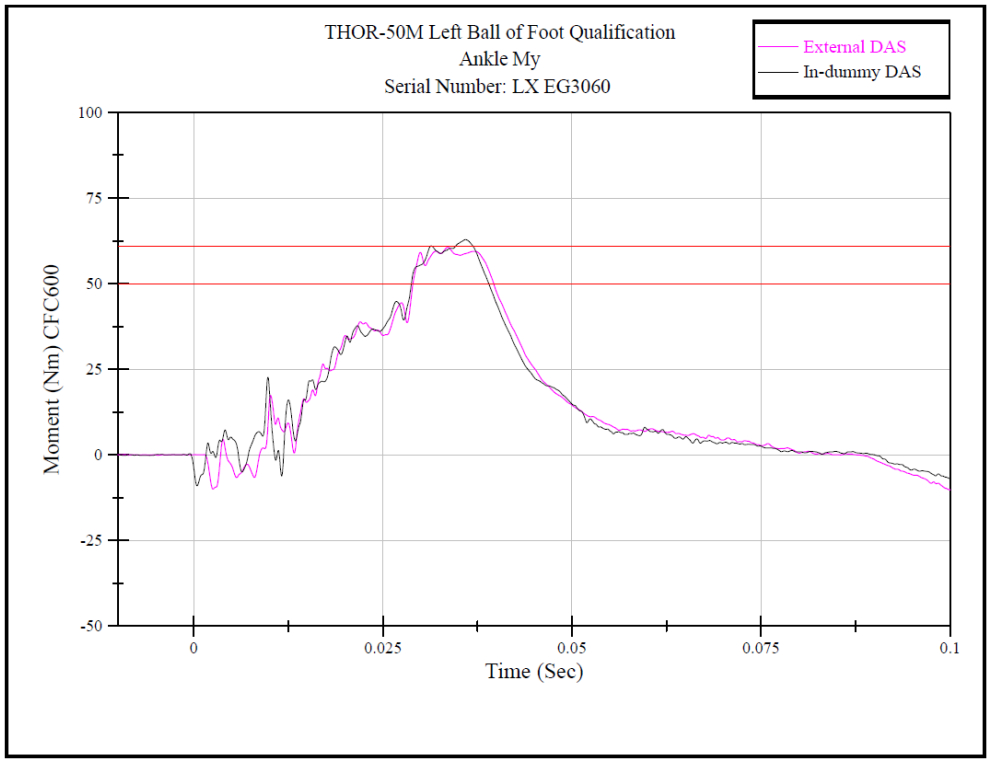


*Figure 64. Left ball of foot: Ankle My for external and in-dummy DAS EG2595 LX EG3060*

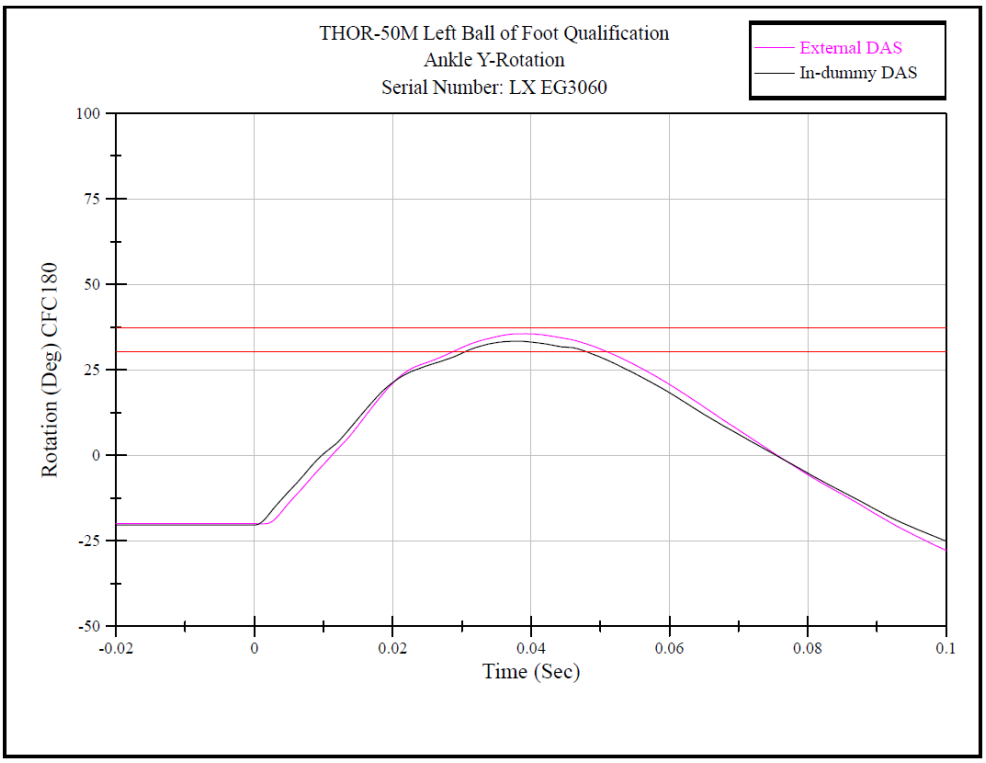


*Figure 65. Left ball of foot: Ankle Y-axis rotation for external and in-dummy DAS EG2595 LX EG3060*

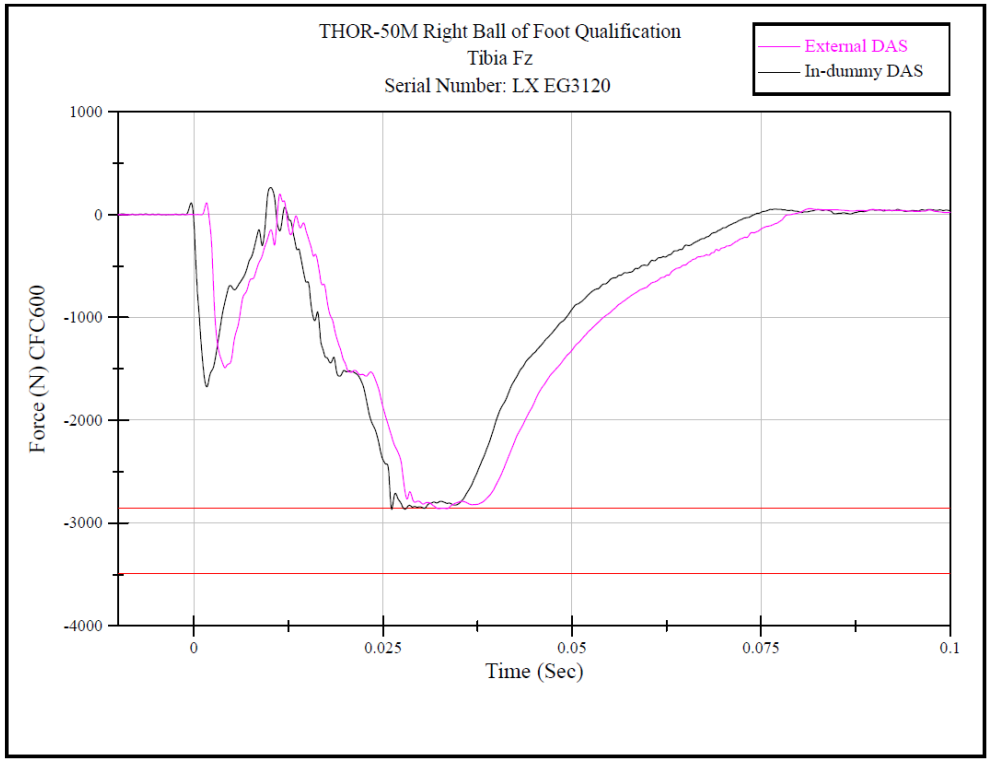


*Figure 66. Right ball of foot: Tibia Fz for external and in-dummy DAS EG2595 LX EG3120*

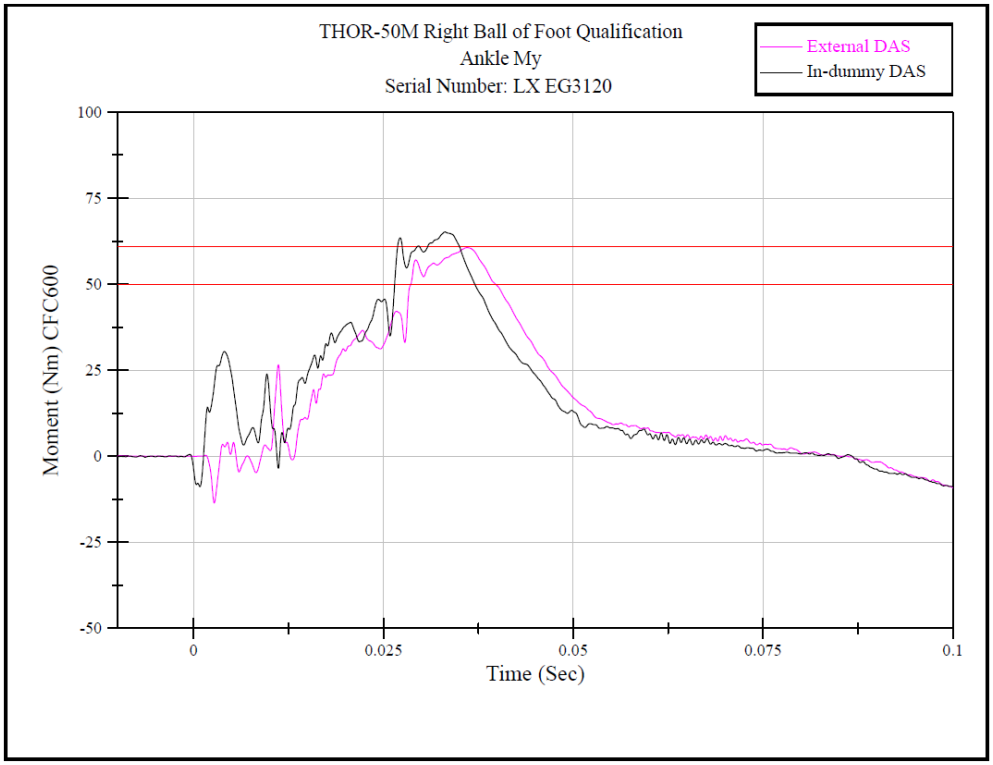


*Figure 67. Right ball of foot: Ankle My for external and in-dummy DAS EG2595 LX EG3120*

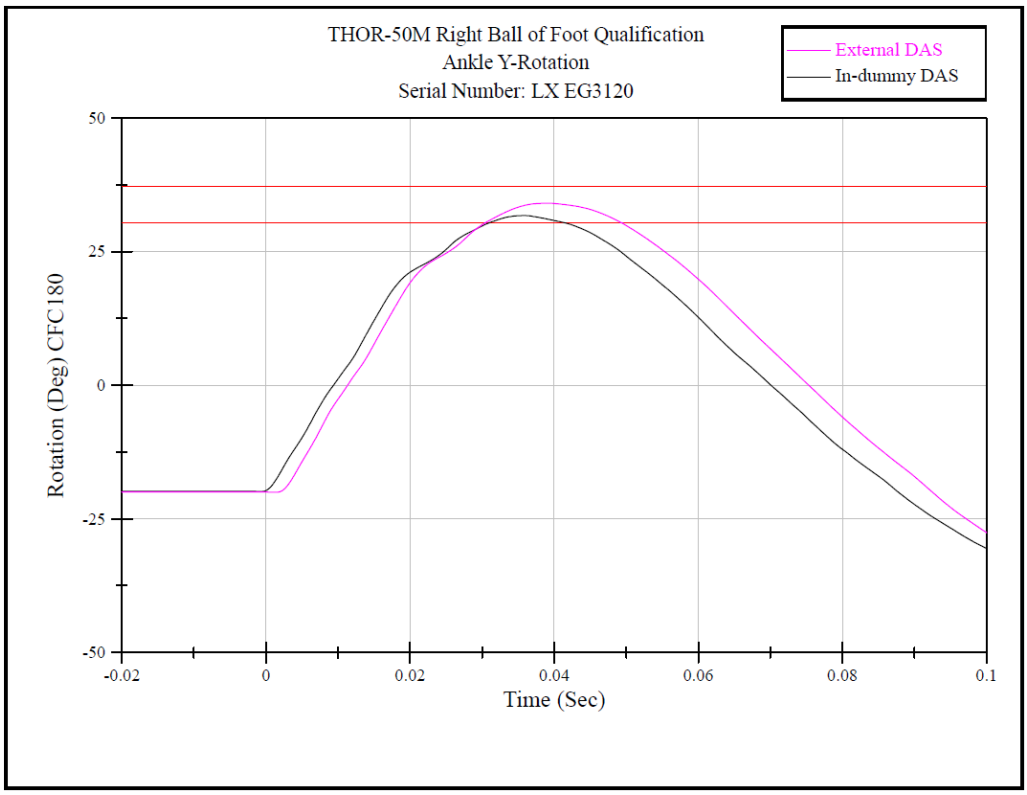


*Figure 68. Right ball of foot: Ankle Y-axis rotation for external and in-dummy DAS EG2595 LX EG3120*

### *Discussion*

The external DAS ATD marginally met all qualification requirements while the in-dummy DAS ATD did not (Table 28 and Table 29). In the instances where the in-dummy DAS ATD did not pass the qualification requirements, the external DAS ATD only marginally passed the qualification requirements. The variance observed between the two tests is consistent with acceptable test-to-test variability. Therefore, it is improbable that the DAS is accountable for the in-dummy DAS ATD not meeting all qualification requirements.

The tibia force for the left and right legs were both at the lower end of the qualification requirement during the external DAS ATD test. During the in-dummy DAS ATD test, the tibia force for the left leg was below the requirement value and the tibia force for the right leg passed with a 12 N margin.

The ankle Y-axis moment was at the upper end of the requirement for the left and right external DAS ATD tests. During the in-dummy DAS ATD series, the left and right ankle Y-axis moment exceeded the requirement.

The definition of T0 was revised between the external and in-dummy DAS ATD tests. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 63 to Figure 68.

## Heel

### *Methodology*

The external DAS ATD and in-dummy DAS ATD underwent heel qualification tests following the qualification procedures described in the 2018 NHTSA qualifications manual. This test examines the dynamic impact response of the heel. In these tests, the molded shoe was used as described in the THOR-50M drawing package (NHTSA, 2023a, 2023b) , while the leg is held rigidly with the tibia horizontal. The pendulum impacts the heel at a velocity of 4.00 ± 0.05 m/s. During these tests, the lower tibia force (Fz) was measured.

### *Qualification Results*

This section shows the results of the heel qualification tests for the external DAS ATD and in-dummy DAS ATD. Table 30 and Table 31 show the test data, followed by plot overlays comparing the two dummy configurations. The left (LX EG3060) and right (LX EG3120) legs were tested for each ATD. The external DAS ATD passed both the left and right heel requirement. The in-dummy DAS ATD passed the left heel but did not pass the right heel requirement.

*Table 30. Left Heel Qualification Results for External and In-Dummy DAS EG2595 LX EG3060*

| **Parameter** | **Specification (September 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180425-11** | | **181211-4** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 3.95 | 4.05 | Pass | 4 | Pass | 4.03 |
| Peak Lower Tibia, Fz (N) | -3,478 | -2,846 | Pass | -3,329 | Pass | -3,316 |

*Table 31. Right Heel Qualification Results for External and In-Dummy DAS EG2595 LX EG3120*

| **Parameter** | **Specification (September 2018)** | | **External DAS** | | **In-Dummy DAS** | |
|---|---|---|---|---|---|---|
| | | | **180413-9** | | **181204-17** | |
| | **Min.** | **Max.** | **Pass/Fail** | **Value** | **Pass/Fail** | **Value** |
| Impact Velocity (m/s) | 3.95 | 4.05 | Pass | 4 | Pass | 4 |
| Peak Lower Tibia, Fz (N) | -3,478 | -2,846 | Pass | -3,454 | Fail | -3,567 |

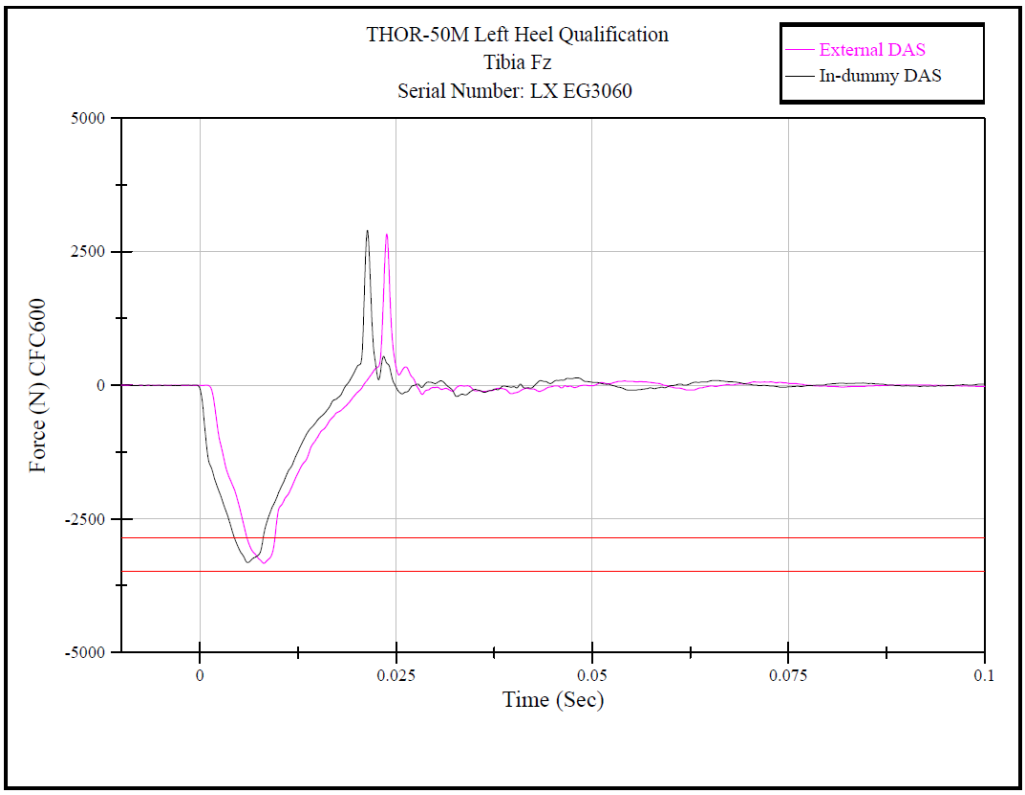


*Figure 69. Left heel: Tibia Fz for external and in-dummy DAS EG2595 LX EG3060*

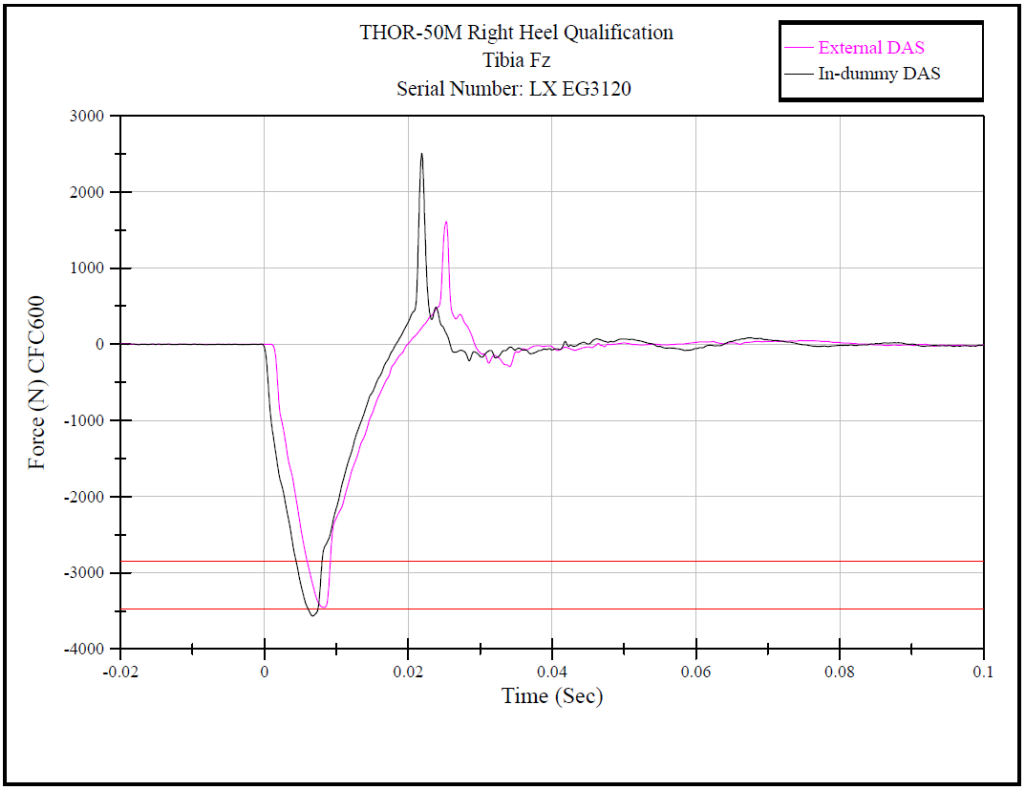


*Figure 70. Right heel: Tibia Fz for external and in-dummy DAS EG2595 LX EG3120*

### *Discussion*

The left and right external DAS ATD met the qualification requirement while the right in-dummy DAS ATD did not (Table 30 and Table 31). In the instance where the in-dummy DAS ATD did not pass the qualification requirements, the external DAS ATD only marginally passed the qualification requirements. The variance observed between the two tests is consistent with acceptable test-to-test variability. Therefore, it is improbable that the DAS is accountable for the in-dummy DAS ATD not meeting all qualification requirements.

The right in-dummy DAS tibia force exceeded the qualification requirement. However, for the right impact, the external results were already at the upper limit of the qualification requirement so while the in-dummy result was slightly greater than the qualification limit, it was like the external DAS result.

The definition of T0 was revised between the external and in-dummy DAS ATD tests to be a force threshold as opposed to a contact switch. This revision resulted in a code change that was responsible for the time shift illustrated in Figure 69 and Figure 70.

## Qualification Results Summary

The SLICE6 DAS, one possible implementation of an in-dummy DAS for the THOR-50M ATD, was evaluated for equivalence after being integrated into a THOR-50M. The in-dummy DAS ATD has undergone evaluations through two full suites of qualification testing. The first series of testing, using the 2018 NHTSA qualifications manual, revealed some differences when comparing individual responses against one another and against the requirements, though in most cases the difference between the baseline and alternate configurations were in the expected test-to-test variability. For the 2018 qualification tests, expected test-to-test variability can be considered as the width of the qualification specifications, which is standardized across all modes at plus or minus 10 percent from the midpoint of the corridor. In all but five measurements, the response of the in-dummy DAS configuration was in the qualification corridor. Of the five measurements that did not meet the qualification specification, most were close enough to the corridor boundary that repeat tests with variations in impact velocity or pre-test positioning would likely bring the response into the specification window. Four of these five were also in 10 percent of the response of the baseline configuration. One exception occurred in the upper leg test, where the peak acetabulum resultant force in the in-dummy DAS configuration was lower than the baseline design. This is likely a test configuration issue as opposed to a difference due to DAS instrumentation.

To capture the impact of the changes made between the 2018 and 2023 versions of the qualification procedures manuals, a second complete set of qualification tests was conducted with the in-dummy DAS using the 2023 qualification specifications (NHTSA, 2023c). The passing results of the second set of in-dummy DAS qualification testing are detailed in Table 32 and Appendix B: Results Using 2023 Qualification Procedure.

*Table 32. Qualification Results Using 2023 Qualification Procedure for In-Dummy DAS ATD*

| Test Mode | Parameter | Units | 2023 Specification | | Pass/Fail | In-Dummy DAS |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| **Head** | Peak Probe Force | N | 5,022 | 6,138 | PASS | 5,455.3 |
| | Peak Head CG Resultant Acceleration | g | 105.3 | 128.7 | PASS | 109.86 |
| **Face** | Peak Probe Force | N | 6,378 | 7,796 | PASS | 7,292 |
| | Peak Head CG Resultant Acceleration | g | 124 | 152 | PASS | 135.3 |
| **Neck Extension** | Peak Upper Neck My | Nm | -25.3 | -20.7 | PASS | -21.92 |
| | Peak Upper Neck Fz | N | -3,210 | -2,626 | PASS | -3,124.3 |
| | Peak Head Angular Velocity ωy | deg/s | *1,855 | *2,267 | PASS | 2,111.7 |
| **Neck Frontal Flexion** | Peak Upper Neck My | Nm | 27.9 | 34.1 | PASS | 34.06 |
| | Upper Neck Fz Most Positive Value Prior to 40ms | N | 774 | 946 | PASS | 784.8 |
| | Peak Head Angular Velocity ωy | deg/s | -2,172 | -1,777 | PASS | -1,895.5 |
| | Peak Head Rotation | deg | -71.0 | -58.1 | PASS | -59.82 |

| Test Mode | Parameter | Units | 2023 Specification | | Pass/Fail | In-Dummy DAS |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| **Neck Lateral Flexion** | Left Upper Neck Mx Most Positive Value after 40ms | Nm | 44.8 | 54.7 | PASS | 52.18 |
| | Left First Peak Upper Neck Angular Velocity ωx | deg/s | -1,498 | -1226 | PASS | -1,359.5 |
| | Left Peak Head Rotation | deg | -45.9 | -37.6 | PASS | -37.62 |
| | Right Upper Neck Mx Most Negative Value after 40ms | Nm | -54.7 | -44.8 | PASS | -51.37 |
| | Right First Max Upper Neck Angular Velocity ωx | deg/s | 1,126 | 1,498 | PASS | 1,333.2 |
| | Right Peak Head Rotation | deg | 37.6 | 45.9 | PASS | 37.73 |
| **Neck Torsion** | Left Peak Upper Neck Mz | Nm | 37.3 | 45.6 | PASS | 43.83 |
| | Left Peak Neck Fixture Rotation | deg | -52.7 | -43.1 | PASS | -43.83 |
| | Left First Peak Upper Neck Angular Velocity ωz | deg/s | -1,529 | -1,251 | PASS | -1,374.9 |
| | Right Peak Upper Neck Mz | Nm | -45.6 | -37.3 | PASS | -43.58 |
| | Right Peak Neck Fixture Rotation | deg | 43.1 | 52.7 | PASS | 44.08 |
| | Right First Peak Upper Neck Angular Velocity ωz | deg/s | 1,251 | 1,529 | PASS | 1,407.7 |

| Test Mode | Parameter | Units | 2023 Specification | | Pass/Fail | In-Dummy DAS |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| Upper Thorax | Peak Probe Force | N | < 3,039 | | PASS | 2,680 |
| | Peak Upper Left Resultant Deflection | mm | 48.3 | 59 | PASS | 52.2 |
| | Peak Upper Right Resultant Deflection | mm | 48.3 | 59 | PASS | 51.5 |
| | Difference | mm | < 5 | | PASS | 0.7 |
| | Force at Left Peak Resultant Deflection | N | 2,409 | 2,944 | PASS | 2,668 |
| | Force at Right Peak Resultant Deflection | N | 2,409 | 2,944 | PASS | 2,679 |
| Lower Thorax | Left Peak Probe Force | N | 3,136 | 3,832 | PASS | 3,797.4 |
| | Left Resultant Deflection at Peak Force | mm | 45.8 | 56 | PASS | 46.87 |
| | Right Peak Probe Force | N | 3,136 | 3,832 | PASS | 3,741 |
| | Right Resultant Deflection at Peak Force | mm | 45.8 | 56 | PASS | 49.8 |
| Abdomen | Peak Probe Force | N | 2,626 | 3,210 | PASS | 2,826 |
| | Left X-axis Deflection at Peak Force | mm | -91.3 | -74.7 | PASS | -89.4 |
| | Right X-axis Deflection at Peak Force | mm | -91.3 | -74.7 | PASS | -85.8 |
| | Difference | mm | < 8.0 | | PASS | 4.0 |

| Test Mode | Parameter | Units | 2023 Specification | | Pass/Fail | In-Dummy DAS |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| Upper Leg | Left Peak Probe Force | N | *7,500 | *9,166 | PASS | 8,394.1 |
| | Left Peak Femur Force, Fz | N | *-4,512 | *-4,428 | PASS | -5,073.4 |
| | Left Peak Resultant Acetabulum Force | N | *2,464 | *3,012 | PASS | 2,884.8 |
| | Right Peak Probe Force | N | *7,500 | *9,166 | PASS | 8,094.2 |
| | Right Peak Femur Force, Fz | N | *-4,512 | *-4,428 | PASS | -4,936.5 |
| | Right Peak Resultant Acetabulum Force | N | *2,464 | *3,012 | PASS | 2,897.8 |
| Knee | Left Peak Femur Force, Fz | N | -7,156 | -5,855 | PASS | -6,198.1 |
| | Left Knee Deflection at Peak Femur Force | mm | -22.2 | -18.2 | PASS | -20.13 |
| | Right Peak Femur Force, Fz | N | -7,156 | -5,855 | PASS | -6,506.6 |
| | Right Knee Deflection at Peak Femur Force | mm | -22.2 | -18.2 | PASS | -19.66 |
| Ankle Inversion | Left Peak Lower Tibia, Fz | N | -555 | -454 | PASS | -483 |
| | Left Peak Ankle Resistive Moment | Nm | -43 | -35.2 | PASS | -36.6 |
| | Left Peak Ankle X-axis Rotation | deg | -37.9 | -31 | PASS | -31.7 |
| | Right Peak Lower Tibia, Fz | N | -555 | -454 | PASS | -534 |
| | Right Peak Ankle Resistive Moment | Nm | 35.2 | 43 | PASS | 40.3 |
| | Right Peak Ankle X-axis Rotation | deg | 31 | 37.9 | PASS | 33.8 |

| Test Mode | Parameter | Units | 2023 Specification | | Pass/Fail | In-Dummy DAS |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| Ankle Eversion | Left Peak Lower Tibia, Fz | N | -629 | -514 | PASS | -580 |
| | Left Peak Ankle Resistive Moment | Nm | 38.7 | 47.3 | PASS | 42.6 |
| | Left Peak Ankle X-axis Rotation | deg | 26.6 | 32.5 | PASS | 27.5 |
| | Right Peak Lower Tibia, Fz | N | -629 | -514 | PASS | -611 |
| | Right Peak Ankle Resistive Moment | Nm | -47.3 | -38.7 | PASS | -45.4 |
| | Right Peak Ankle X-axis Rotation | deg | -32.5 | -26.6 | PASS | 29.0 |
| Ball of Foot | Left Peak Lower Tibia, Fz | N | *-3,487 | *-2,853 | PASS | -2,923 |
| | Left Peak Ankle Resistive Moment | Nm | 49.8 | 60.9 | PASS | 56.3 |
| | Left Peak Ankle Y-axis Rotation | deg | 30.4 | 37.2 | PASS | 33.7 |
| | Right Peak Lower Tibia, Fz | N | -3,490 | -2,855 | PASS | -2,935 |
| | Right Peak Ankle Resistive Moment | Nm | 49.8 | 60.9 | PASS | 56 |
| | Right Peak Ankle Y-axis Rotation | deg | 30.4 | 37.2 | PASS | 32.5 |
| Heel | Left Peak Lower Tibia, Fz | N | -3,478 | -2,846 | PASS | -3,470 |
| | Right Peak Lower Tibia, Fz | N | -3,478 | -2,846 | PASS | -3,456 |

* shows a difference between 2018 and 2023 version

## Sled Tests

Additional testing was conducted using THOR-50M S/N EG2595 (in-dummy DAS) in two simplified sled test conditions: Gold Standard 1 and Gold Standard 2. These tests are described in more detail, along with a comparison of the in-dummy DAS configuration to the baseline THOR-50M configuration (external DAS), in a separate report (NHTSA, 2024) The goal of this testing was to determine if any differences occurred between the external and internal DAS configurations, and if so, whether the magnitude of these differences would affect the biofidelity and injury criteria development analyses.

Overall, there were some differences between the external and in-dummy DAS configurations, but these differences were either small relative to biofidelity and injury criteria analyses or could be explained by differences in input conditions.

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## Oblique Crash Tests

NHTSA conducted tests involving the THOR-50M in both external and in-dummy DAS configurations in the right front passenger seat in a series of vehicle crash tests, using three different deformable barrier faces in the OMDB test mode. The objective of these tests was to evaluate the equivalence of the three different barrier faces, which theoretically provided an opportunity to assess the repeatability and reproducibility of the THOR-50M driver and right front passenger ATDs onboard each test. Saunders and Parent (2023) describes these tests in more detail. In summary, the analysis of the vehicle response showed differences in vehicle crash pulses and intrusions across barrier faces, which resulted in occupant environments that were not sufficiently consistent for use in repeatability and reproducibility analysis. In other words, it was not possible to separate the variability in the ATD response from the variability in the barrier or vehicle response.

The in-dummy DAS ATD did not experience any durability concerns during the test series.

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## Temperature

The temperature in the thoracic cavity of the ATD can exceed the typically recommended ambient temperature for regulatory and consumer information crash tests. In a recent set of vehicle crash tests, NHTSA closely monitored the rib and the lumbar temperature of the THOR-50M with the in-dummy DAS (Saunders et al., 2023). Two different THOR-50M ATDs were employed, each identified by its serial number: DO9799 (external DAS) and EG2595 (in-dummy DAS) for three FMVSS No. 208 unbelted test configurations (right 30° angle, left 30° angle, frontal 0°) at the regulatory speed of 40 km/hr.

Temperature sensors (IES 1404-LC) were installed at two specific locations on both external and in-dummy DAS ATDs, the lumbar spine (Figure 71, left), and the third rib (Figure 71, right), for the purpose of comparison.


*Figure 71. Temperature sensor locations on lumbar spine (left) and third rib (right)*

Subsequently, temperatures were recorded throughout the testing day. Temperature time-history plots were generated based on five tests in which external and in-dummy DAS ATDs were positioned side by side, with one on the driver's seat and the other on the passenger seat.

For FMVSS No. 208 crash testing, the ATD's stable test temperature is in the range of 20.5 to 22.2° C, inclusive, as defined in 49 CFR Part 571 Subpart B, Section 8.1.8.5. In most cases, the temperature was maintained in this range at the time of the crash, except for the temperature at the lumbar area from the in-dummy DAS ATD (Table 33). The blue highlighted numbers show that the temperature was below the stable range while the red number show the temperature was above. The in-dummy DAS was activated approximately 30 to 40 minutes prior to the test, which caused the temperature in the lumbar spine to rise by 2 to 4° C. While there were slight increases in temperature observed in the rib area, the temperature remained within the specified temperature limits. To consistently maintain the temperature range, it is advisable to limit the DAS "ON" time as a routine practice. Additionally, NHTSA used a portable fume extractor device to assist in maintaining the temperature of the WorldSID-50M side impact dummy, which also incorporates an in-dummy DAS system. This device can also be employed during tests involving the THOR-50M with in-dummy DAS.

*Table 33. Temperature at Various ATD Thoracic Locations Before and During Test*

| Test ID | Temperature (ºC) 30 min before test | | | | | Temperature (ºC) at Test Time | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10821 | 11521 | 90721 | 92221 | 92421 | 10821 | 11521 | 90721 | 92221 | 92421 |
| Ambient | 20.4 | 21.7 | 21.2 | 21.8 | 21.5 | 20.4 | 21.3 | 21.1 | 21.7 | 21.5 |
| DO9799 Rib 2 | 18.9 | 19.7 | 21.2 | 20.9 | 21.5 | 18.9 | 19.8 | 21.3 | 21.1 | 21.6 |
| DO9799 Lumbar | 17.6 | 19.1 | 21 | 20.9 | 21.5 | 17.9 | 19.4 | 21.1 | 21.1 | 21.6 |
| EG2595 Rib 2 | 18.6 | 20.7 | 21.1 | 21.3 | 21.9 | 19 | 21.3 | 21.4 | 21.5 | 22 |
| EG2595 Lumbar | 17.9 | 21.2 | 21.3 | 22 | 22.2 | 19.3 | 25.2 | 24.8 | 24.3 | 25.3 |

## Summary

The SLICE6 DAS, one possible implementation of an in-dummy DAS for the THOR-50M ATD, was evaluated for equivalence after being integrated into a THOR-50M. The in-dummy DAS ATD has undergone evaluations through a full suite of qualification testing. This testing revealed some differences when comparing individual responses against one another and against the requirements, though in most cases the difference between the baseline and alternate configurations were in the expected test-to-test variability. For the 2018 qualification tests, expected test-to-test variability can be considered as the width of the qualification specifications, which is standardized across all modes at plus or minus 10 percent from the midpoint of the corridor. In all but five measurements, the response of the in-dummy DAS configuration was in the qualification corridor. Of the five measurements that did not meet the qualification specification, most were close enough to the corridor boundary that repeat tests with variations in impact velocity or pre-test positioning would likely bring the response into the specification window. Four of these five were also in 10 percent of the response of the baseline configuration. One exception occurred in the upper leg test, where the peak acetabulum resultant force in the in-dummy DAS configuration was lower than the baseline design. This is likely a test configuration issue as opposed to a difference due to DAS instrumentation. In the subsequent 2023 qualification tests, with an updated upper leg qualification procedure, the THOR-50M equipped with the in-dummy DAS setup consistently met the qualification specifications.

After the installation of the SLICE system, this in-dummy DAS configuration has been used in many tests and has consistently qualified without any issues. The THOR-50M, equipped with the in-dummy DAS, was subjected to simplified sled tests in two distinct test conditions. There were some differences in the performance of the external and in-dummy DAS configurations, but these were minor relative to biofidelity and injury criteria or were due to differences in input conditions.

NHTSA tested the THOR-50M in both external and in-dummy DAS configurations in the right front passenger seat during vehicle crash tests using three different deformable barrier faces in OMDB mode. Some OMDB tests showed differences between the configurations, but it was not clear whether this was due to variation in dummy positioning, vehicle response, barrier used, or restraint system response. The in-dummy DAS ATD had no durability issues during the tests.

During the FMVSS 208 unbelted tests, the in-dummy DAS closely monitored temperature changes in the thoracic and lumbar areas. Elevated temperatures were observed in the lumbar spine area. To address this, it is suggested to restrict the duration of DAS operation and/or employ a portable fume extractor device to manage temperature levels effectively.

Based on these tests, NHTSA has tentatively concluded that the THOR-50M with the in-dummy DAS is functionally equivalent to its counterpart equipped with an external DAS. Consequently, NHTSA is proposing the adoption of the in-dummy DAS as a permitted optional instrumentation method for its testing procedures.

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# Appendix A. MASS, MOI, and CG

When installing the SLICE6 into the dummy, modifications were made on several parts of the THOR-50M, such as the lower thoracic spine assembly, to have the attachment of the DAS hardware to the rigid components of the ATD. Following this, measurements were taken for each body segment of an individual dummy, including mass, moment of inertia (MOI), and center of gravity (CG). These measurements were subsequently compared to the external DAS ATDs to ensure that there is no major change after integration of the in-dummy DAS.

To calculate the total thorax mass, an estimated jacket mass of 0.43 kg was included. This jacket mass was only considered in the calculation of thorax mass and was not factored into other specifications such as CGs and MOIs. Table A-1 provides a summary of mass, CG, and MOI for specific dummy serial numbers.

NHTSA plans to verify that the physical hardware maintains the mass, MOI, and CG location of the ATD and its individual body segments. More data will be collected from both external and in-dummy DAS ATDs and tolerances will be included in the final rule.

*Table A-1. CG, MOI, and Mass Measurements*

| | | **CG (CM)** | | | | **Moment of Inertia (KG-CM²)** | | | | **Assembly Weight (KG)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **External DAS** | | | **In-Dummy DAS** | **External DAS** | | | **In-Dummy DAS** | **External DAS** | | | **In-Dummy DAS** |
| Segment | DIR | DL9207 | DO9799 | DO9788 | EG2595 | DL9207 | DO9799 | DO9788 | EG2595 | DL9207 | DO9799 | DO9788 | EG2595 |
| Head | x | -0.76 | 0.56 | 0.25 | 0.79 | 209.13 | 216.12 | 207.68 | 209.25 | 4.51 | 4.68 | 4.50 | 4.49 |
| | y | 0.25 | -0.25 | -0.25 | -0.18 | 224.20 | 230.87 | 222.91 | 221.02 | | | | |
| | z | 5.54 | 5.74 | 5.82 | 5.56 | 154.00 | 158.99 | 154.52 | 150.51 | | | | |
| Neck | x | 0.20 | 0.03 | 0.13 | -0.05 | 151.66 | 152.80 | 152.21 | 151.97 | 2.37 | 2.37 | 2.36 | 2.36 |
| | y | 0.03 | -0.08 | 0.03 | 0.10 | 156.68 | 156.66 | 156.15 | 155.43 | | | | |
| | z | 11.05 | 10.97 | 11.10 | 11.10 | 16.31 | 16.42 | 16.15 | 16.12 | | | | |
| Upper Arm | x | 0.10 | -0.15 | 0.23 | 0.25 | 81.23 | 81.09 | 79.42 | 78.57 | 1.72 | 1.70 | 1.70 | 1.66 |
| | y | -0.10 | -0.20 | -0.10 | -0.13 | 84.60 | 84.93 | 83.35 | 83.38 | | | | |
| | z | -12.78 | -12.50 | -12.73 | -12.52 | 13.32 | 12.84 | 12.93 | 13.16 | | | | |
| Forearm | x | -0.58 | -0.51 | -0.36 | -0.51 | 126.19 | 127.29 | 122.18 | 131.98 | 1.70 | 1.66 | 1.66 | 1.69 |
| | y | -0.03 | -0.03 | -0.03 | 0.10 | 129.45 | 123.94 | 125.66 | 126.85 | | | | |
| | z | -9.27 | -9.32 | -9.30 | -9.40 | 10.48 | 10.04 | 10.05 | 10.29 | | | | |

| *Note: Thorax measurements of DO9799 were taken WITHOUT the jacket. | | CG (CM) | | | | Moment of Inertia (KG-CM²) | | | | Assembly Weight (KG) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | External DAS | | | In-Dummy DAS | External DAS | | | In-Dummy DAS | External DAS | | | In-Dummy DAS |
| Segment | DIR | DL9207 | DO9799 | DO9788 | EG2595 | DL9207 | DO9799 | DO9788 | EG2595 | DL9207 | DO9799 | DO9788 | EG2595 |
| Hand | x | 5.56 | 5.56 | 5.46 | 5.46 | 3.70 | 3.74 | 4.10 | 3.74 | 0.55 | 0.55 | 0.57 | 0.56 |
| | y | 0.25 | 0.25 | -0.18 | 0.20 | 9.54 | 9.75 | 10.66 | 9.78 | | | | |
| | z | -0.25 | 0.53 | -0.1 | 0.00 | 11.37 | 11.49 | 12.76 | 13.16 | | | | |
| Thigh | x | 0.25 | 0.18 | 0.2 | -0.03 | 651.19 | 649.89 | 641.86 | 642.33 | 5.67 | 5.70 | 5.62 | 5.63 |
| | y | 0.53 | -0.25 | -0.18 | 0.15 | 640.44 | 658.07 | 627.29 | 649.17 | | | | |
| | z | 12.7 | 12.45 | 12.45 | 12.65 | 106.53 | 105.19 | 100.86 | 103.13 | | | | |
| Leg | x | -0.74 | -0.81 | -0.66 | -0.66 | 383.91 | 389.39 | 393.21 | 394.40 | 3.32 | 3.39 | 3.40 | 3.56 |
| | y | 0.13 | 0.25 | 0.15 | -0.25 | 394.25 | 396.63 | 412.11 | 402.92 | | | | |
| | z | 20.07 | 19.94 | 19.91 | 19.79 | 26.63 | 26.06 | 23.05 | 35.90 | | | | |
| Foot with Rubber Shoe | x | 4.14 | 4.32 | 4.17 | 4.37 | 19.40 | 19.29 | 18.85 | 18.86 | 1.61 | 1.60 | 1.60 | 1.58 |
| | y | -0.25 | -0.25 | 0.25 | 0.05 | 85.94 | 86.06 | 86.83 | 85.15 | | | | |
| | z | -5.38 | -5.33 | -5.11 | -5.16 | 81.49 | 80.20 | 81.86 | 81.82 | | | | |
| *Thorax | x | 5.18 | 4.37 | 4.24 | 4.65 | 5,284.65 | 4,883.39 | 5,535.24 | 5,440.80 | 23.53 | 21.95 | 23.52 | 23.26 |
| | y | -0.03 | 0.97 | 0.41 | 0.76 | 4,667.92 | 4,254.83 | 4,849.76 | 4,769.01 | | | | |
| | z | 6.38 | 6.45 | 6.38 | 6.50 | 2,082.85 | 1,728.76 | 2,000.22 | 2,019.10 | | | | |
| Abdomen | x | 7.29 | 7.87 | 8.00 | 8.15 | 147.70 | 129.37 | 141.52 | 130.41 | 2.72 | 2.67 | 2.66 | 2.66 |
| | y | 0.08 | -0.08 | -0.03 | 0.20 | 101.16 | 100.28 | 101.60 | 98.60 | | | | |
| | z | 4.9 | 4.5 | 4.29 | 4.57 | 195.12 | 203.39 | 189.78 | 206.62 | | | | |
| Pelvis | x | 11.15 | 11.18 | 10.92 | 10.85 | 1,593.79 | 1,639.33 | 1,592.66 | 1,605.71 | 15.18 | 15.24 | 15.23 | 14.98 |
| | y | 0 | 0 | 0 | 0.05 | 915.31 | 915.79 | 898.68 | 884.28 | | | | |
| | z | -5.69 | -4.93 | -5.84 | -5.87 | 2,112.92 | 2,139.73 | 2,070.06 | 2,078.60 | | | | |

# Appendix B. Results Using 2023 Qualification Procedure

NHTSA performed an additional full qualification series with the in-dummy DAS THOR-50M using the 2023 qualification procedure. The specifications and qualification results are summarized in Table 32 and Figures B-1 to B-70.

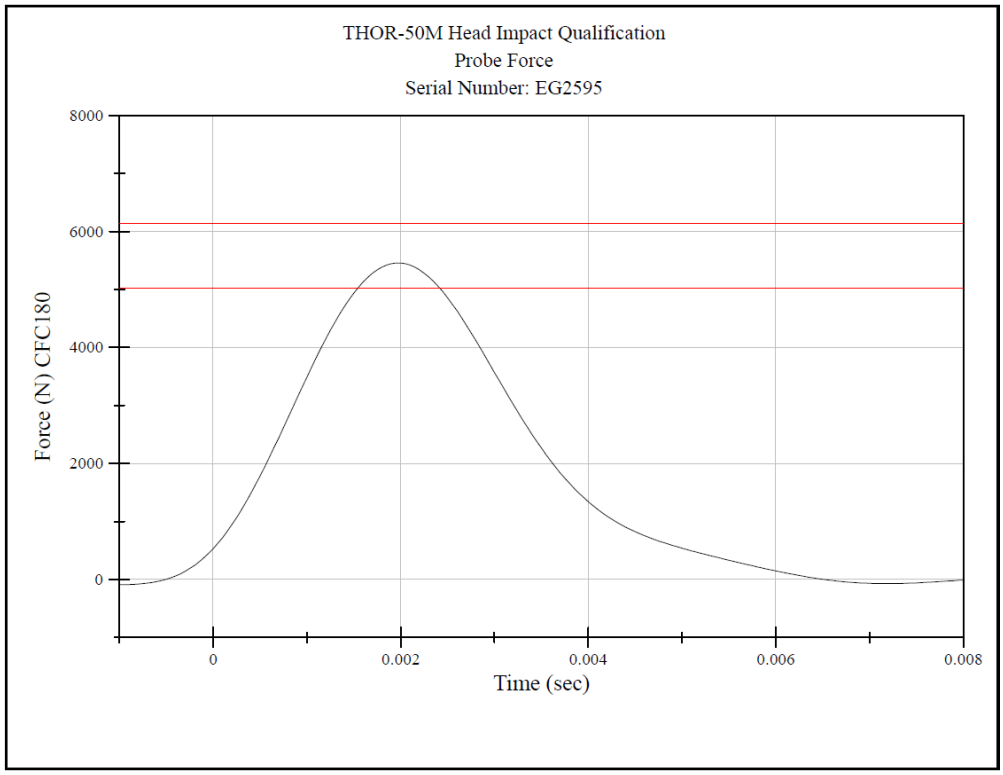


*Figure B-1. Head impact: Probe force for in-dummy DAS EG2595 (2023 version)*

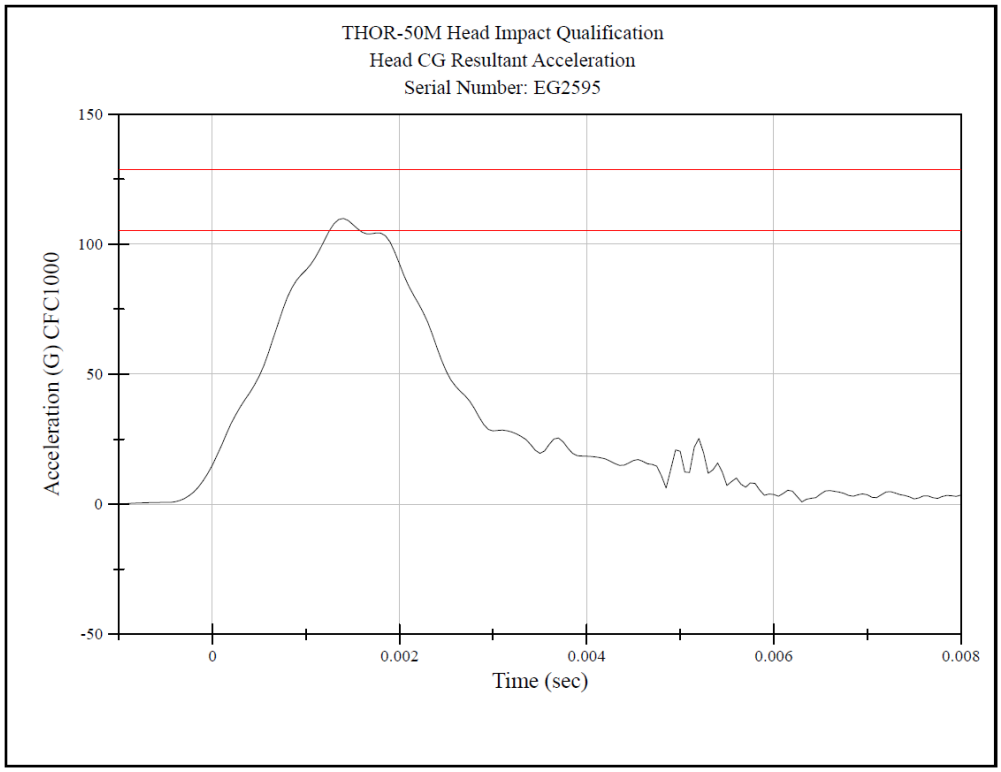


*Figure B-2. Head impact: Head CG resultant acceleration for in-dummy DAS EG2595 (2023 version)*

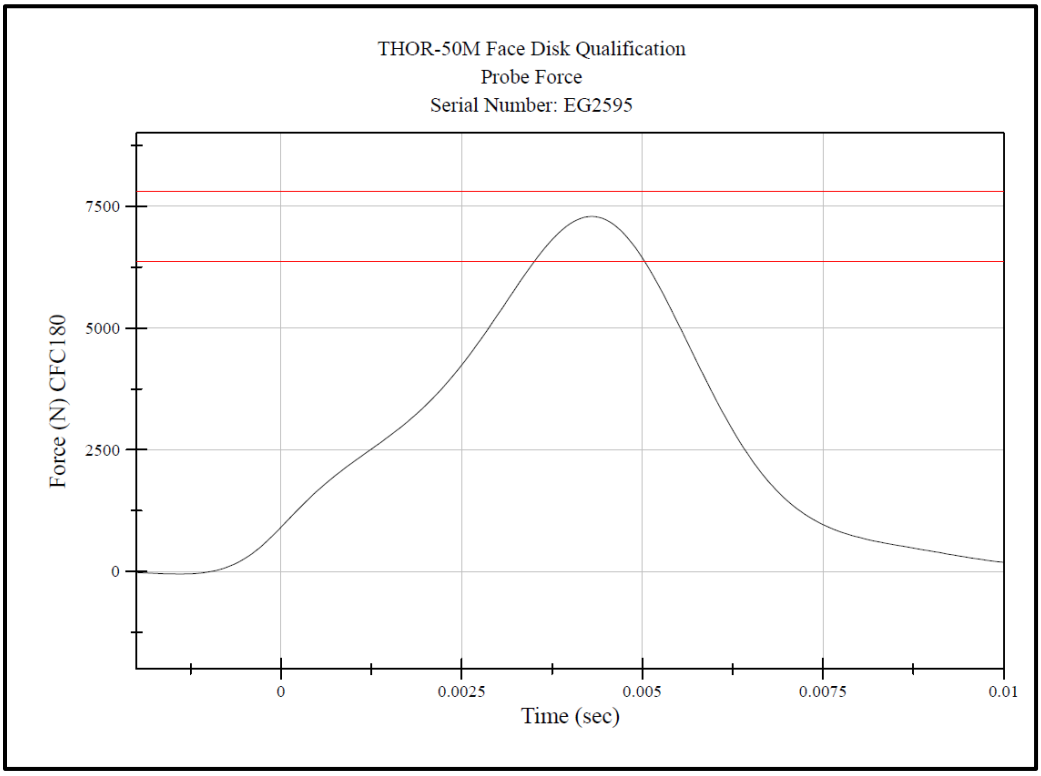


*Figure B-3. Face rigid disk impact: Probe force for in-dummy DAS EG2595 (2023 version)*

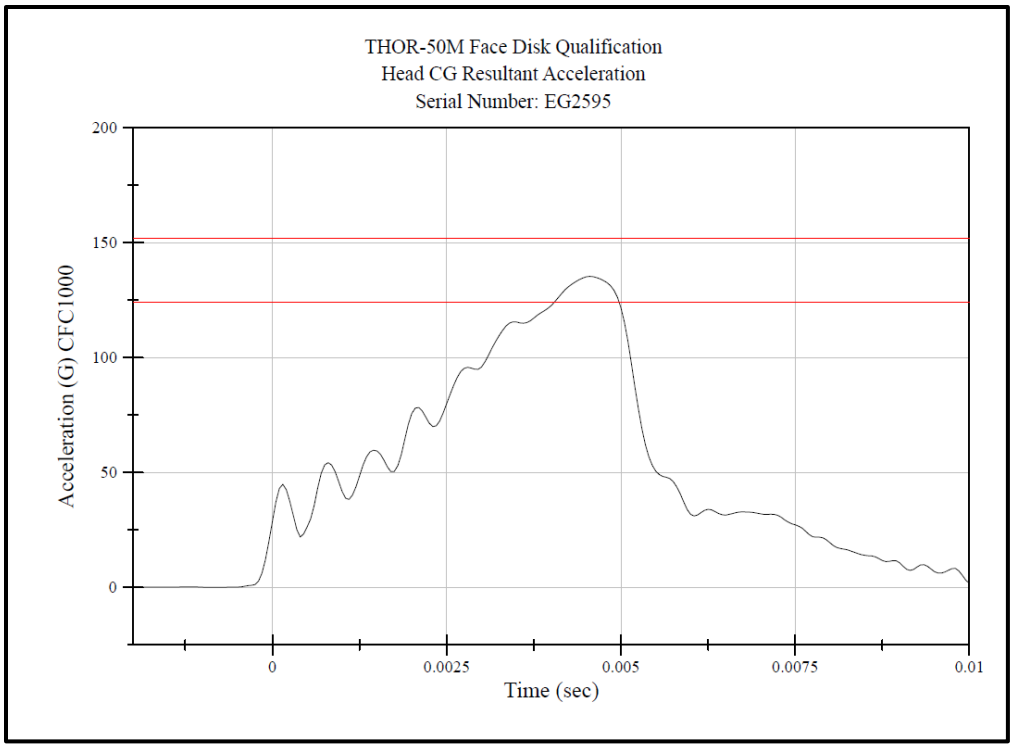


*Figure B-4. Face rigid disk impact: Head CG resultant acceleration for in-dummy DAS EG2595 (2023 version)*

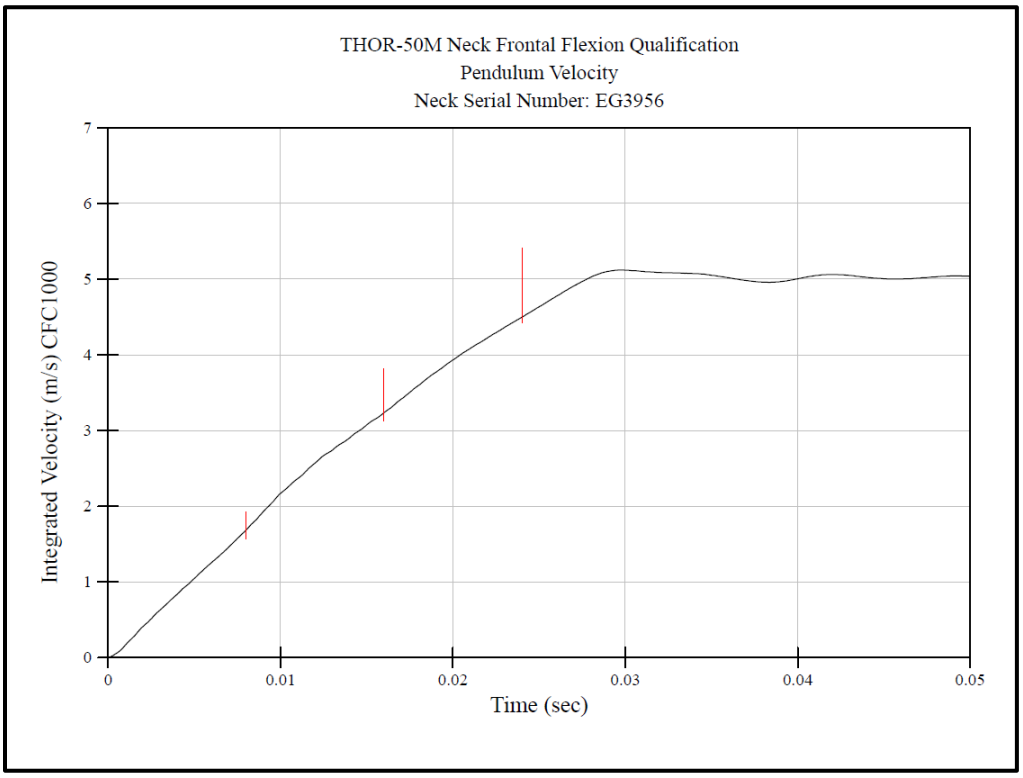


*Figure B-5. Neck frontal flexion: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

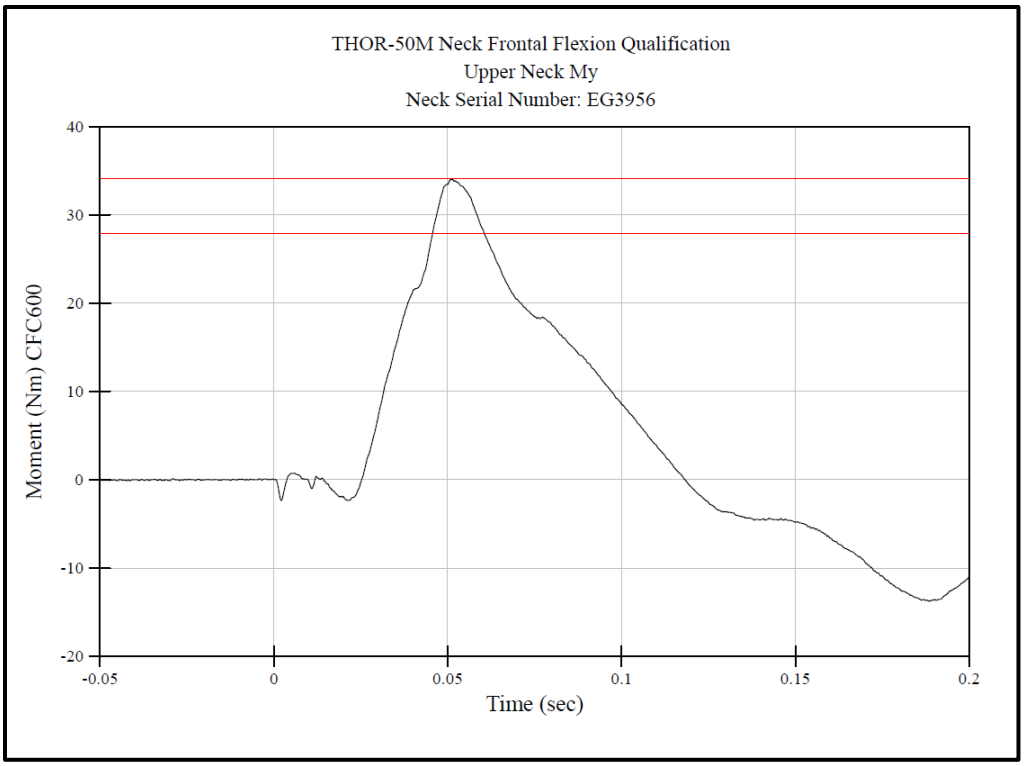


*Figure B-6. Neck frontal flexion: Upper neck My for in-dummy DAS neck EG3956 (2023 version)*

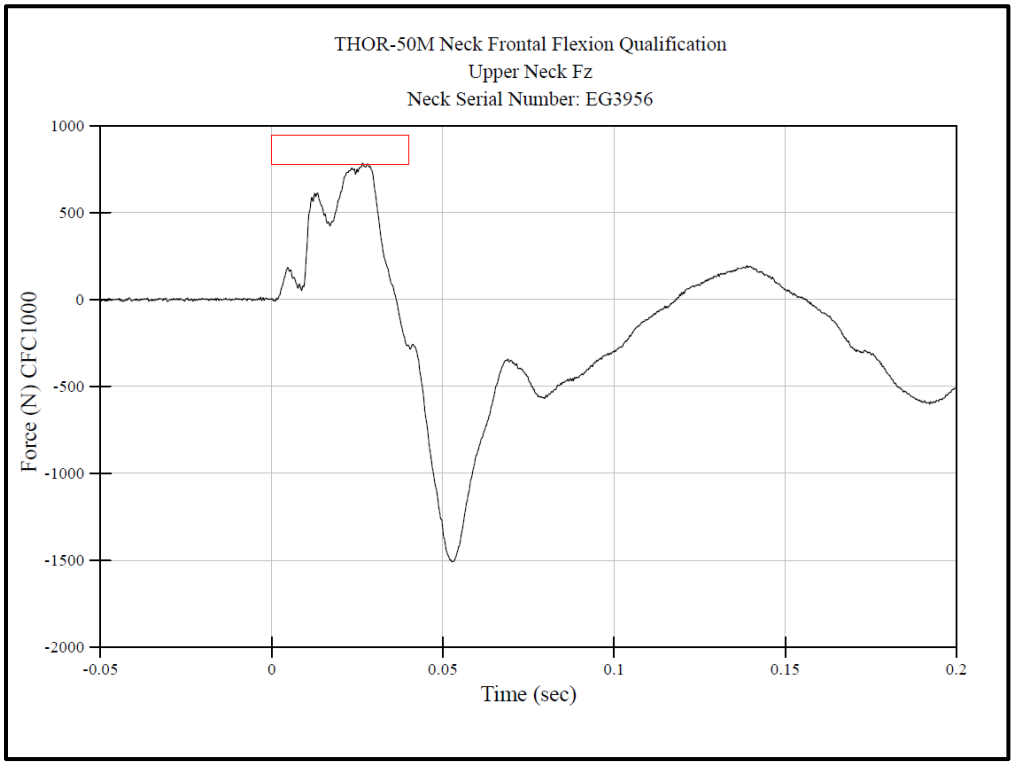


*Figure B-7. Neck frontal flexion: Upper neck Fz for in-dummy DAS neck EG3956 (2023 version)*

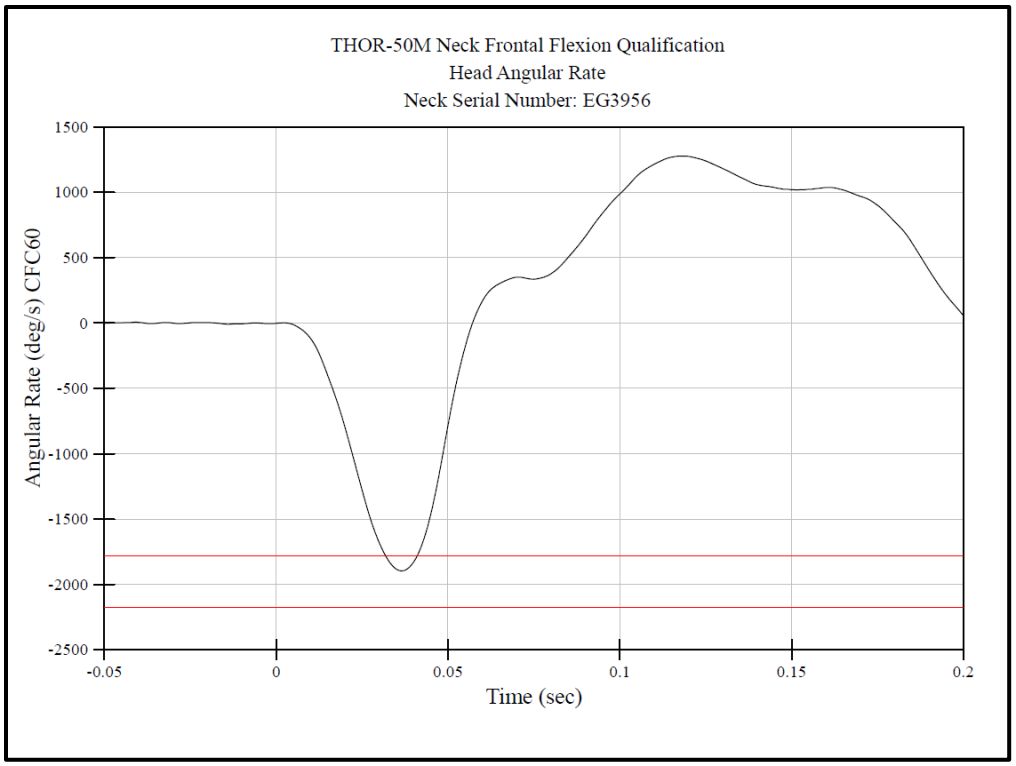


*Figure B-8. Neck frontal flexion: Head angular velocity ωy for in-dummy DAS neck EG3956 (2023 version)*

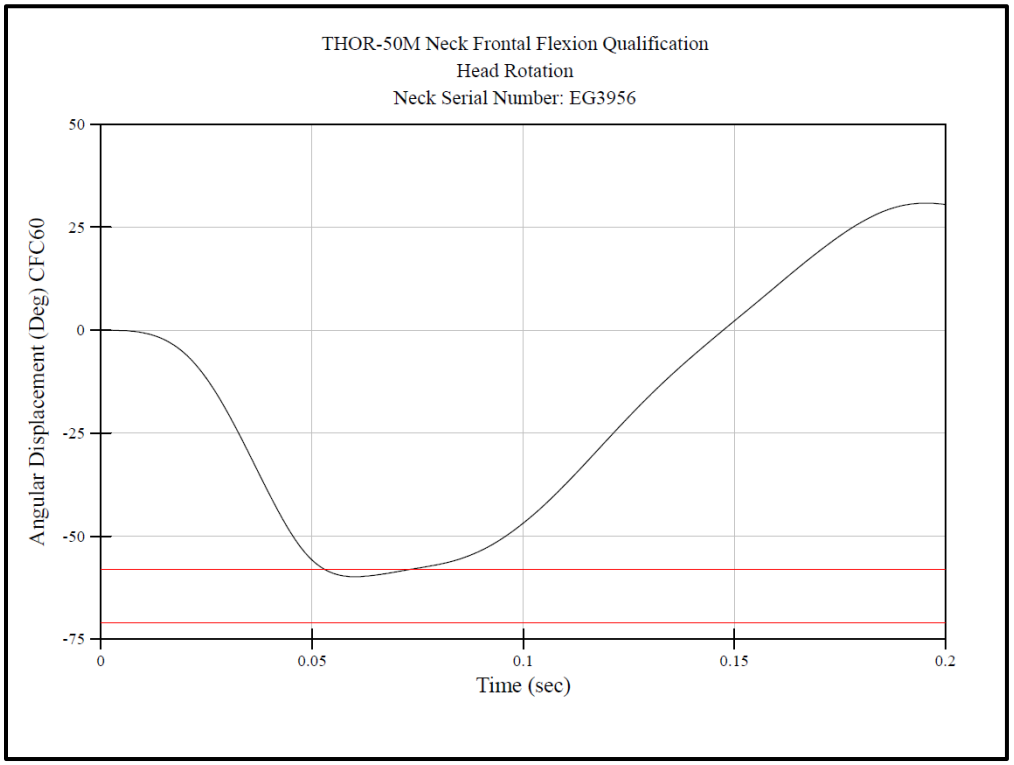


*Figure B-9. Neck frontal flexion: Head rotation for in-dummy DAS neck EG3956 (2023 version)*

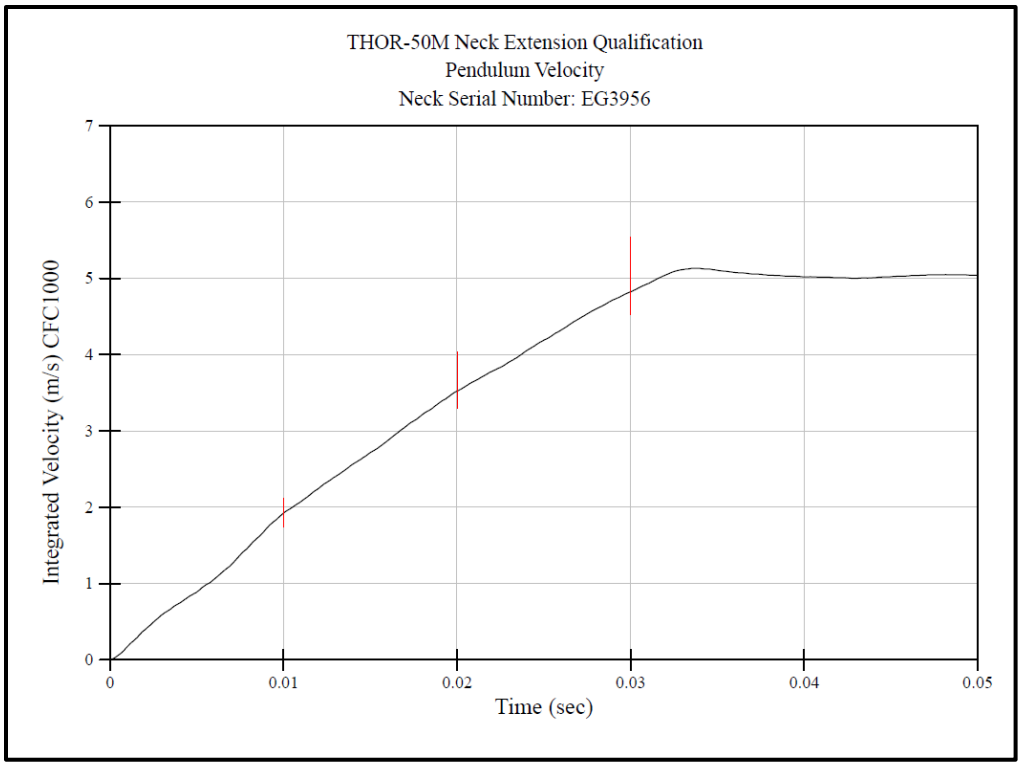


*Figure B-10. Neck extension: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

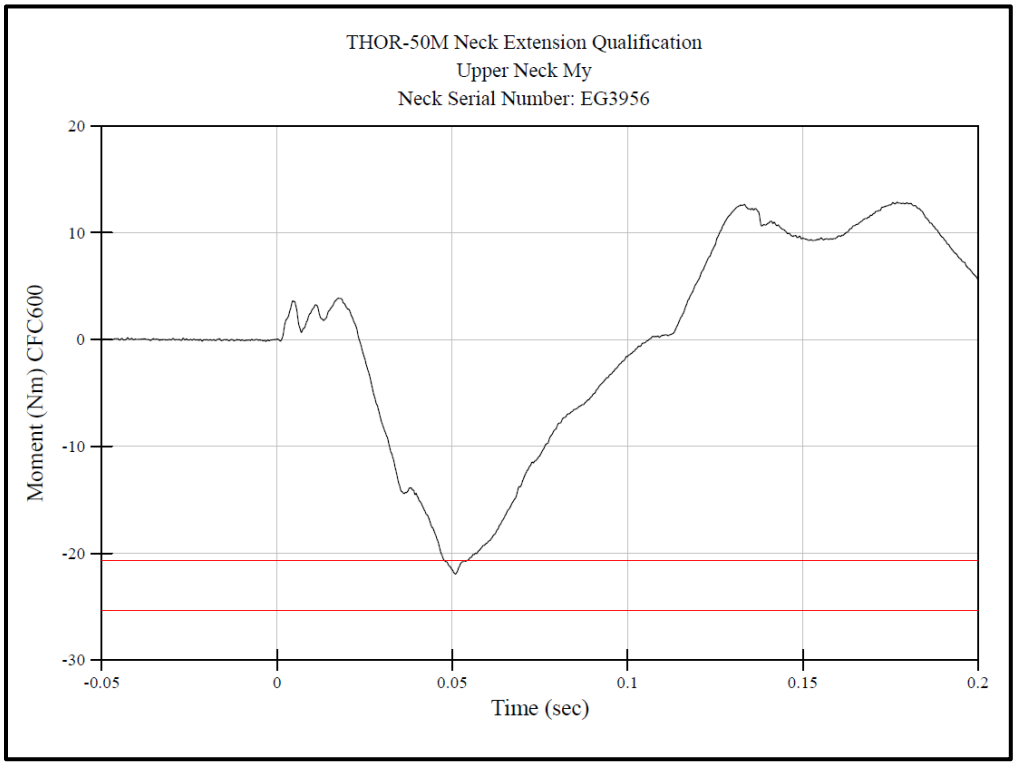


*Figure B-11. Neck extension: Upper neck My for in-dummy DAS neck EG3956 (2023 version)*

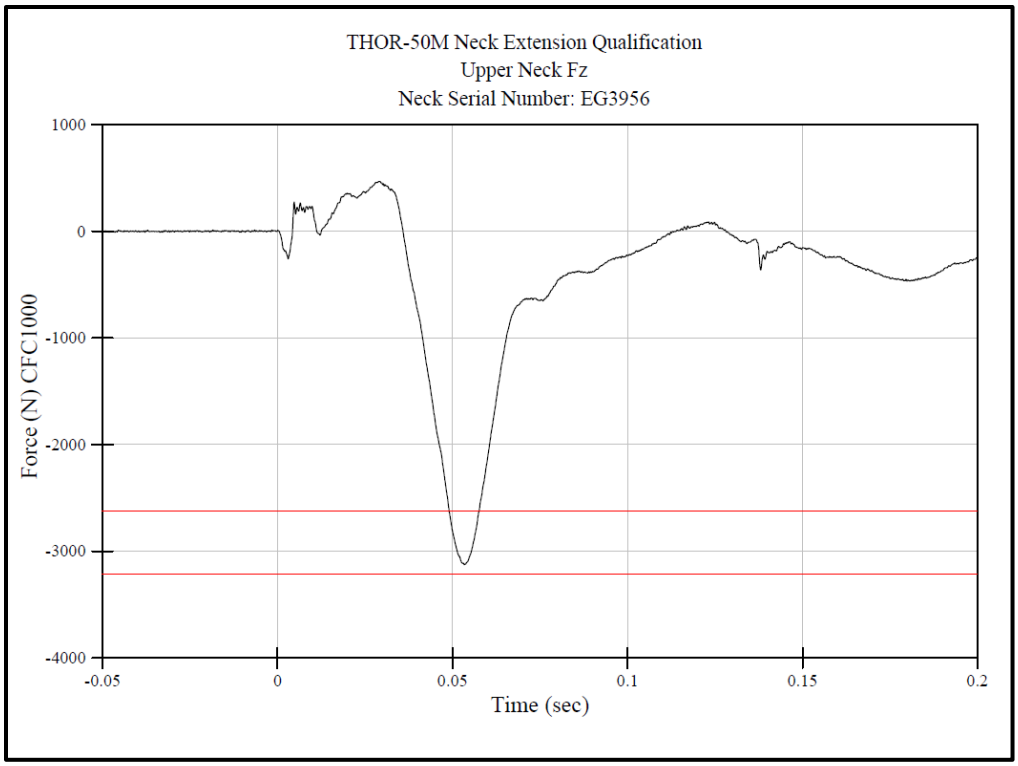


*Figure B-12. Neck extension: Upper neck Fz for in-dummy DAS neck EG3956 (2023 version)*

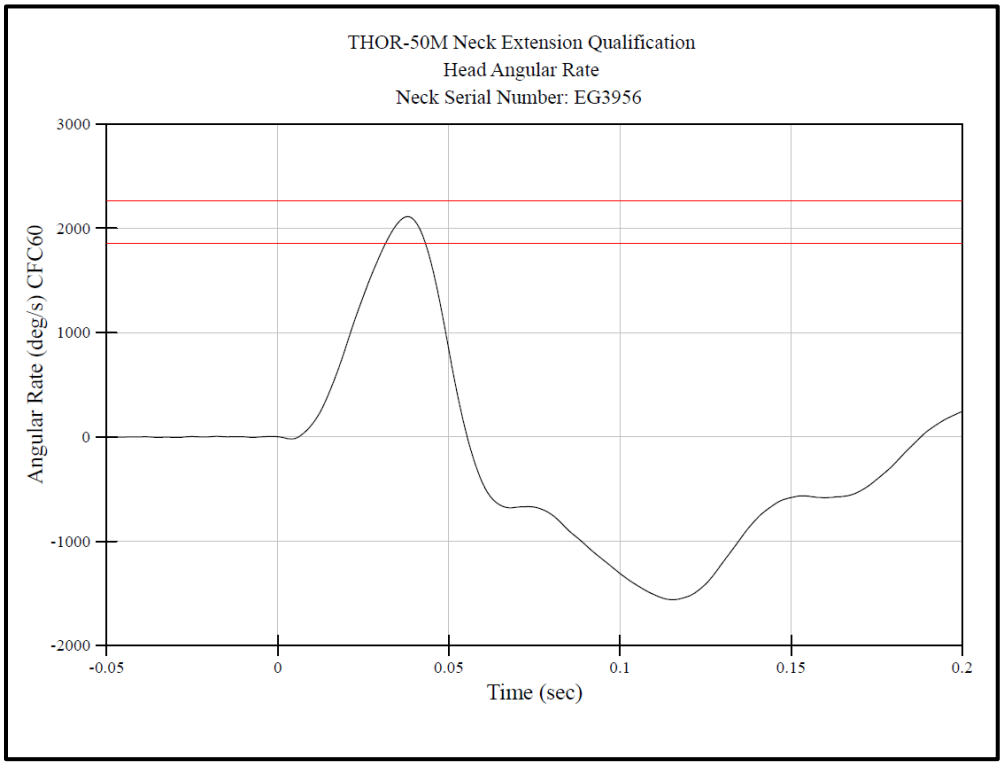


*Figure B-13. Neck extension: Head angular velocity ωy for in-dummy DAS neck EG3956 (2023 version)*

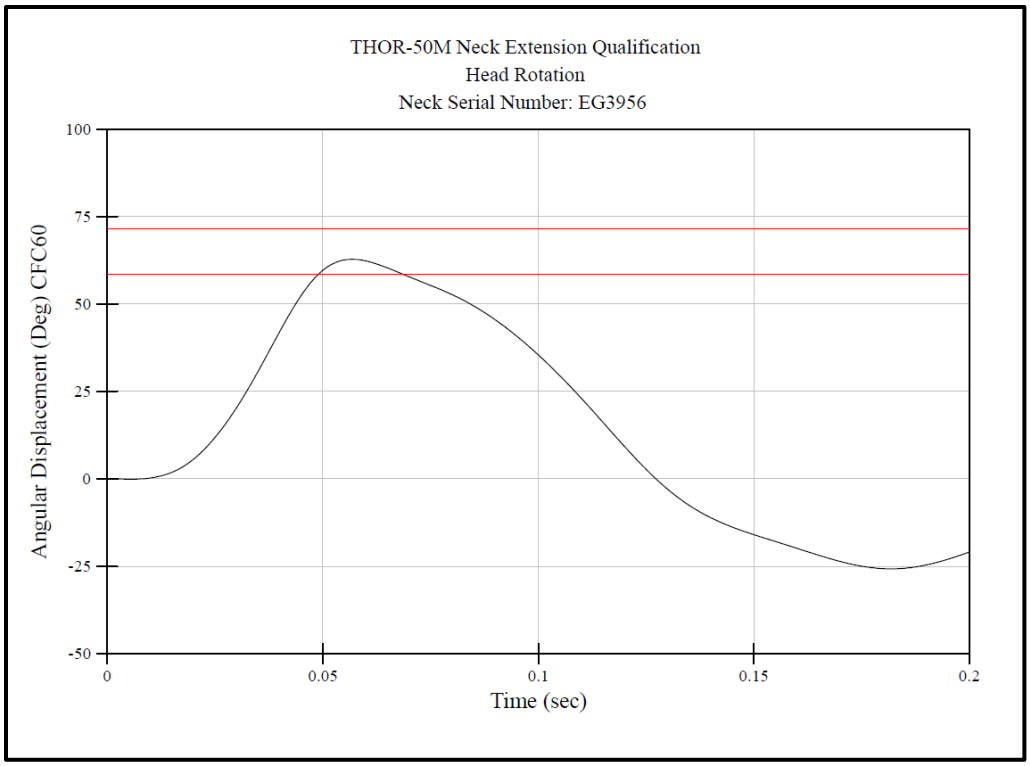


*Figure B-14. Neck extension: Head rotation for in-dummy DAS neck EG3956 (2023 version)*

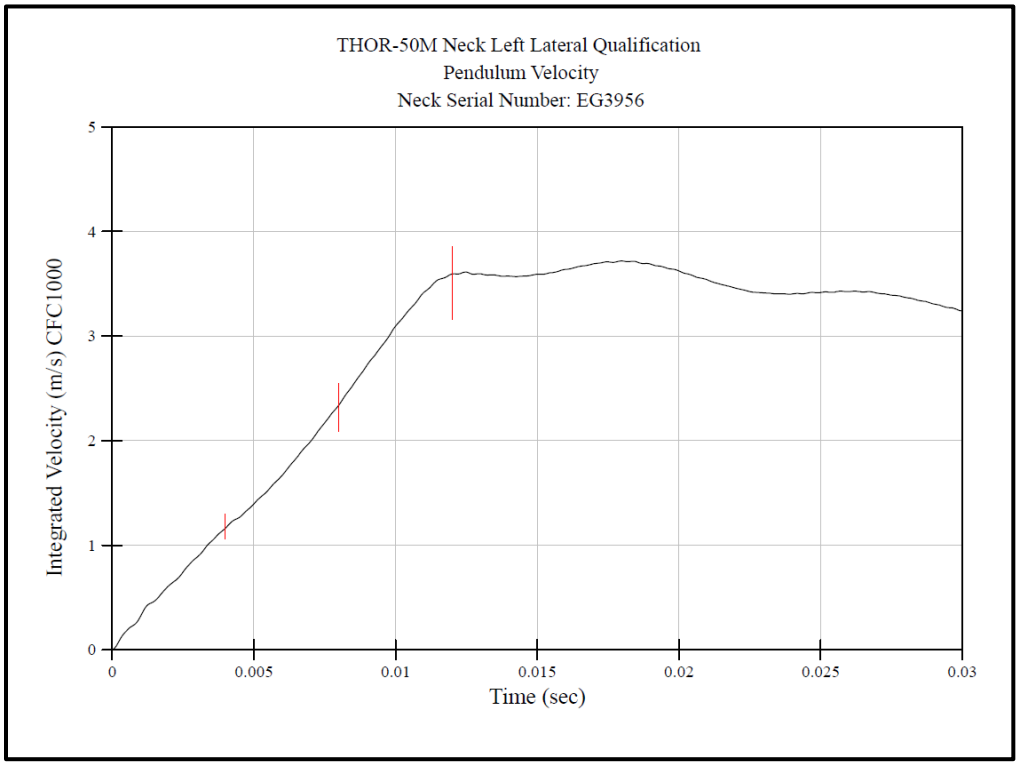


*Figure B-15. Neck left lateral flexion: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

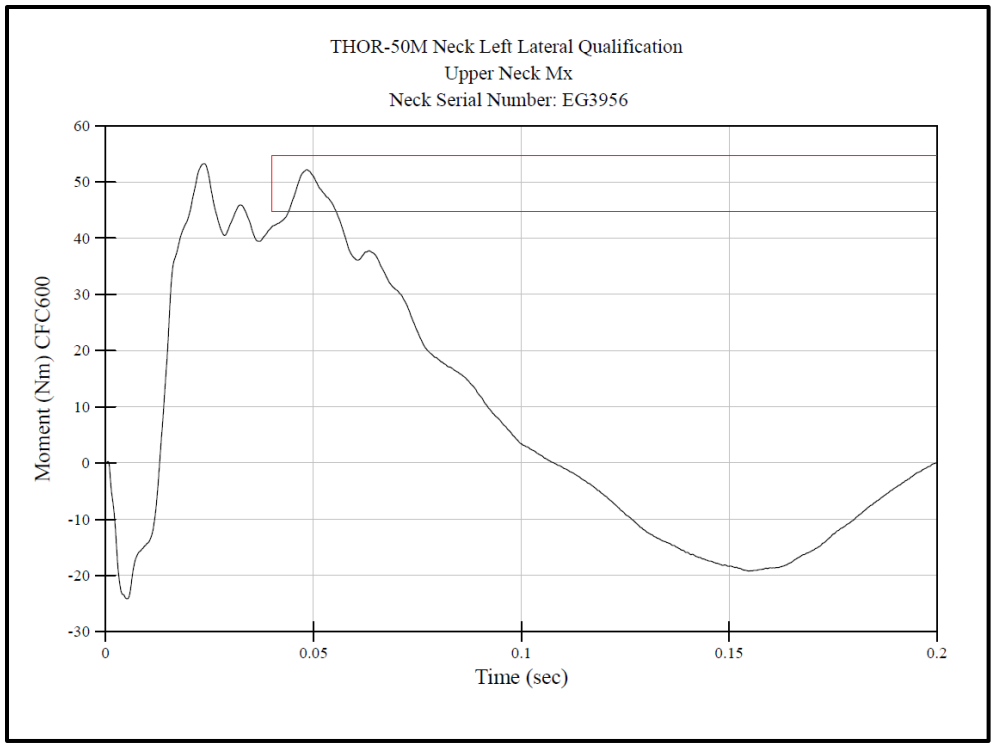


*Figure B-16. Neck left lateral flexion: Upper neck Mx for in-dummy DAS neck EG3956 (2023 version)*

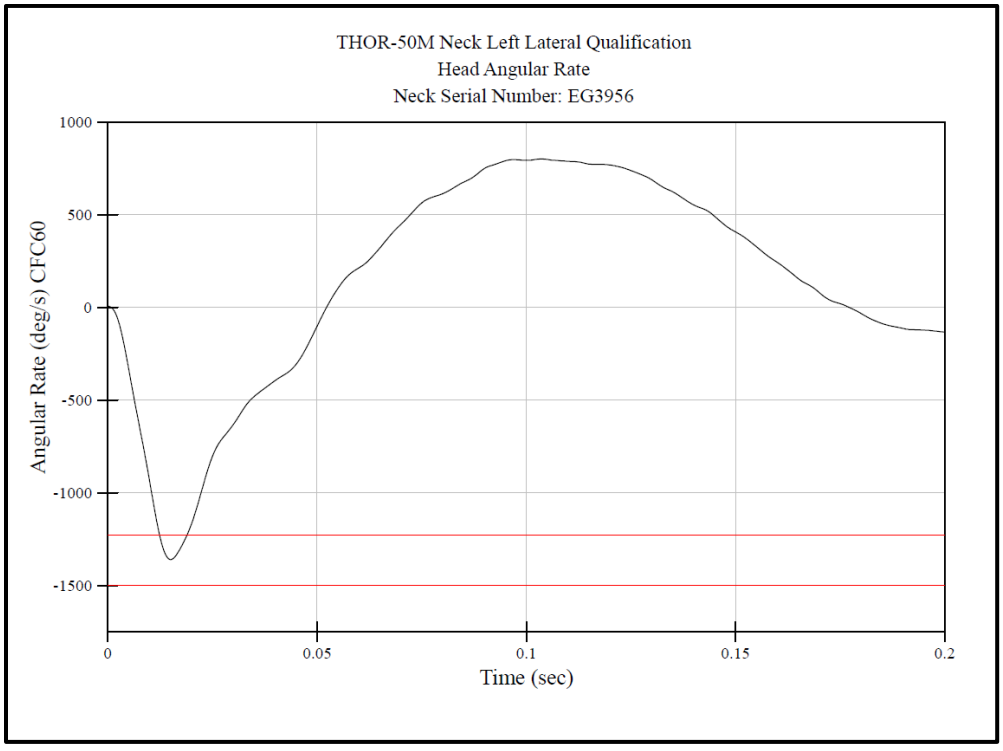


*Figure B-17. Neck left lateral flexion: Head angular velocity ωx for in-dummy DAS neck EG3956 (2023 version)*

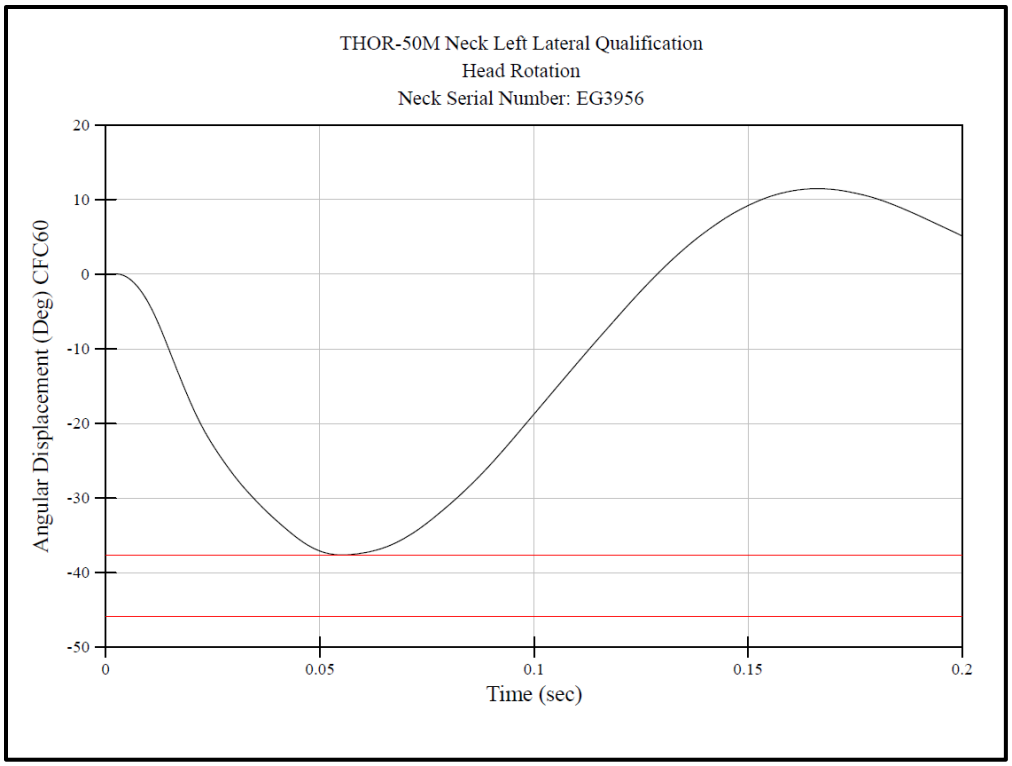


*Figure B-18. Neck left lateral flexion: Head rotation for in-dummy DAS neck EG3956 (2023 version)*

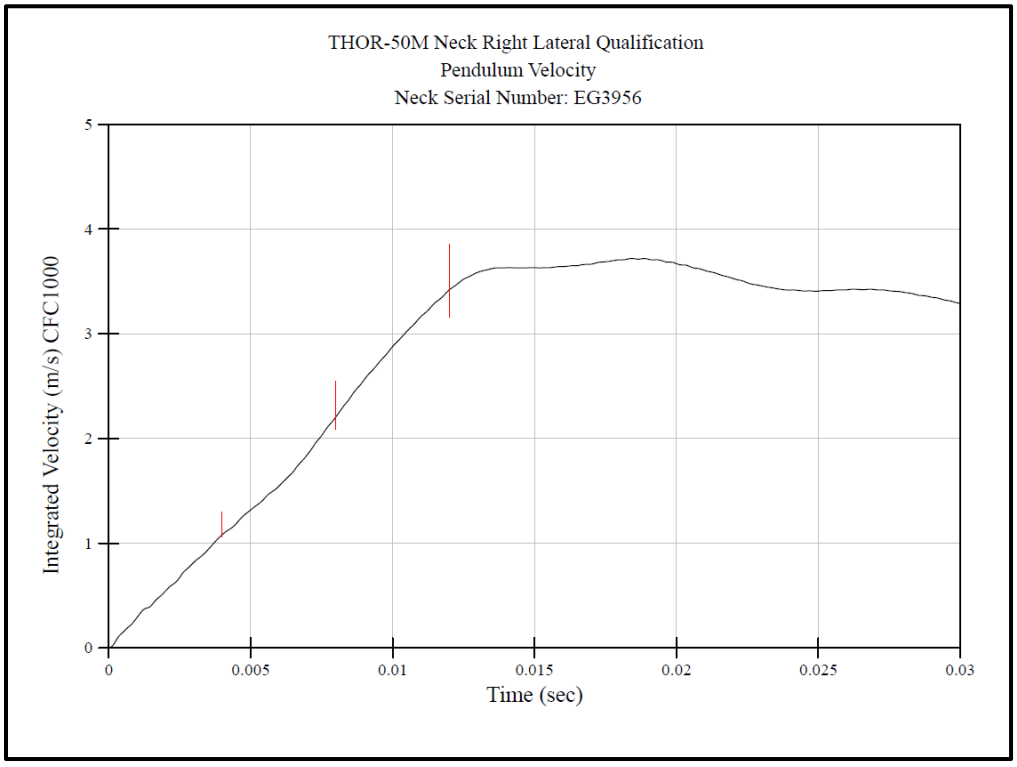


*Figure B-19. Neck right lateral flexion: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

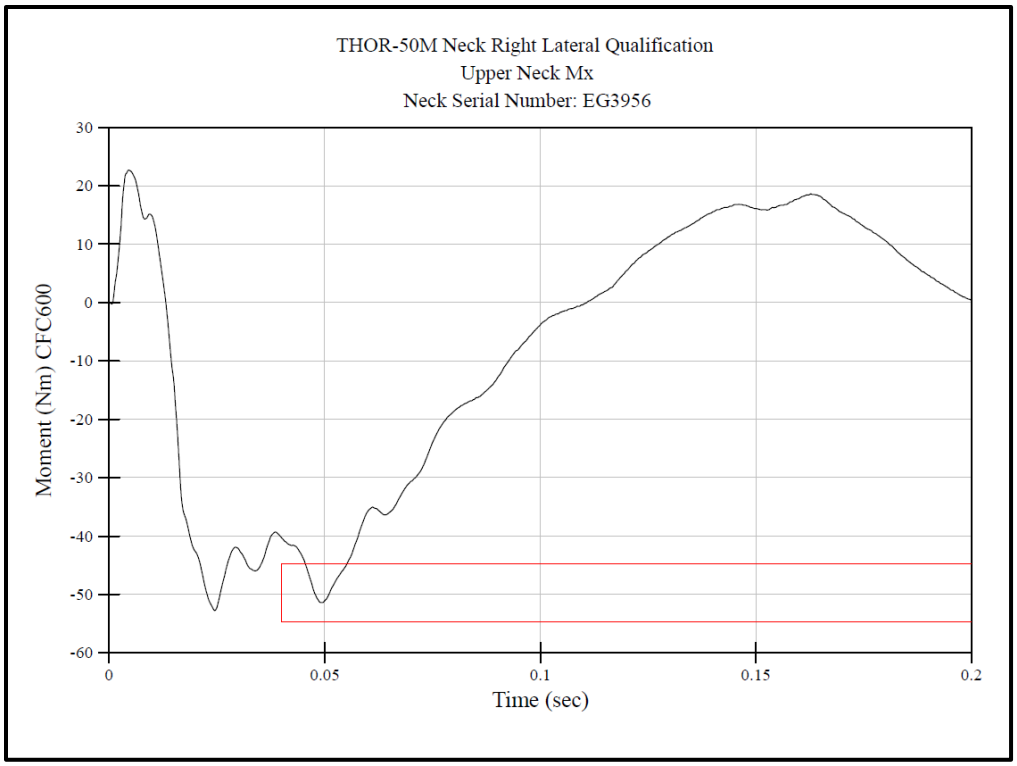


*Figure B-20. Neck right lateral flexion: Upper neck Mx for in-dummy DAS neck EG3956 (2023 version)*

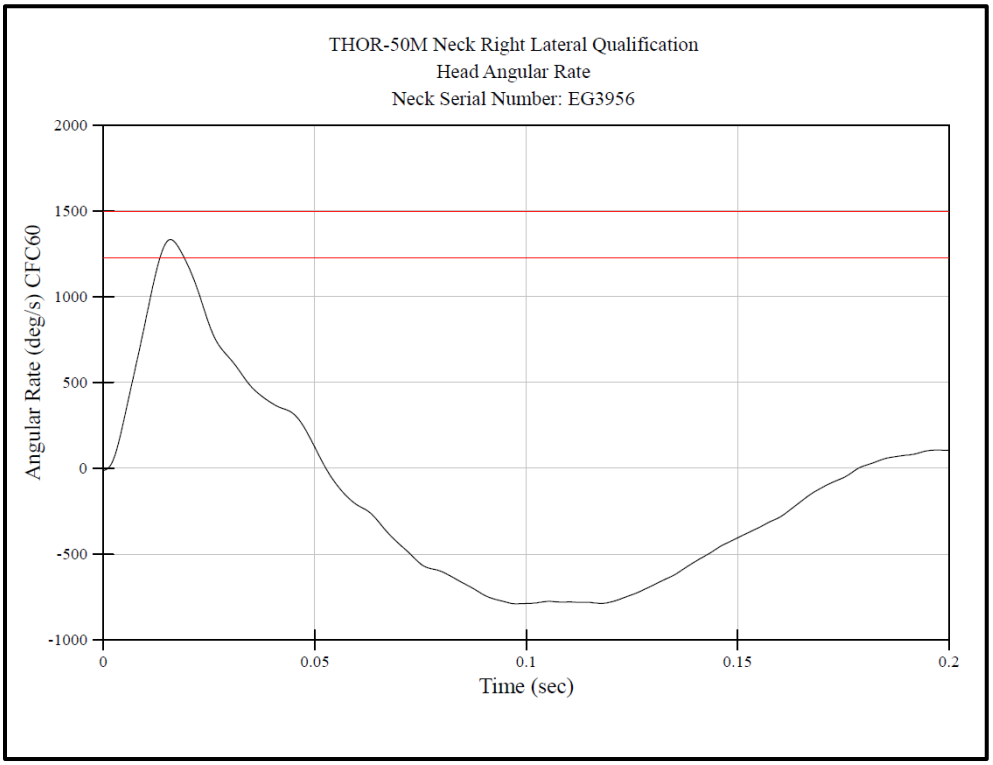


*Figure B-21. Neck right lateral flexion: Head angular velocity ωx for in-dummy DAS neck EG3956 (2023 version)*

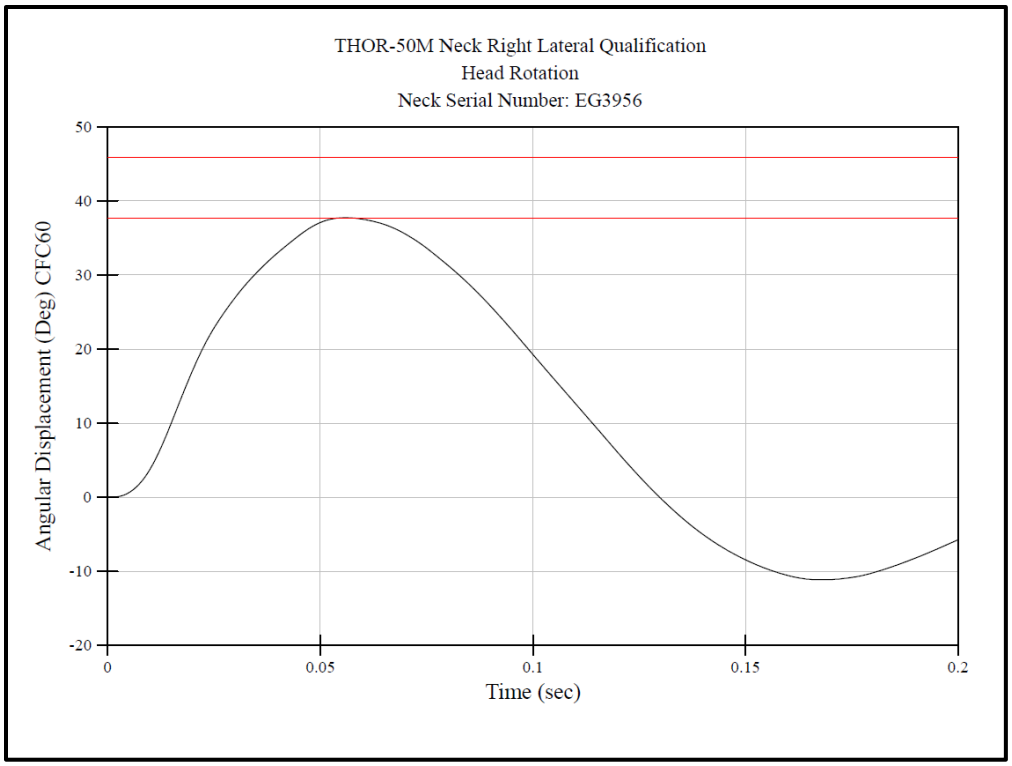


*Figure B-22. Neck right lateral flexion: Head rotation for in-dummy DAS neck EG3956 (2023 version)*

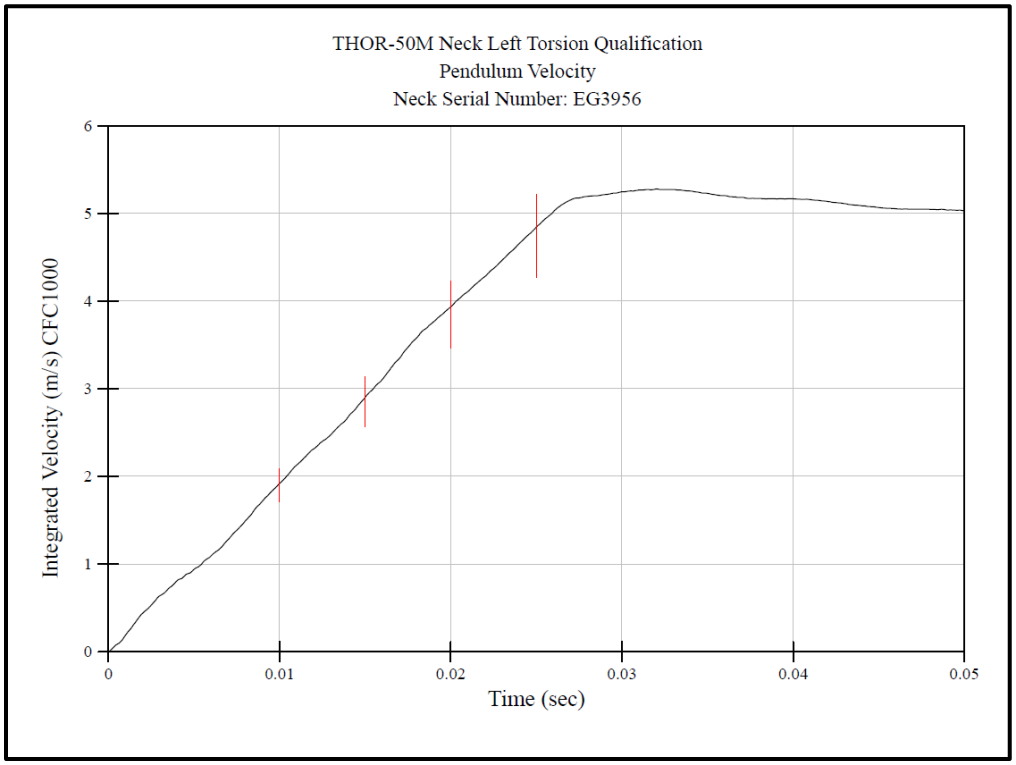


*Figure B-23. Neck left torsion: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

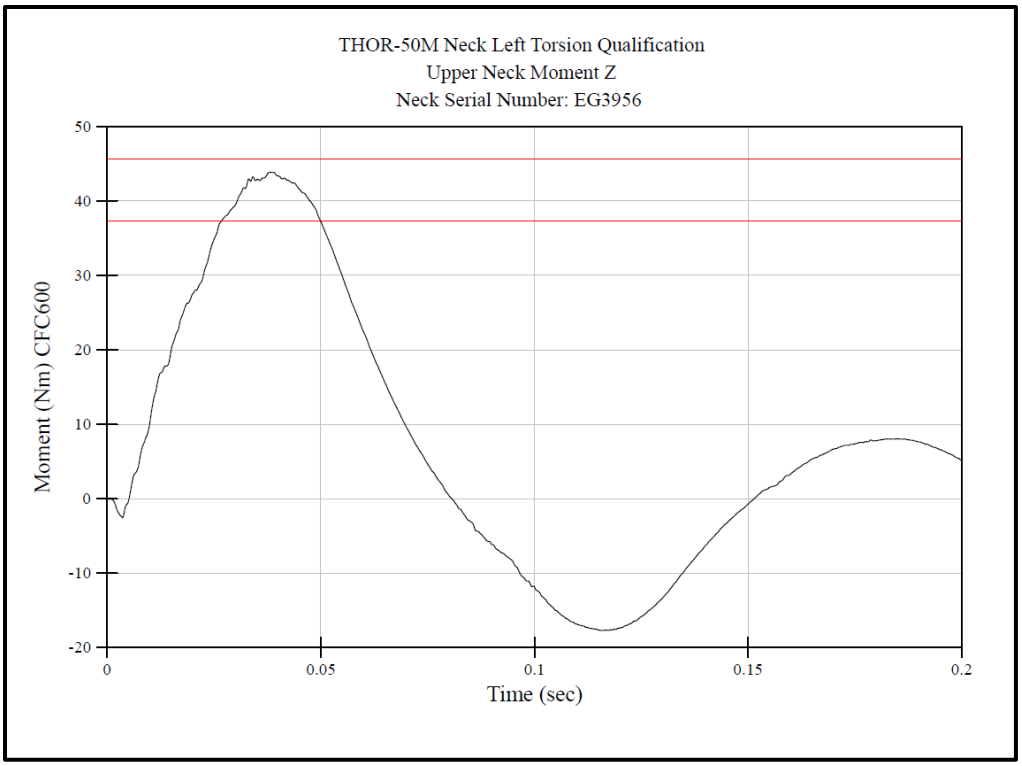


*Figure B-24. Neck left torsion: Upper neck Mz for in-dummy DAS neck EG3956 (2023 version)*

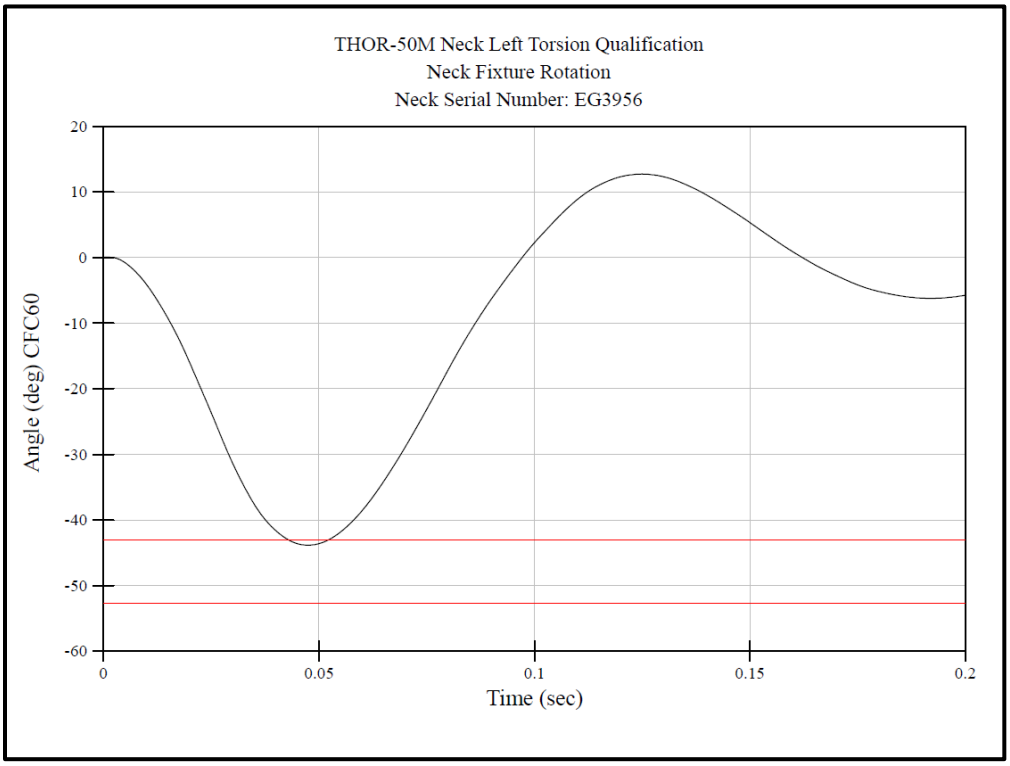


*Figure B-25. Neck left torsion: Neck fixture rotation for in-dummy DAS neck EG3956 (2023 version)*

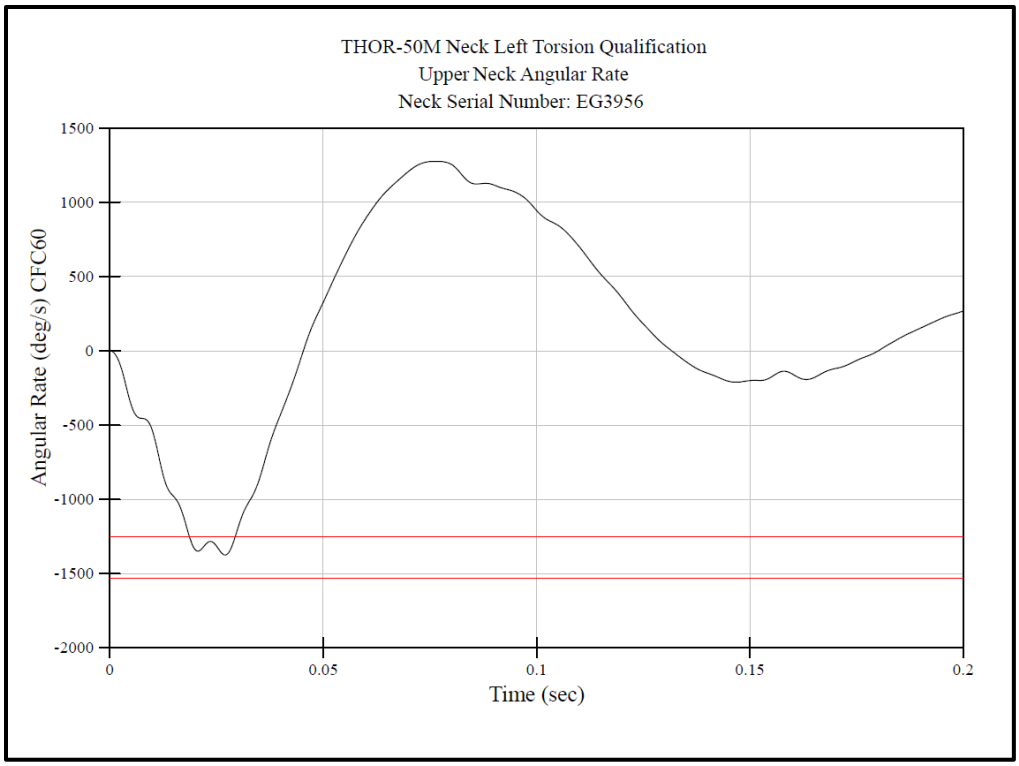


*Figure B-26. Neck left torsion: Upper neck angular velocity ωz for in-dummy DAS neck EG3956 (2023 version)*

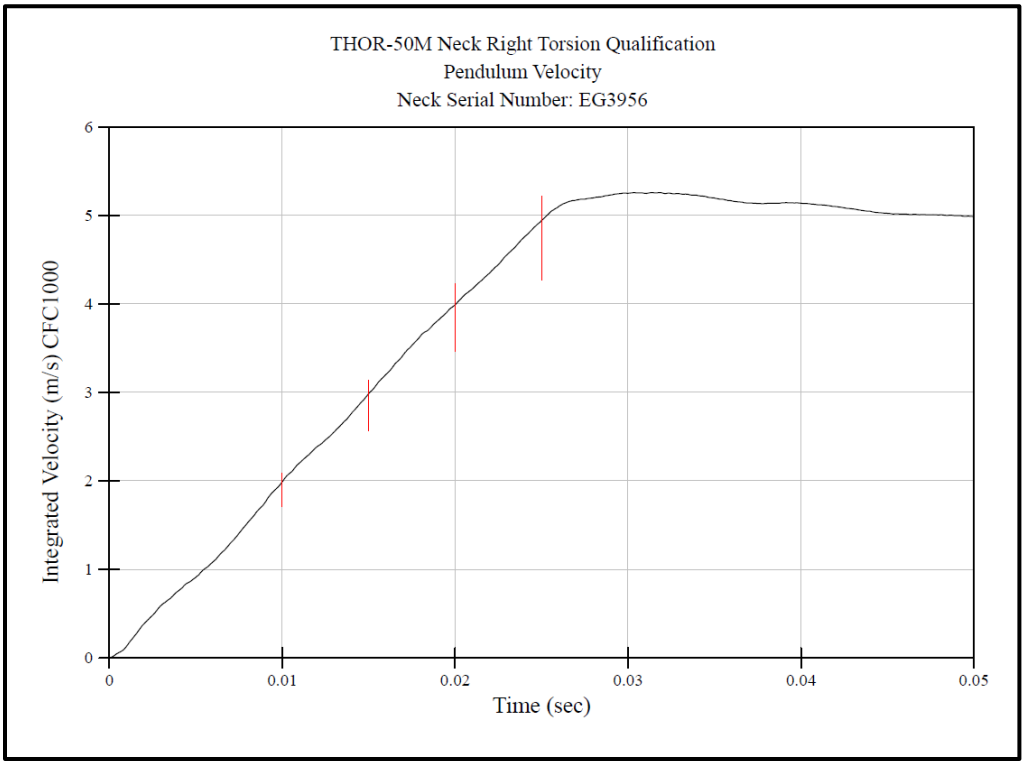


*Figure B-27. Neck right torsion: Pendulum velocity for in-dummy DAS neck EG3956 (2023 version)*

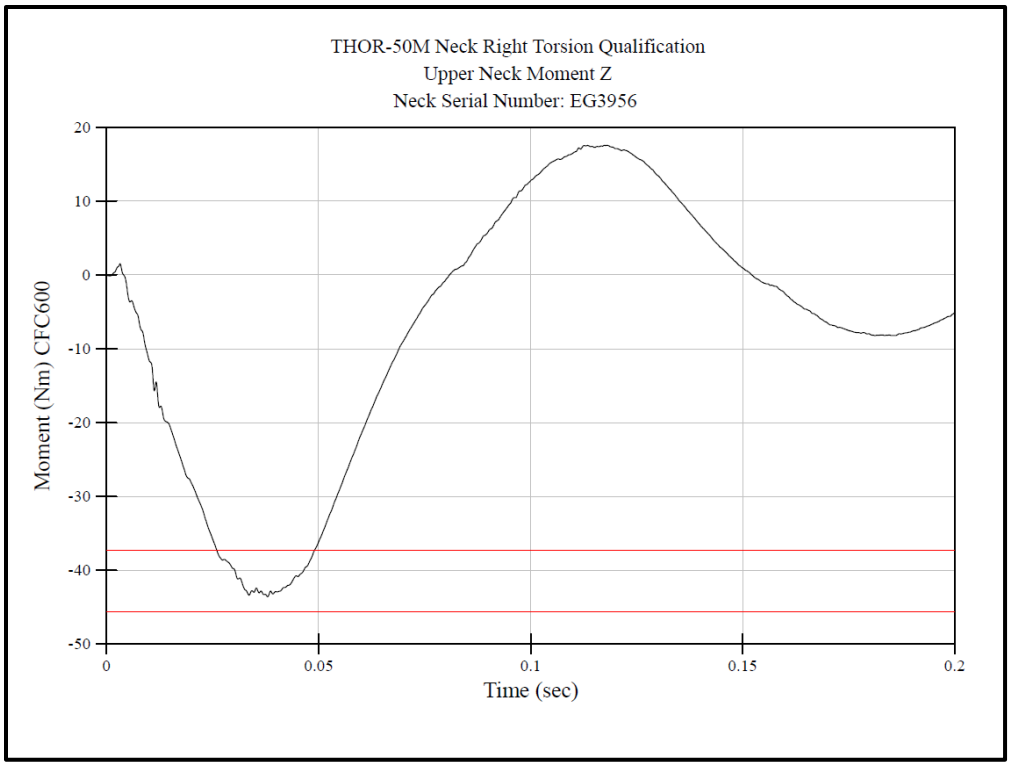


*Figure B-28. Neck right torsion: Upper neck Mz for in-dummy DAS neck EG3956 (2023 version)*

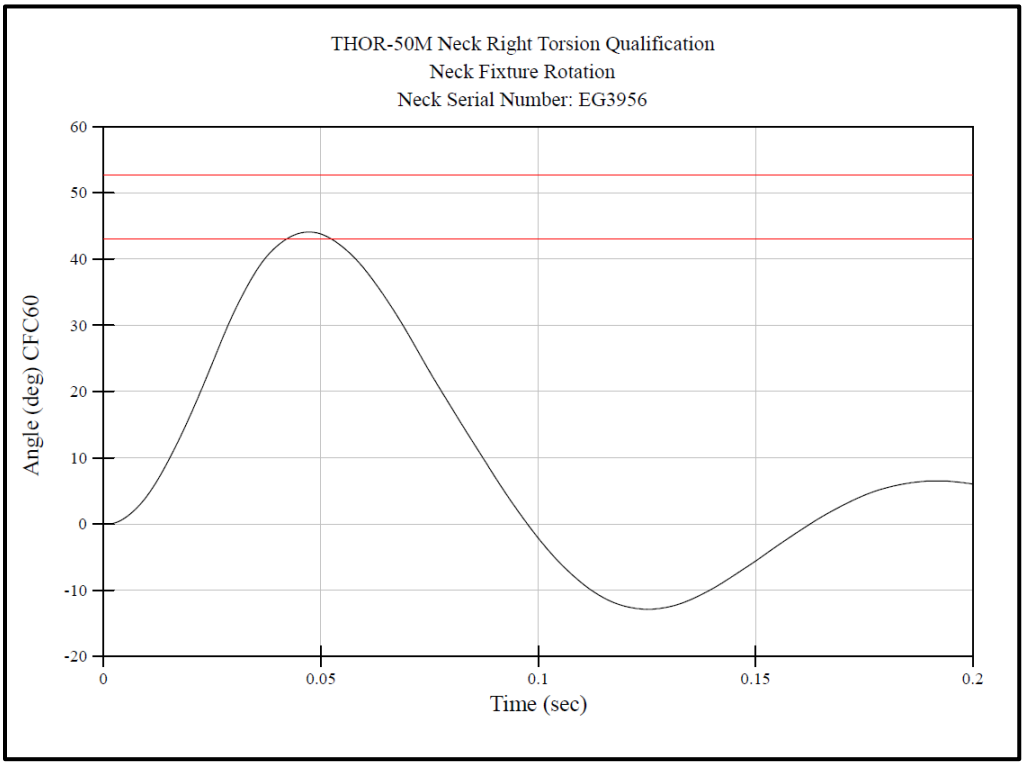


*Figure B-29. Neck right torsion: Neck fixture rotation for in-dummy DAS neck EG3956 (2023 version)*

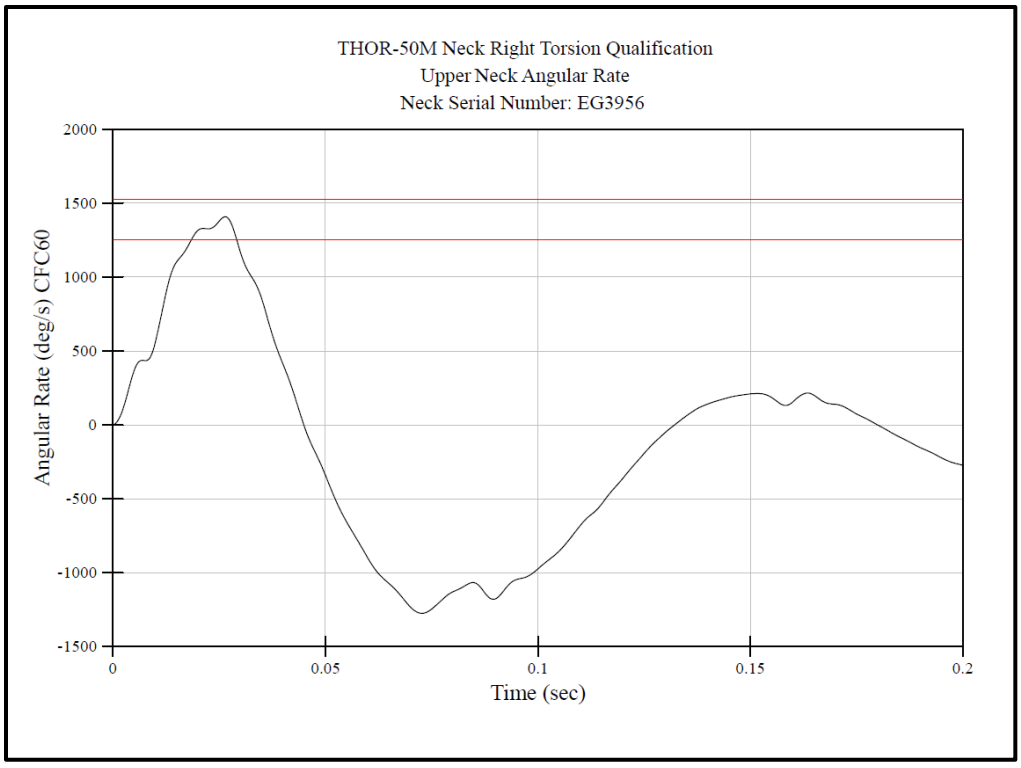


*Figure B-30. Neck right torsion: Upper neck angular velocity ωz for in-dummy DAS neck EG3956 (2023 version)*

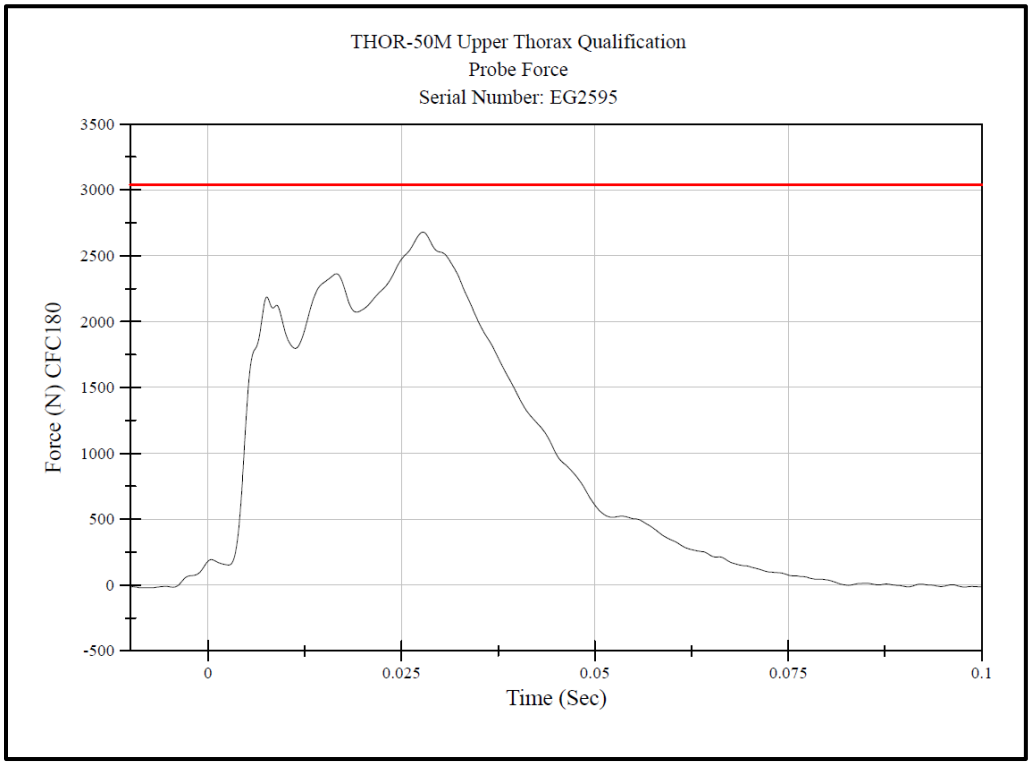


*Figure B-31. Upper thorax impact: Probe force for in-dummy DAS EG2595 (2023 version)*

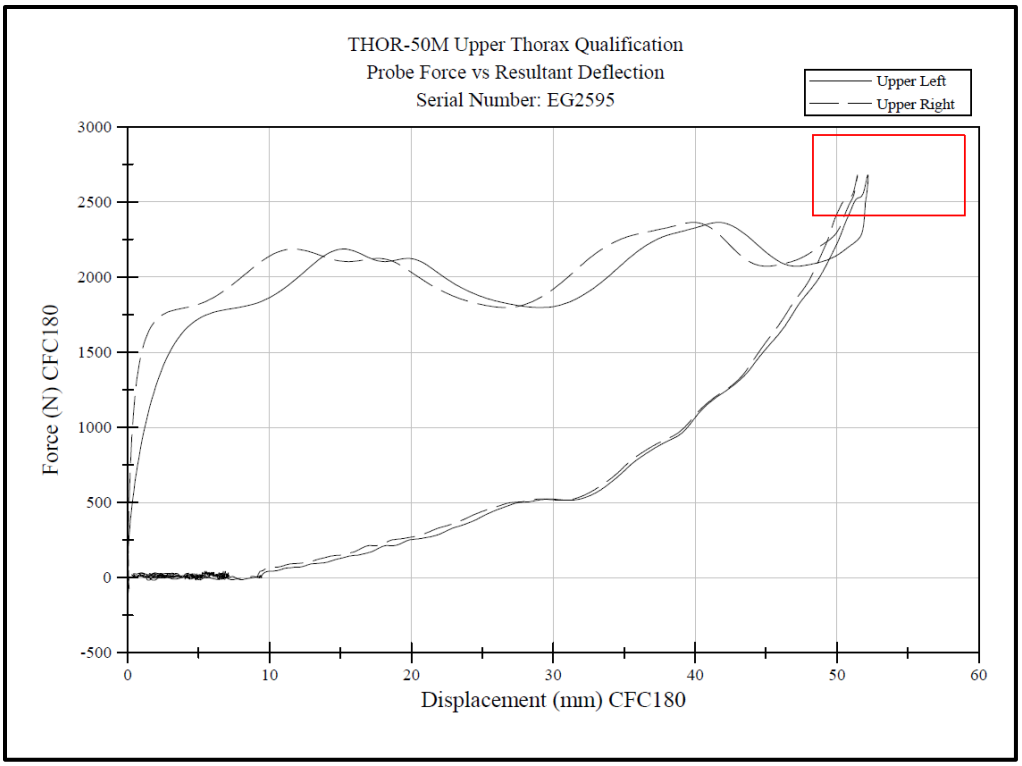


*Figure B-32. Upper thorax impact: Probe force vs resultant deflection for in-dummy DAS EG2595 (2023 version)*

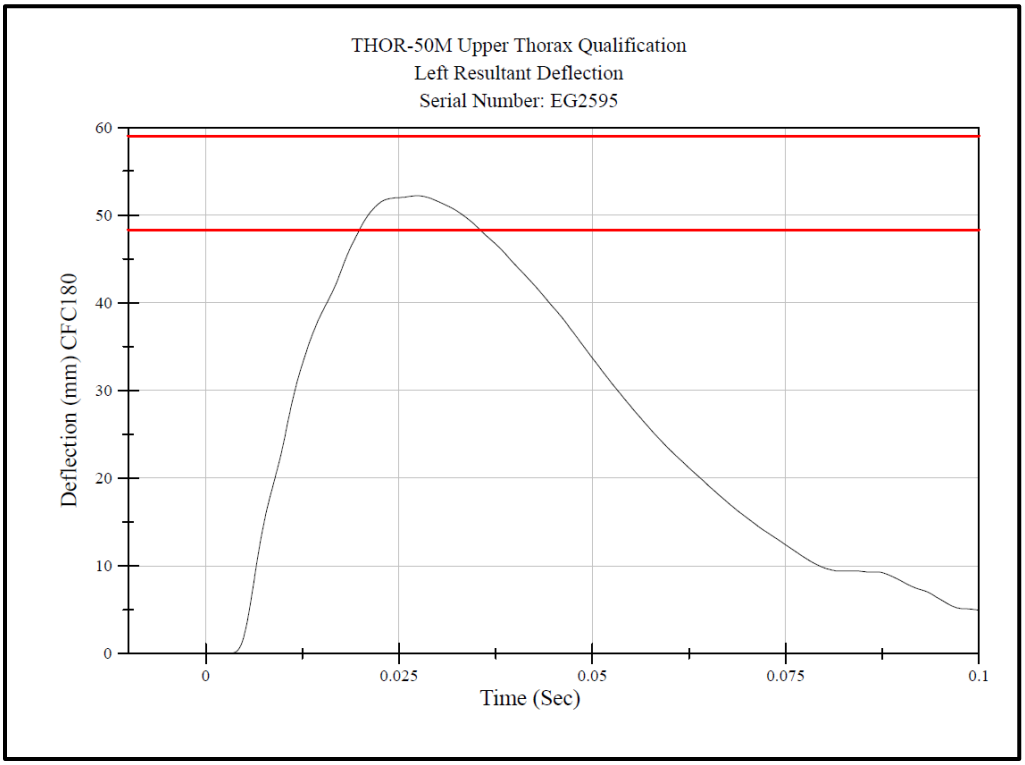


*Figure B-33. Upper thorax impact: Left resultant deflection for in-dummy DAS EG2595 (2023 version)*

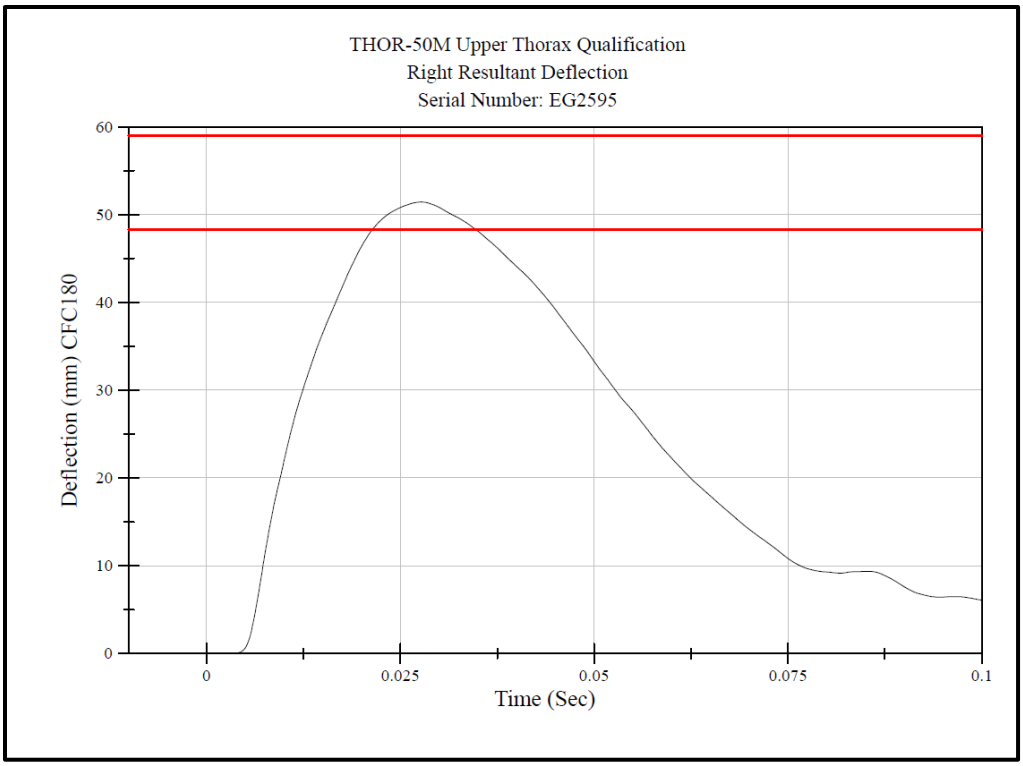


*Figure B-34. Upper thorax impact: Right resultant deflection for in-dummy DAS EG2595 (2023 version)*

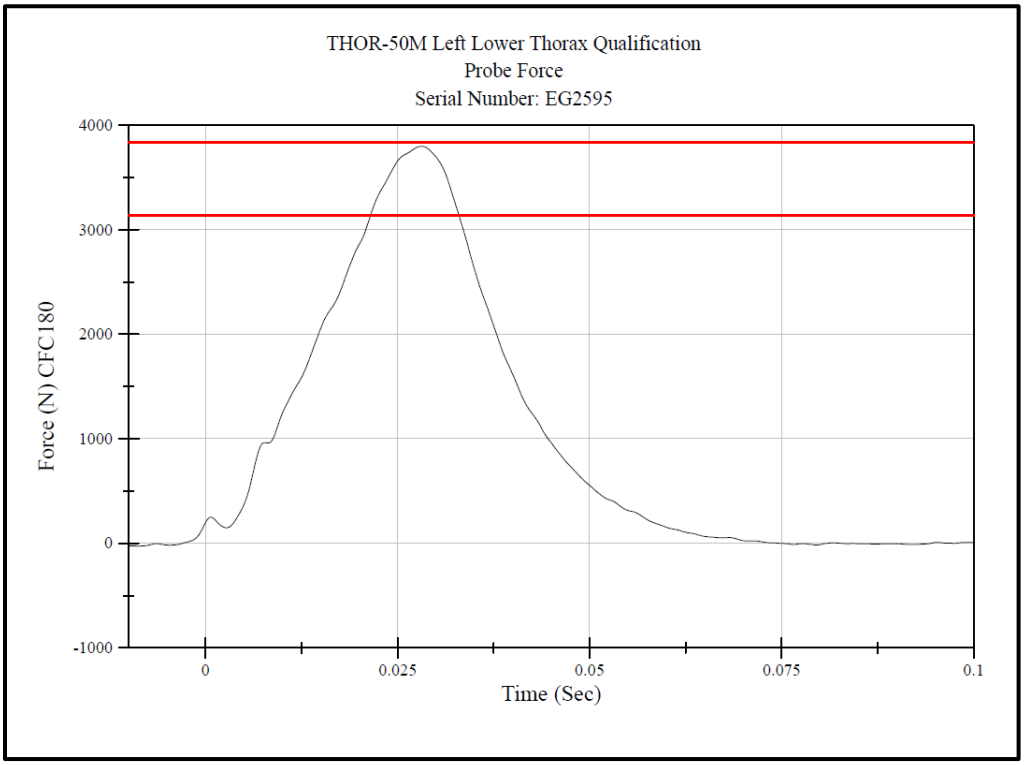


*Figure B-35. Lower left thorax: Probe force for in-dummy DAS EG2595 (2023 version)*

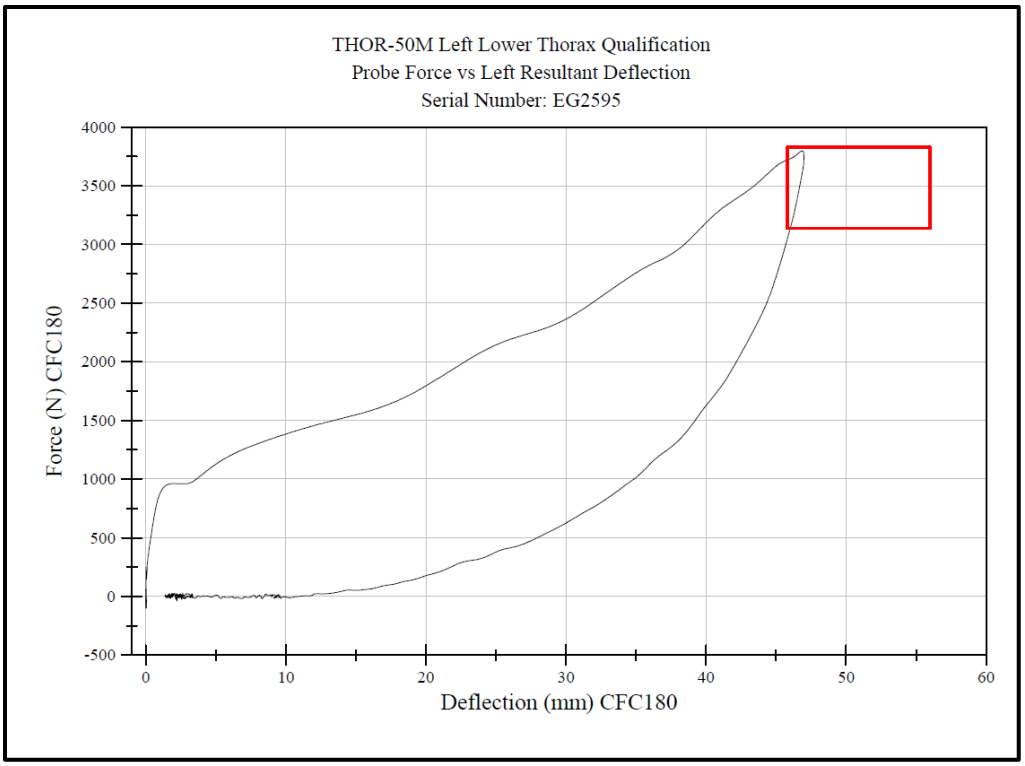


*Figure B-36. Lower left thorax: Probe force vs resultant deflection for in-dummy DAS EG2595 (2023 version)*

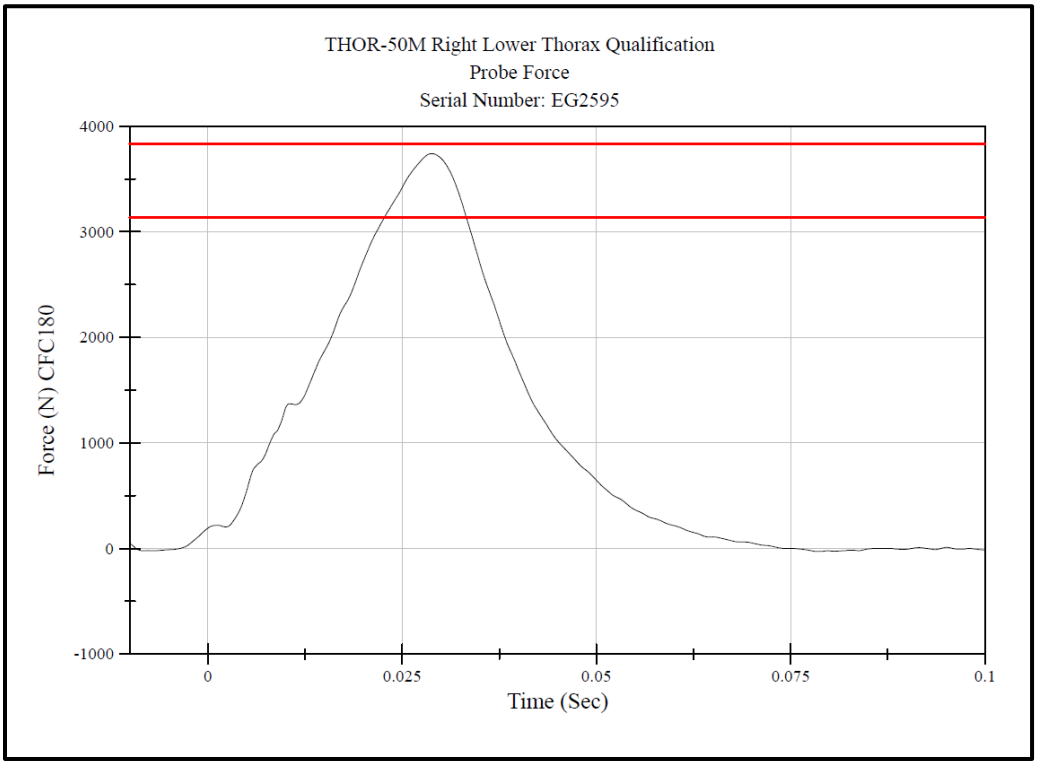


*Figure B-37. Lower right thorax: Probe force for in-dummy DAS EG2595 (2023 version)*

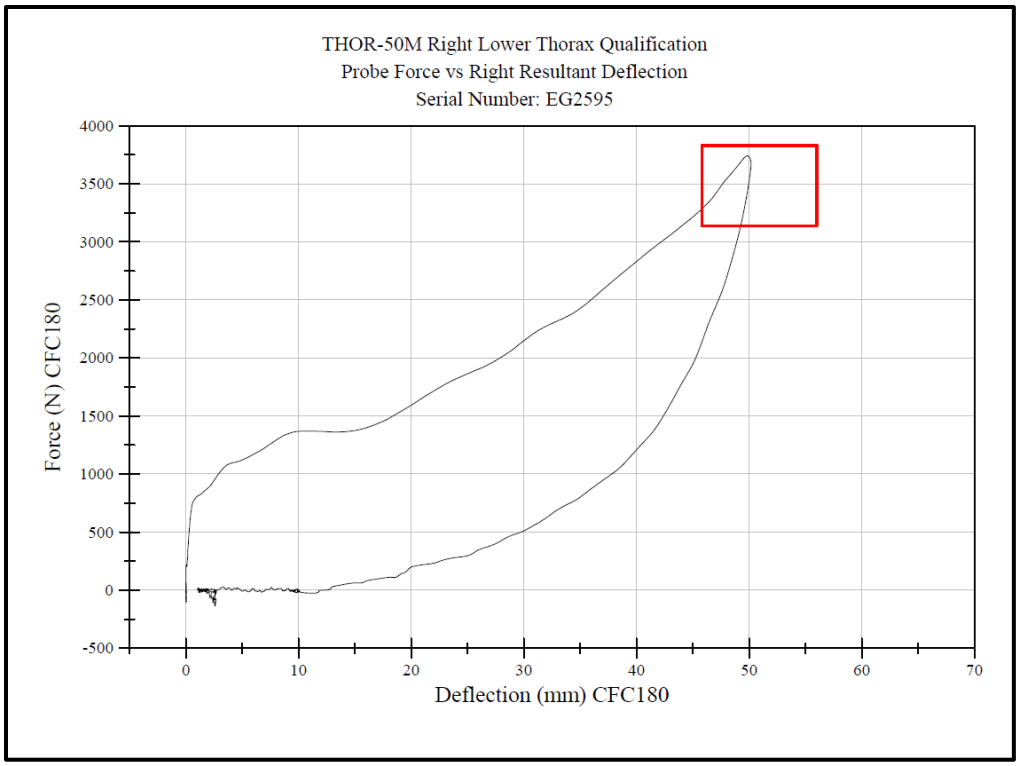


*Figure B-38. Lower right thorax: Probe force vs resultant deflection for in-dummy DAS EG2595 (2023 version)*

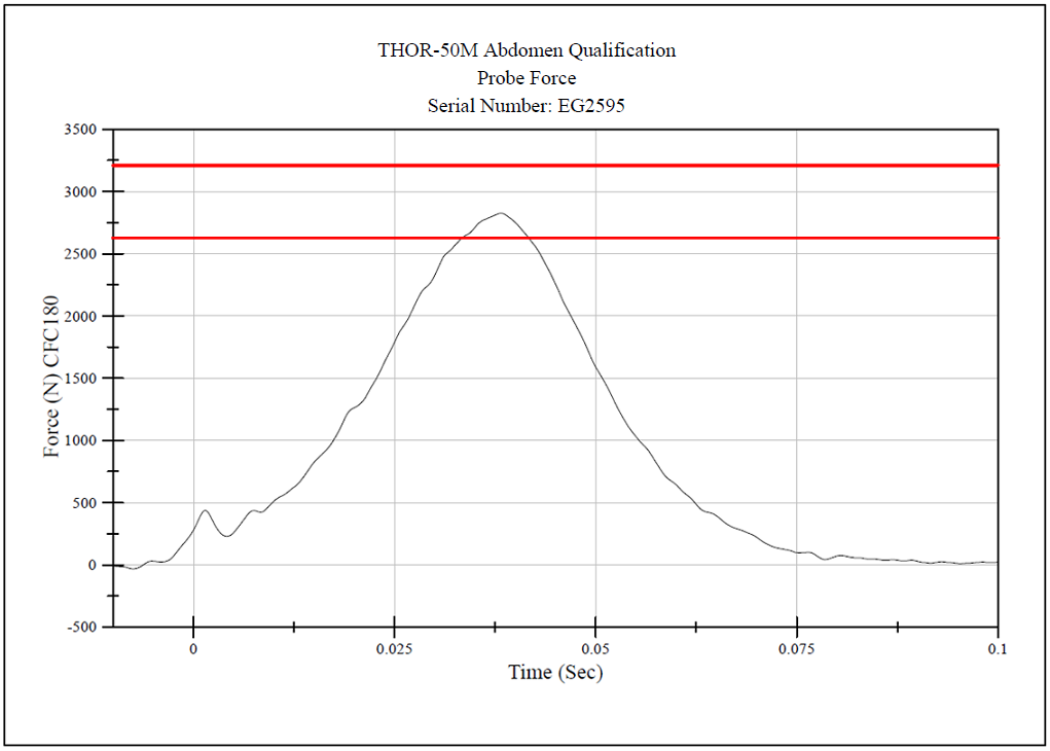


*Figure B-39. Abdomen: Probe force for in-dummy DAS EG2595 (2023 version)*

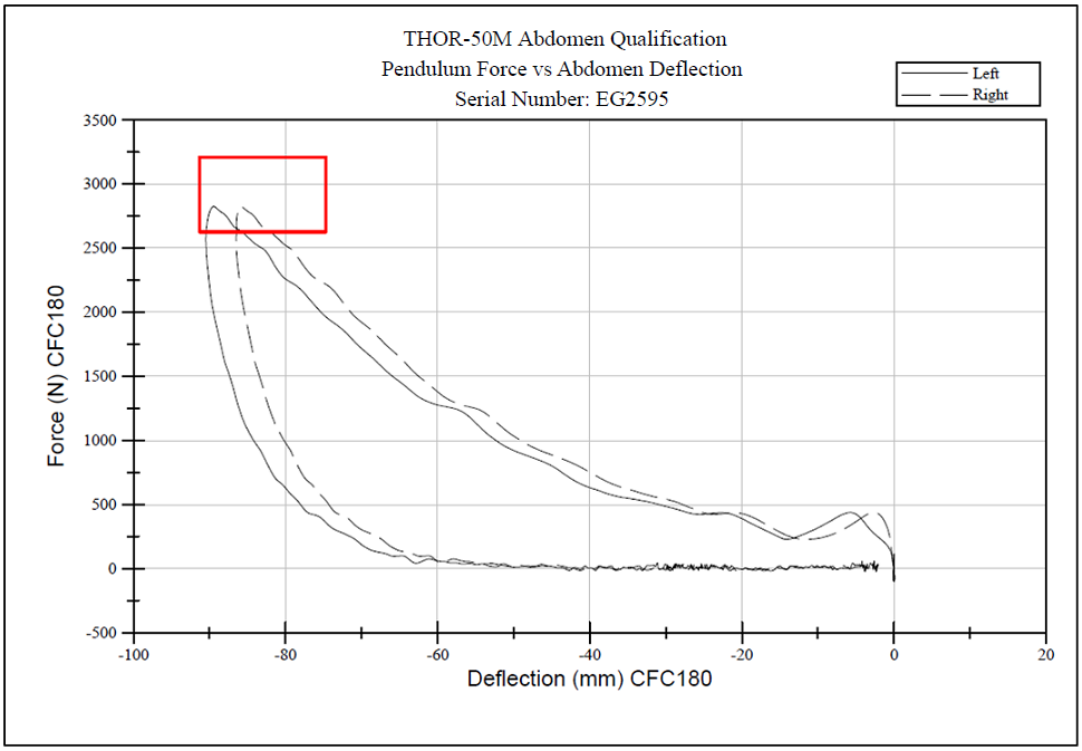


*Figure B-40. Abdomen: Probe force versus abdomen deflection for in-dummy DAS EG2595 (2023 version)*

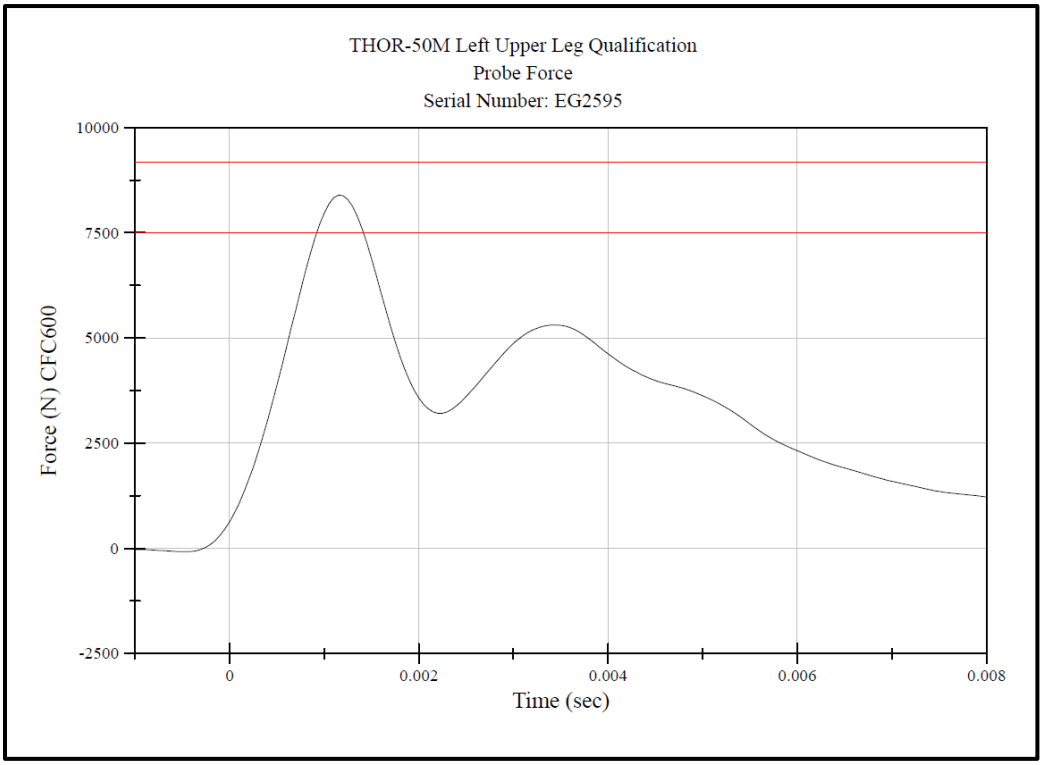


*Figure B-41. Left upper leg: Probe force for in-dummy DAS EG2595 (2023 version)*

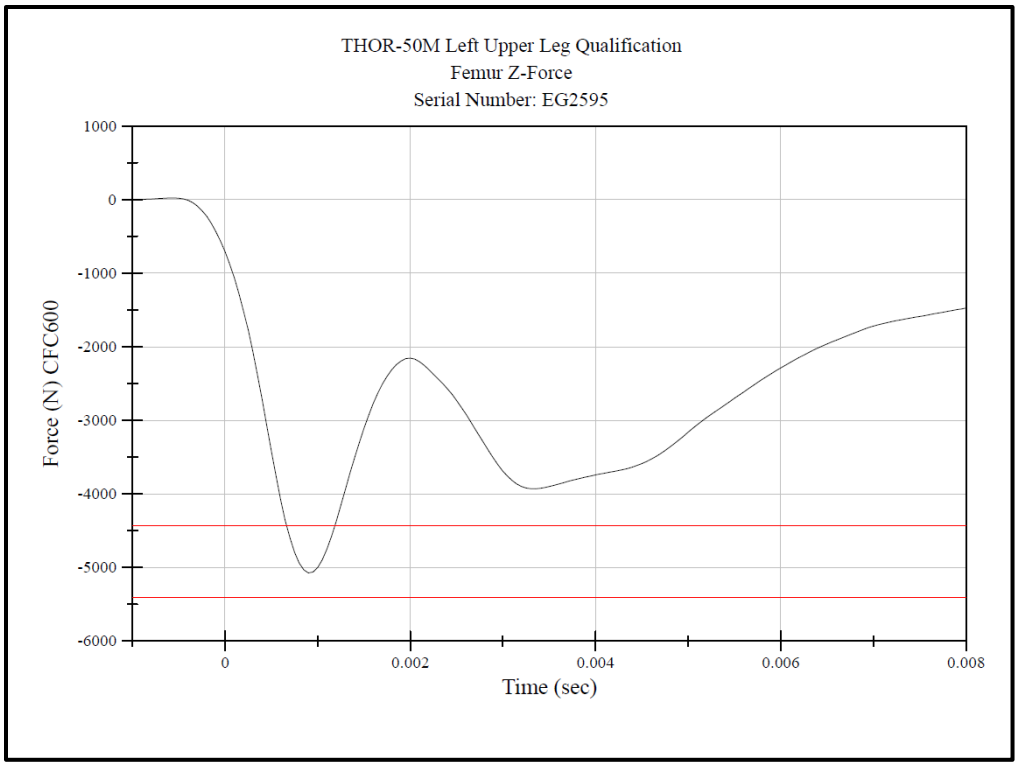


*Figure B-42. Left upper leg: Femur Fz for in-dummy DAS EG2595 (2023 version)*

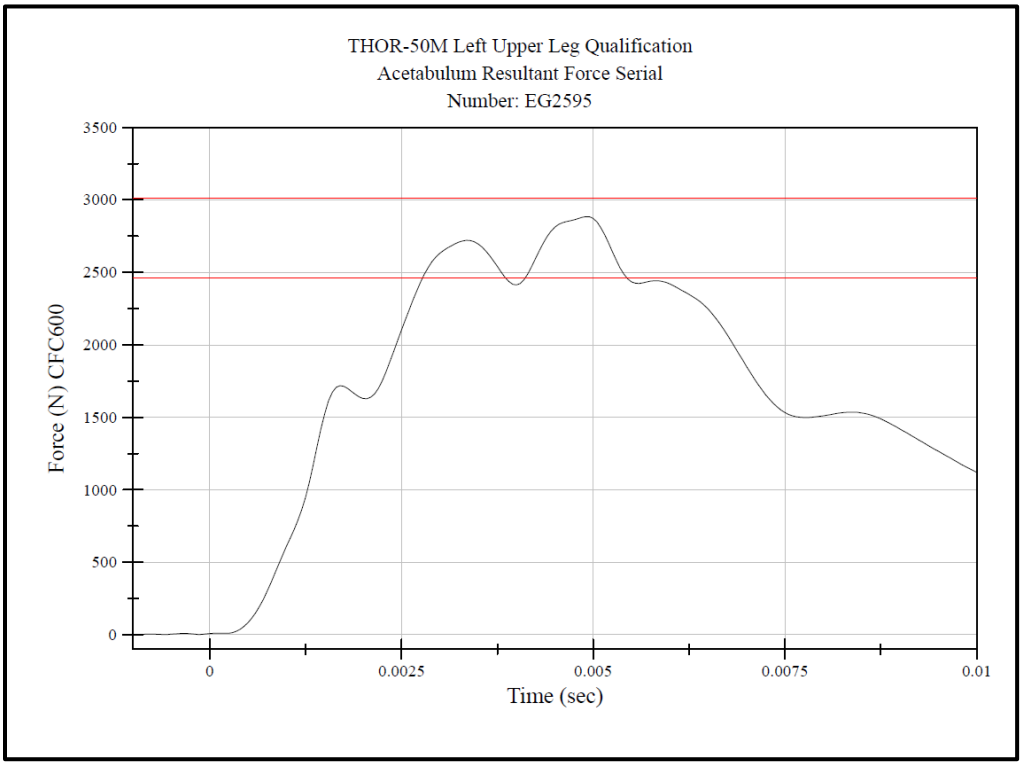


*Figure B-43. Left upper leg: Acetabulum resultant force for in-dummy DAS EG2595 (2023 version)*

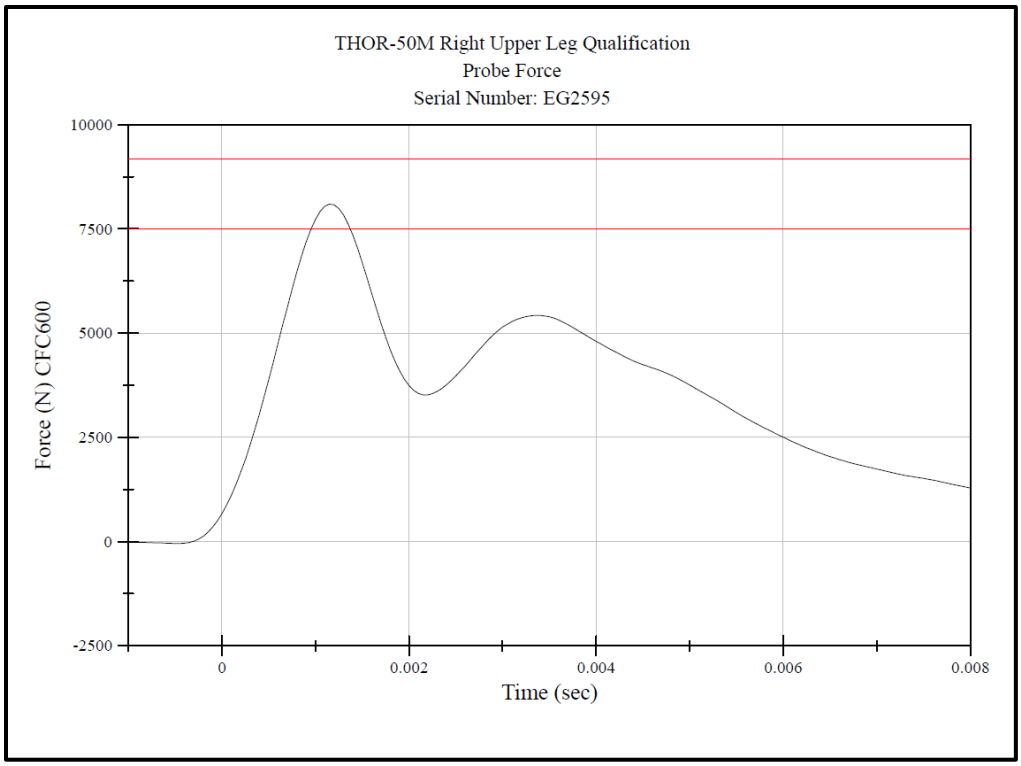


*Figure B-44. Right upper leg: Probe force for in-dummy DAS EG2595 (2023 version)*

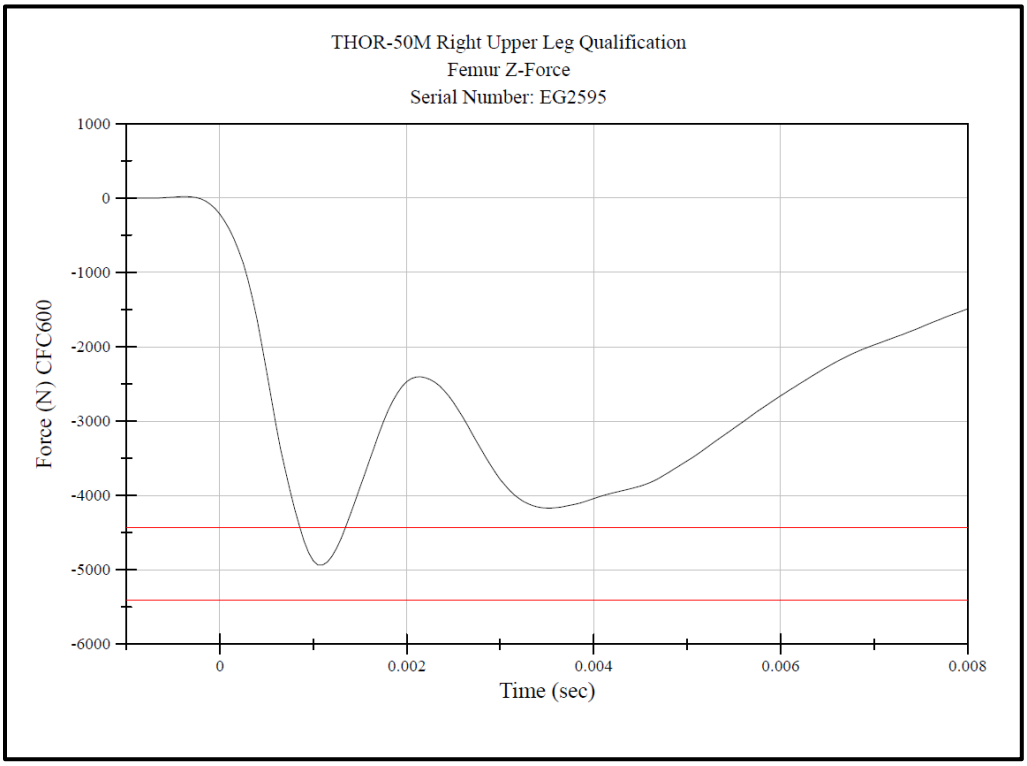


*Figure B-45. Right upper leg: Femur Fz for in-dummy DAS EG2595 (2023 version)*

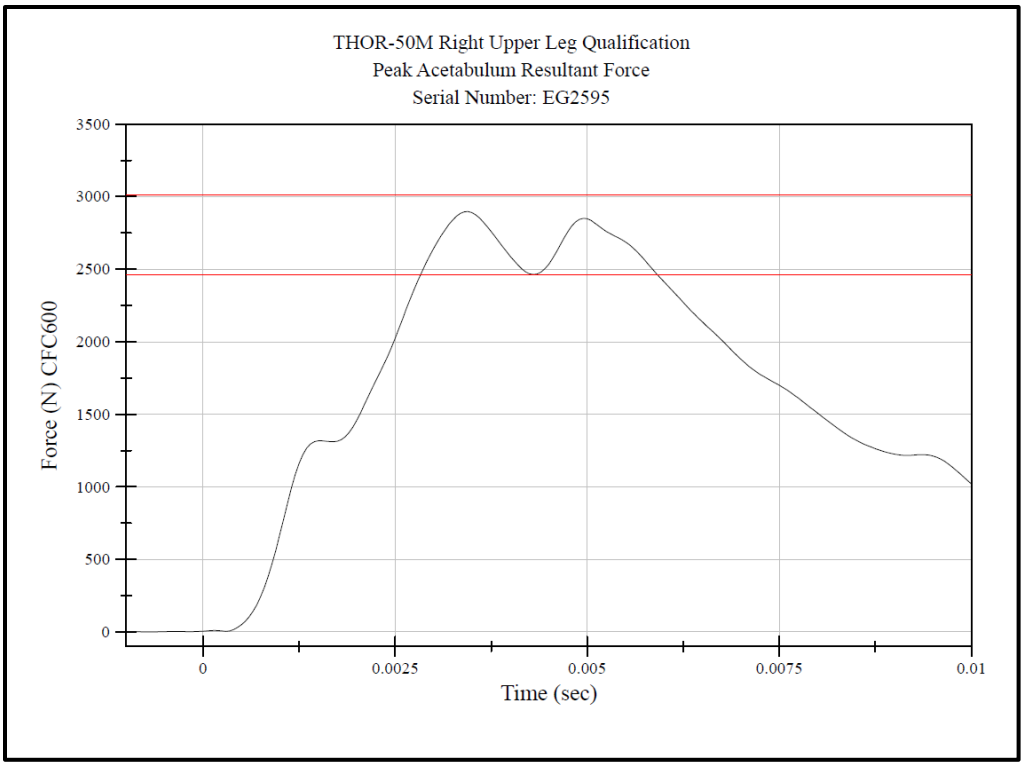


*Figure B-46. Right upper leg: Acetabulum resultant force for in-dummy DAS EG2595 (2023 version)*

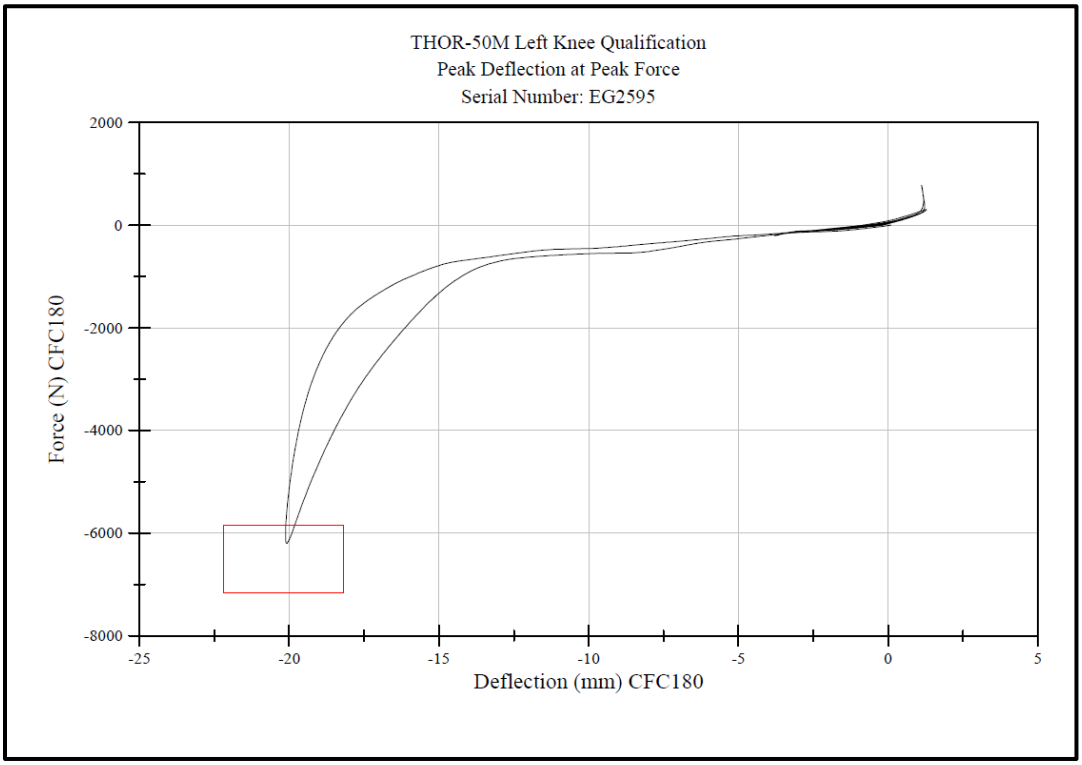


*Figure B-47. Left knee: Femur force Fz vs. X-axis knee deflection for in-dummy DAS EG2595 (2023 version)*

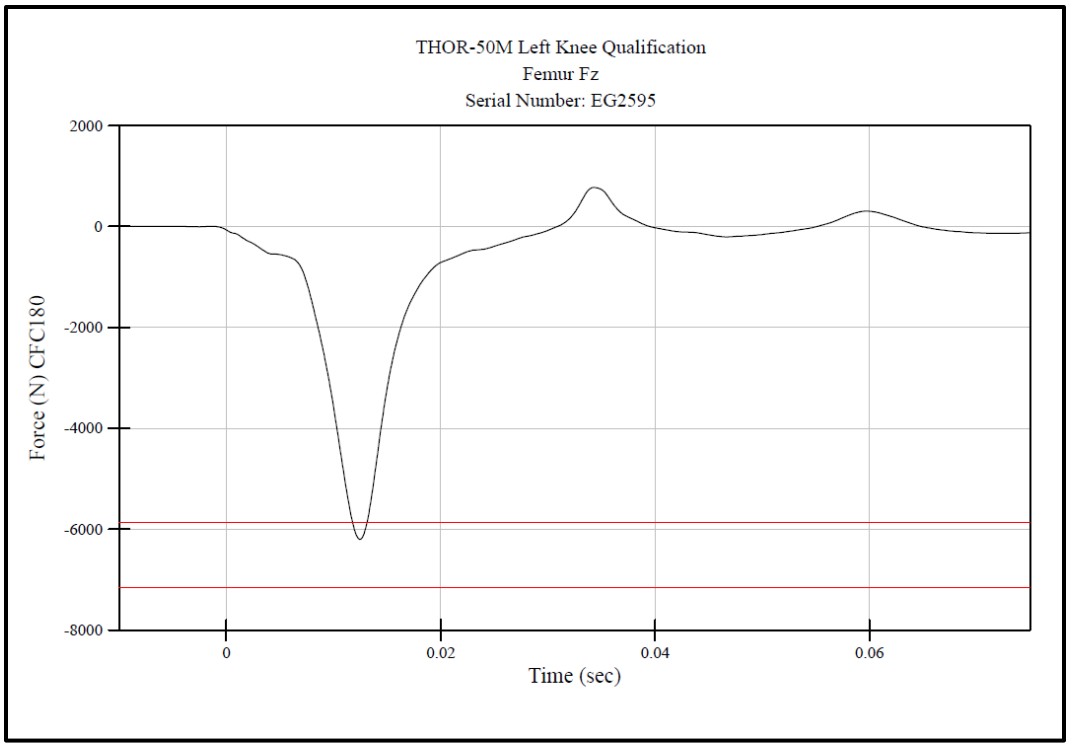


*Figure B-48. Left knee: Femur Fz for in-dummy DAS EG2595 (2023 version)*

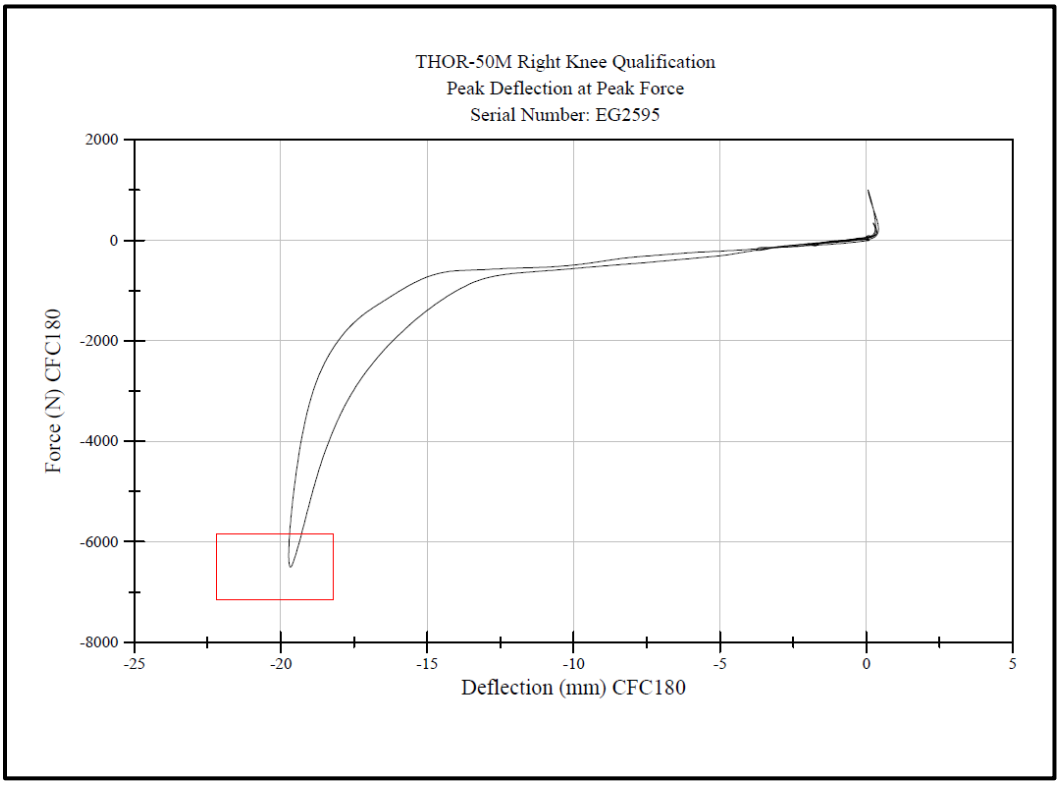


*Figure B-49. Right knee: Femur Fz vs. X-axis knee deflection for in-dummy DAS EG2595 (2023 version)*

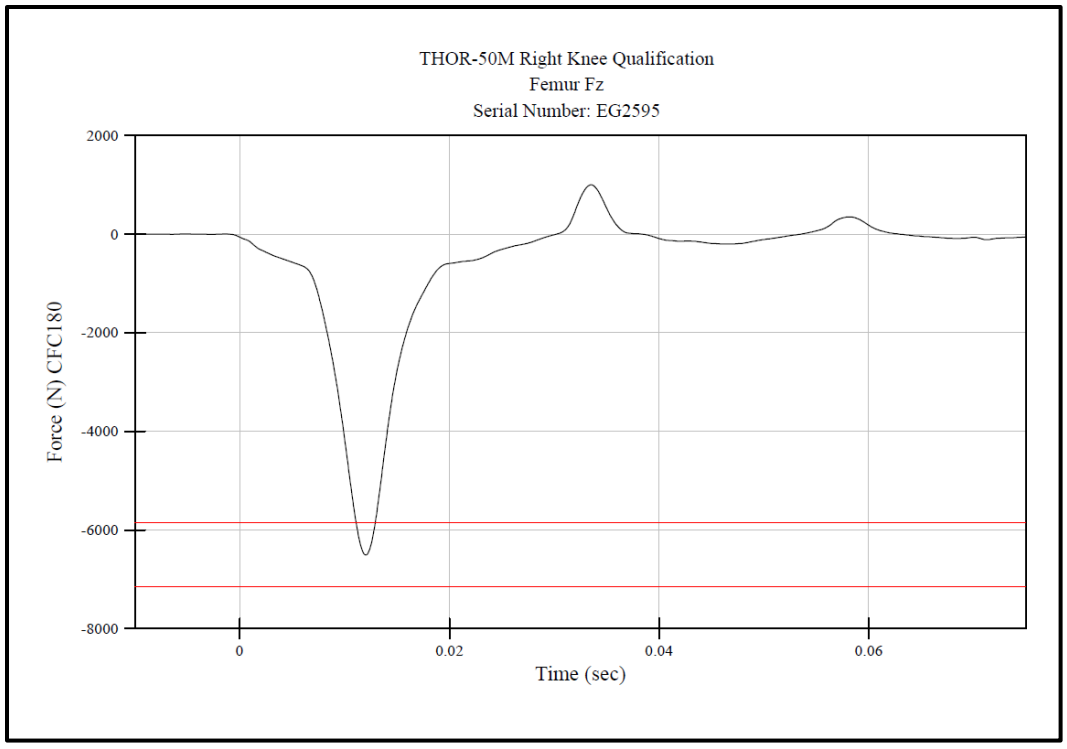


*Figure B-50. Right knee: Femur Fz for in-dummy DAS EG2595 (2023 version)*

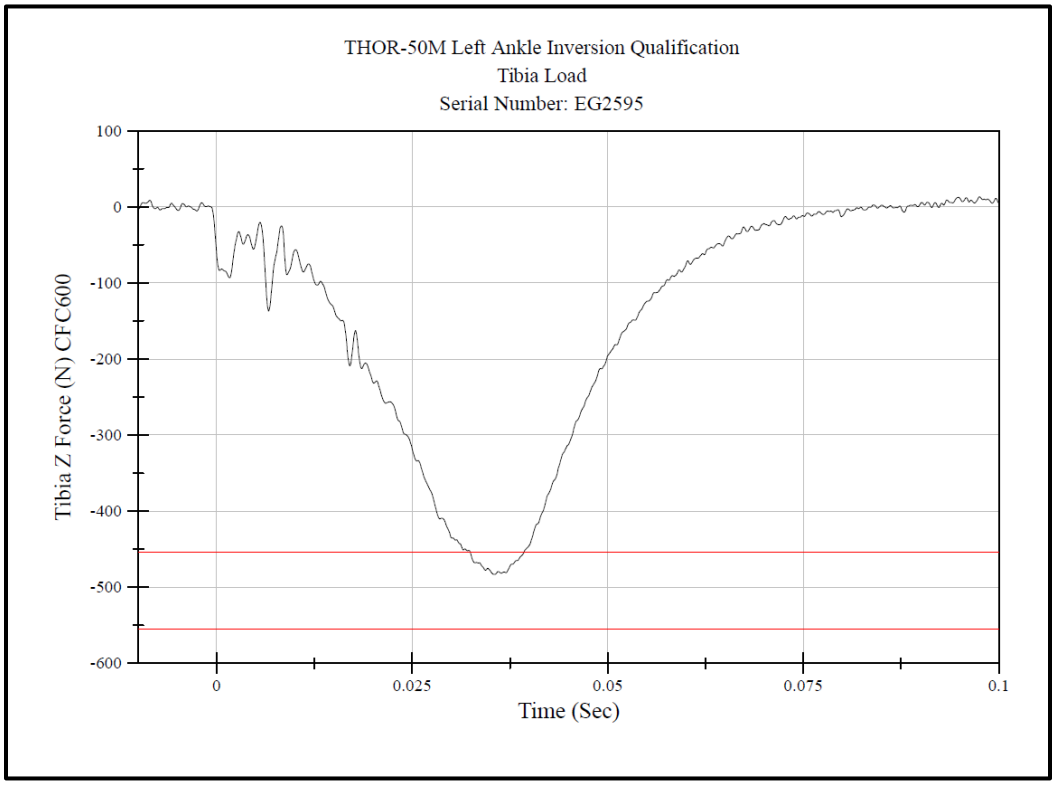


*Figure B-51. Left ankle inversion: Tibia Fz for in-dummy DAS EG2595 (2023 version)*

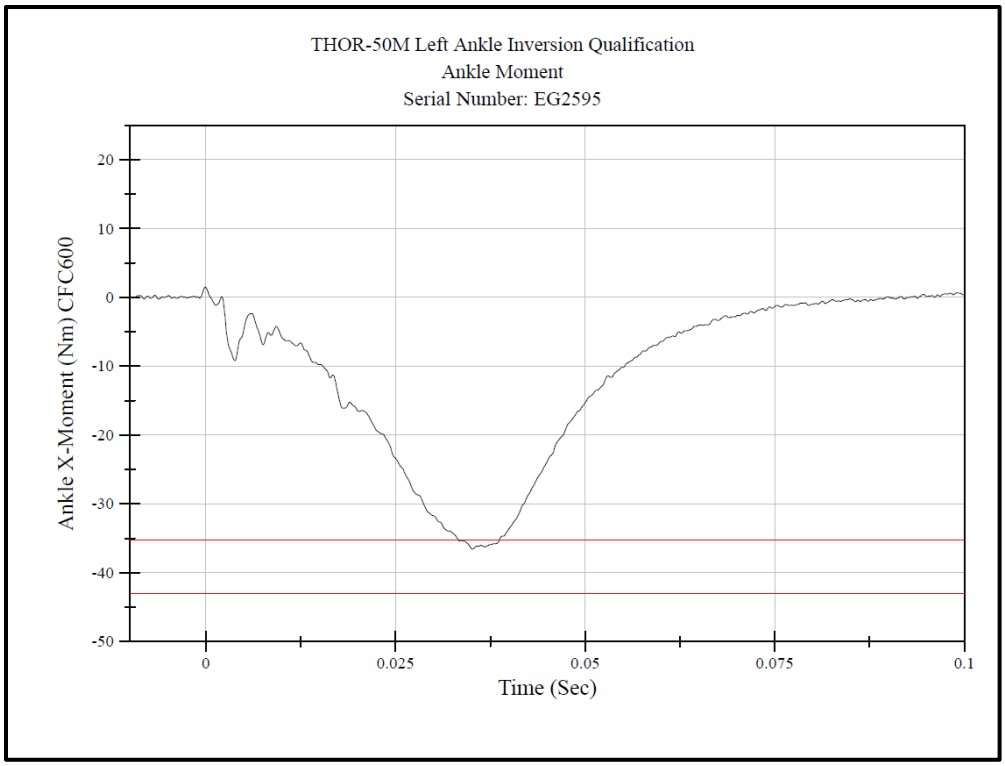


*Figure B-52. Left ankle inversion: Ankle Mx for in-dummy DAS EG2595 (2023 version)*

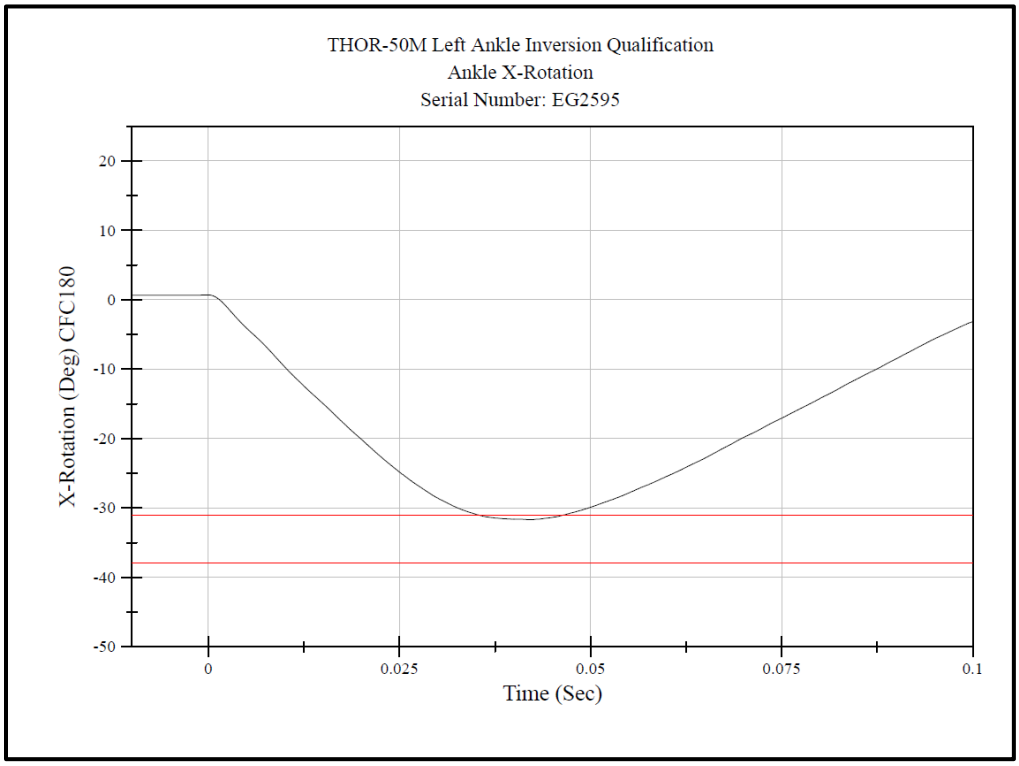


*Figure B-53. Left ankle inversion: Ankle X-axis rotation for in-dummy DAS EG2595 (2023 version)*

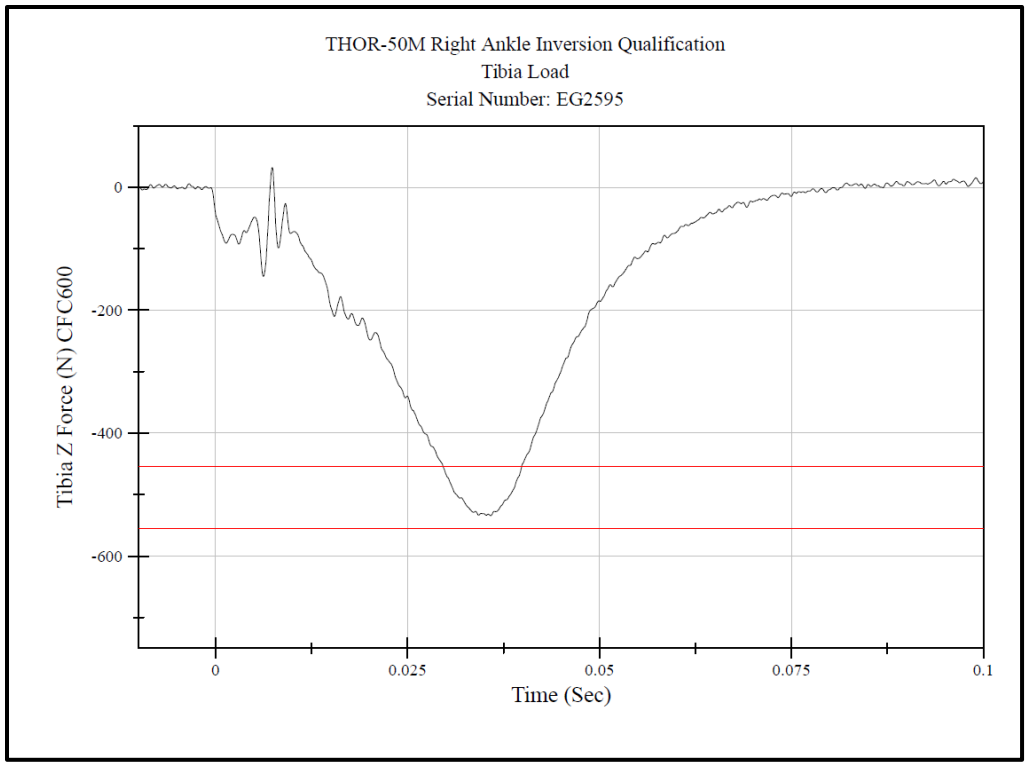


*Figure B-54. Right ankle inversion: Tibia Fz for in-dummy DAS EG2595 (2023 version)*

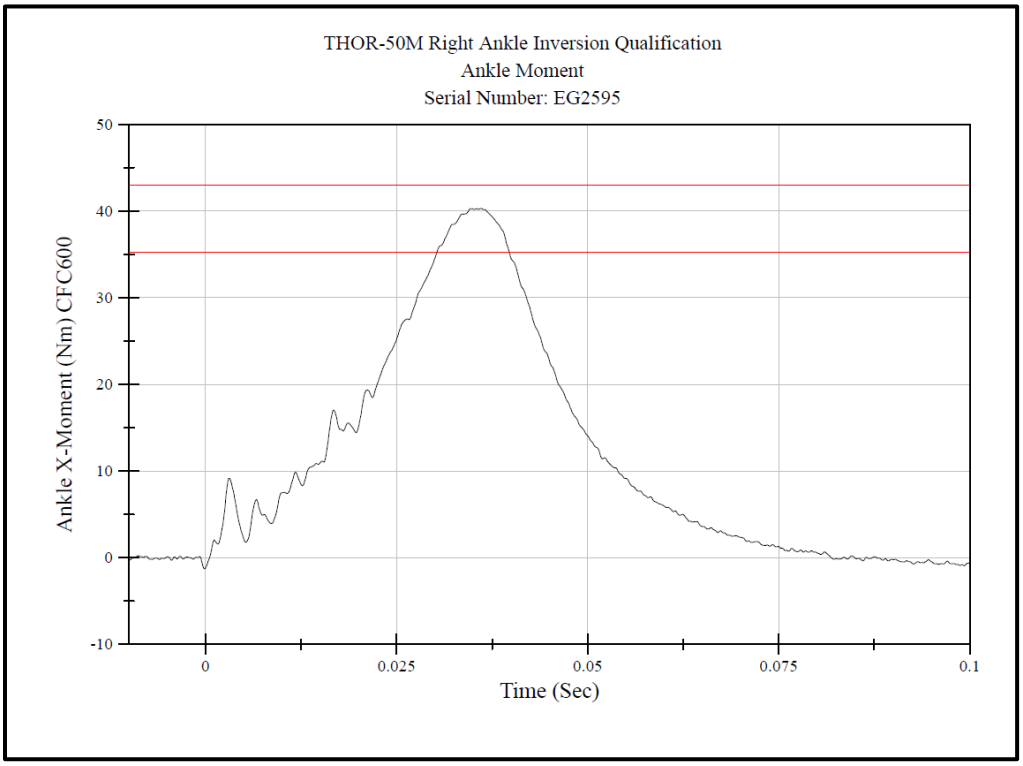


*Figure B-55. Right ankle inversion: Ankle Mx for in-dummy DAS EG2595 (2023 version)*

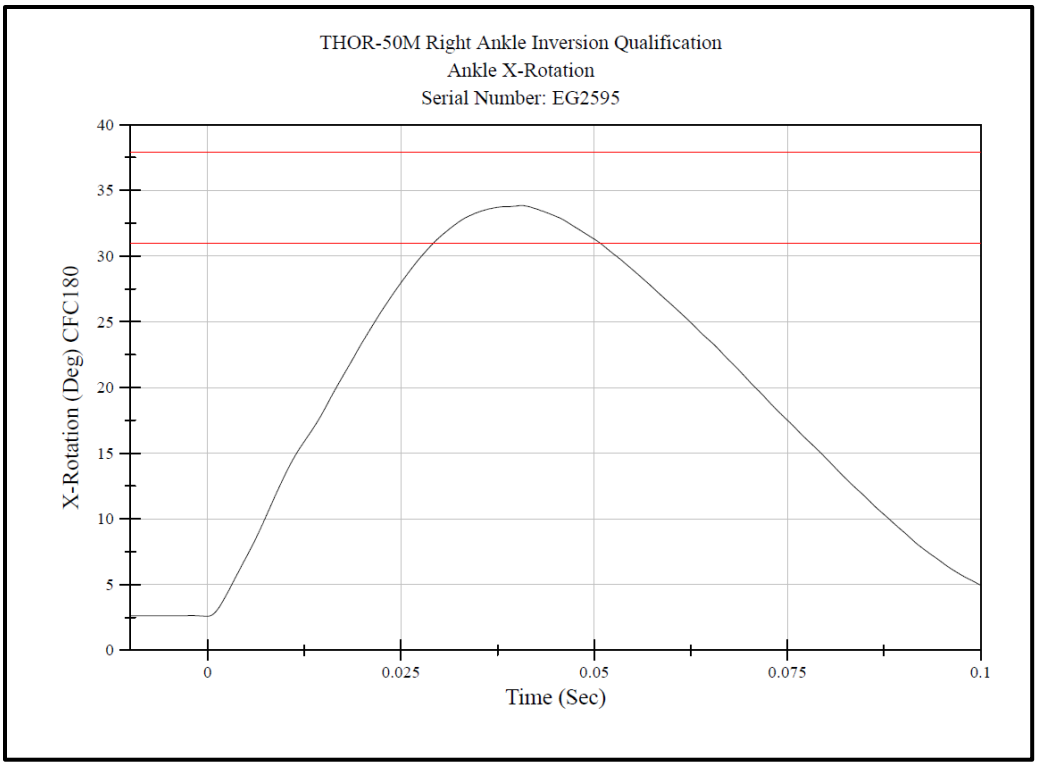


*Figure B-56. Right ankle inversion: Ankle X-axis rotation for in-dummy DAS EG2595 (2023 version)*

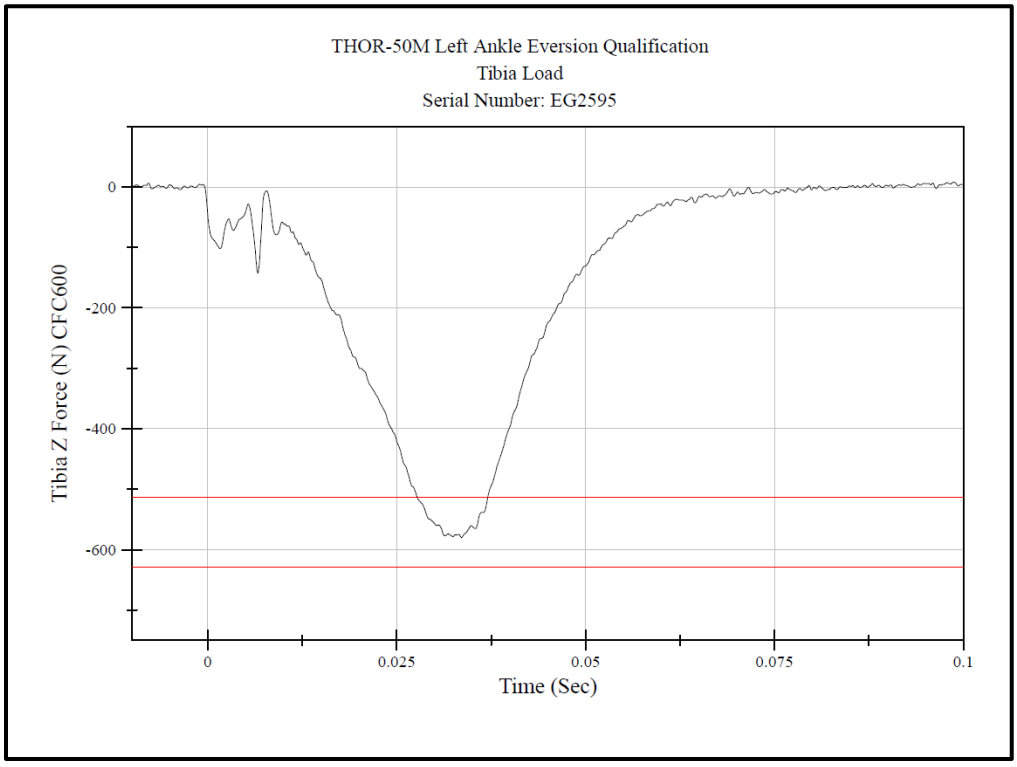


*Figure B-57. Left ankle eversion: Tibia Fz for in-dummy DAS EG2595 (2023 version)*

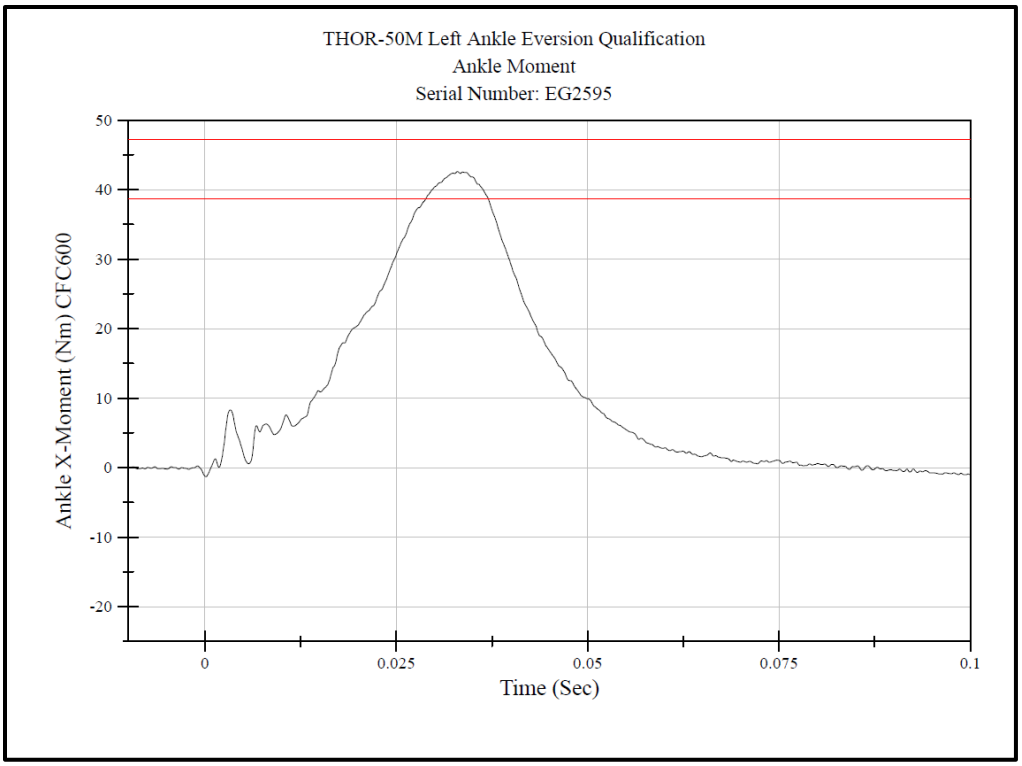


*Figure B-58. Left ankle eversion: Ankle Mx for in-dummy DAS EG2595 (2023 version)*

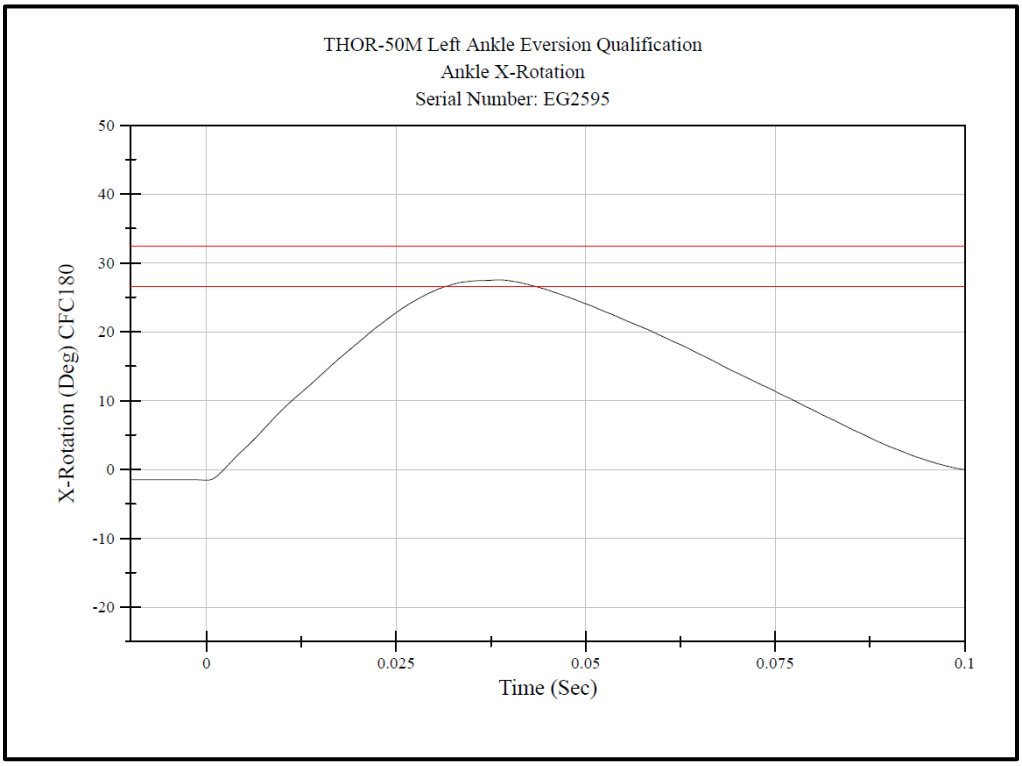


*Figure B-59. Left ankle eversion: Ankle X-axis rotation for in-dummy DAS EG2595 (2023 version)*

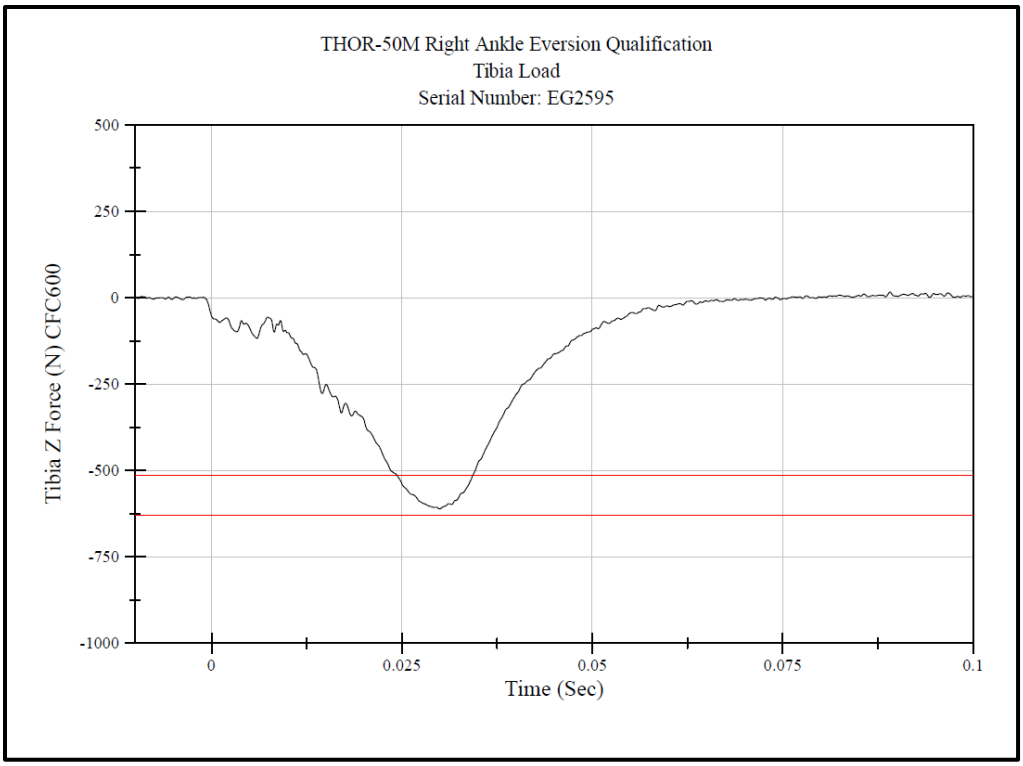


*Figure B-60. Right ankle eversion: Tibia force Fz for in-dummy DAS EG2595 (2023 version)*

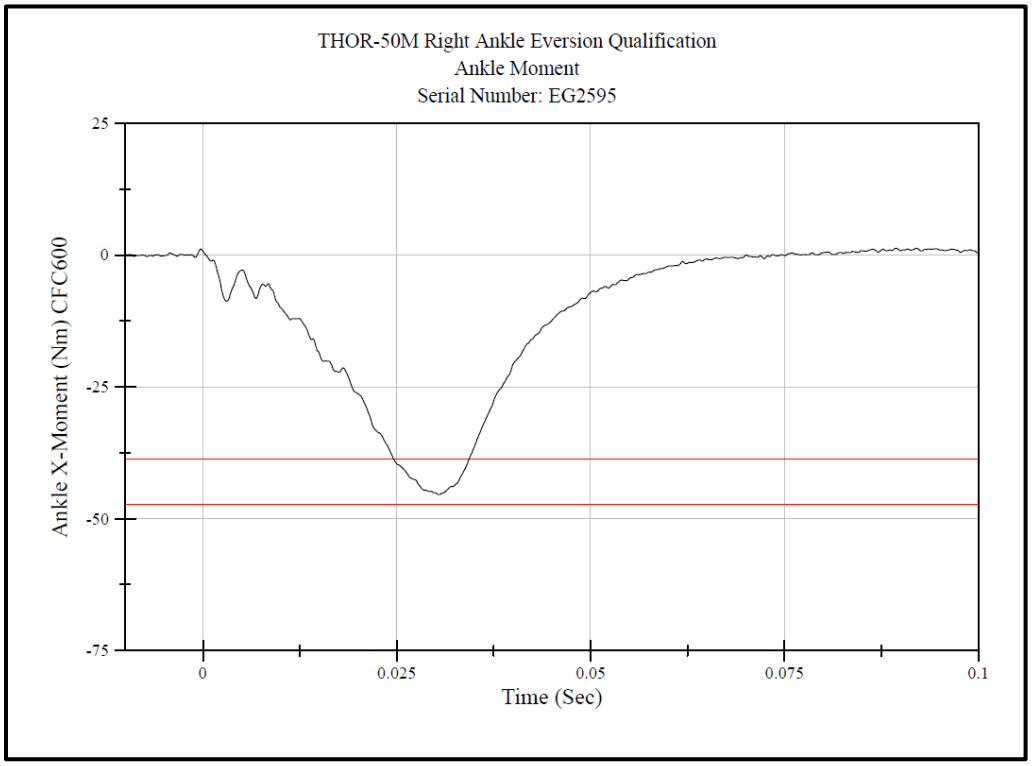


*Figure B-61. Right ankle eversion: Ankle Mx for in-dummy DAS EG2595 (2023 version)*

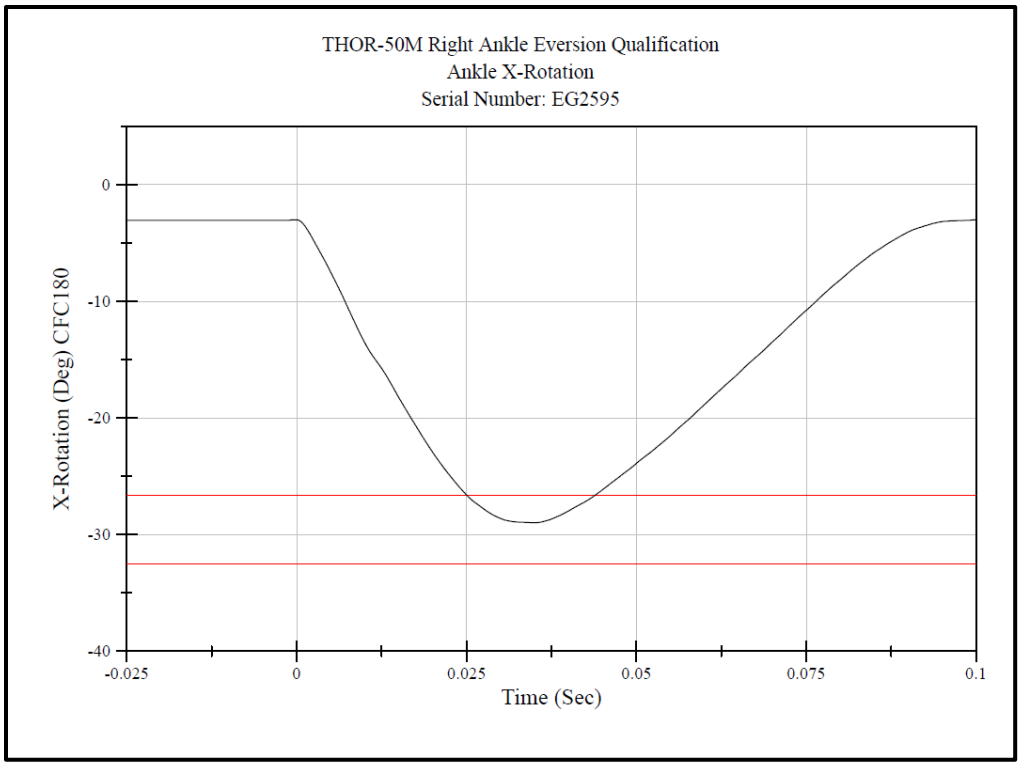


*Figure B-62. Right ankle eversion: Ankle X-axis rotation for in-dummy DAS EG2595 (2023 version)*

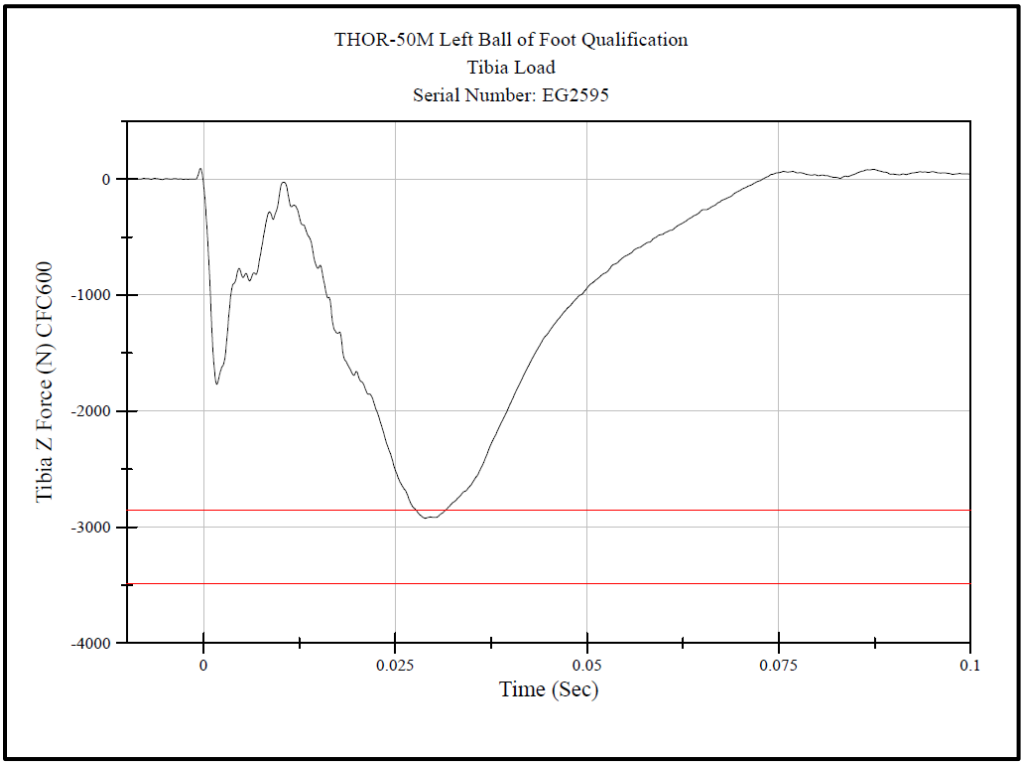


*Figure B-63. Left ball of foot: Tibia Fz for in-dummy DAS EG2595 (2023 version)*

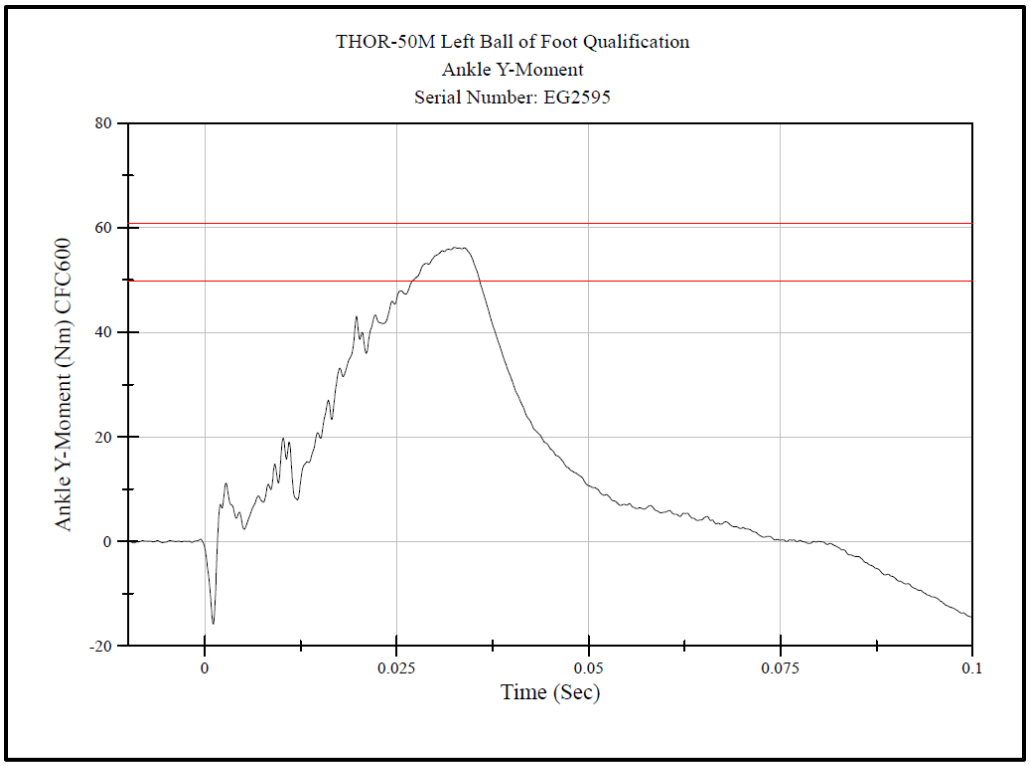


*Figure B-64. Left ball of foot: Ankle My for in-dummy DAS EG2595 (2023 version)*

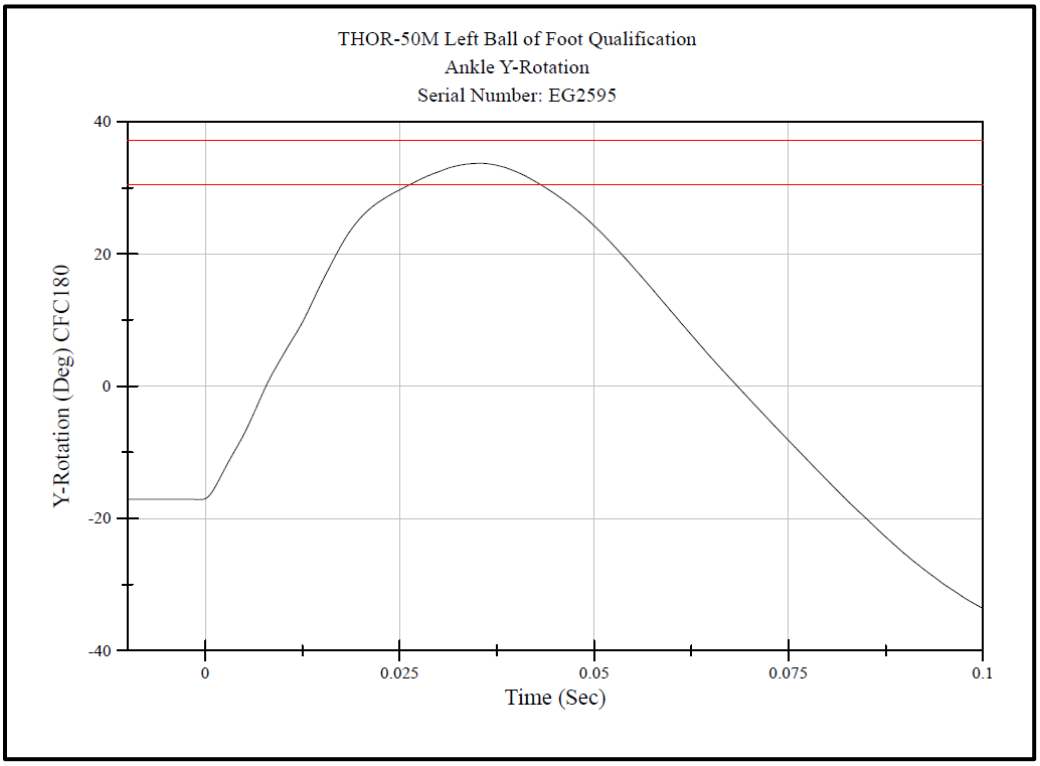


*Figure B-65. Left ball of foot: Ankle Y-axis rotation for in-dummy DAS EG2595 (2023 version)*

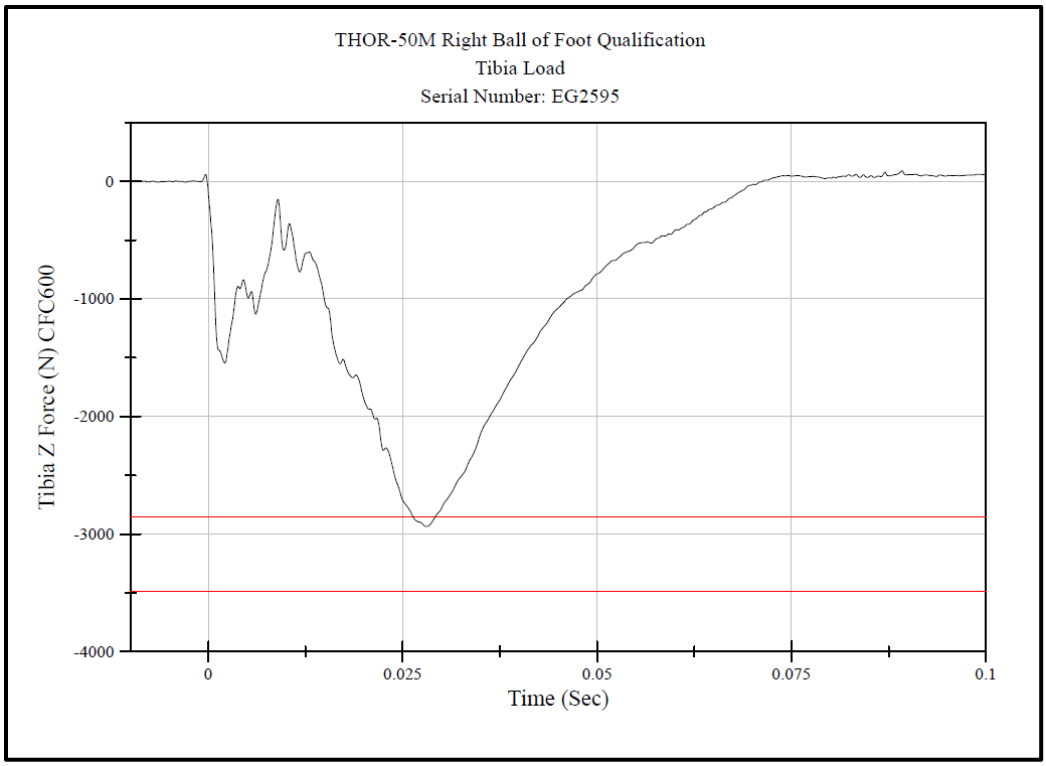


*Figure B-66. Right ball of foot: Tibia Fz for in-dummy DAS EG2595 (2023 version)*

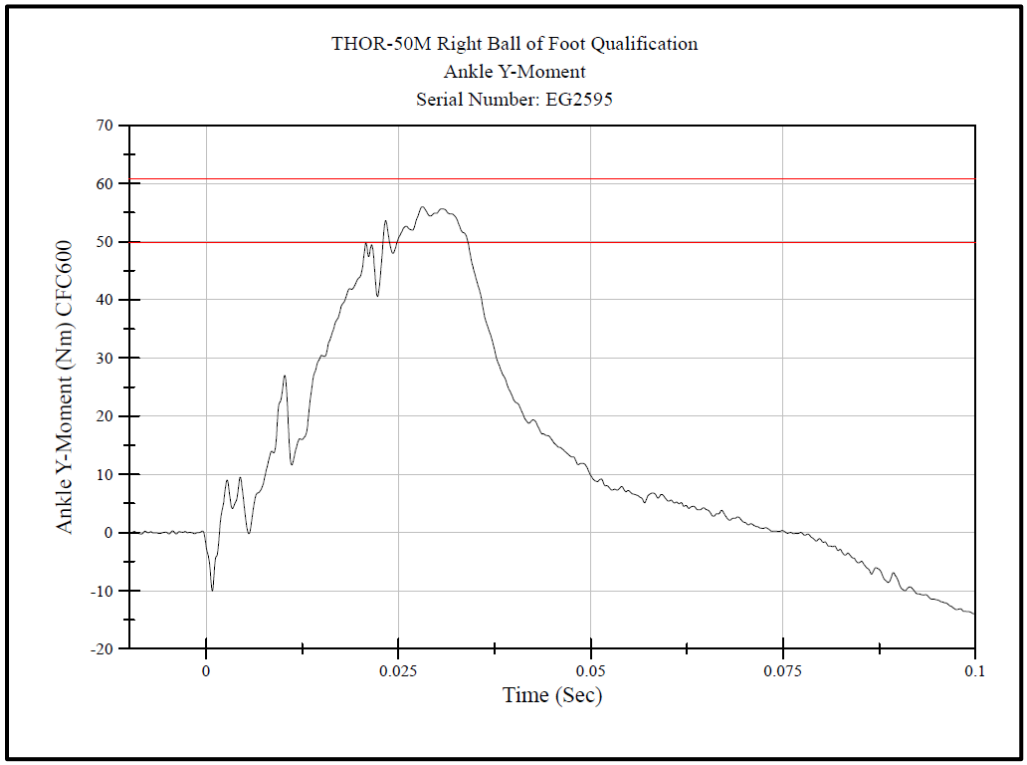


*Figure B-67. Right ball of foot: Ankle My for in-dummy DAS EG2595 (2023 version)*

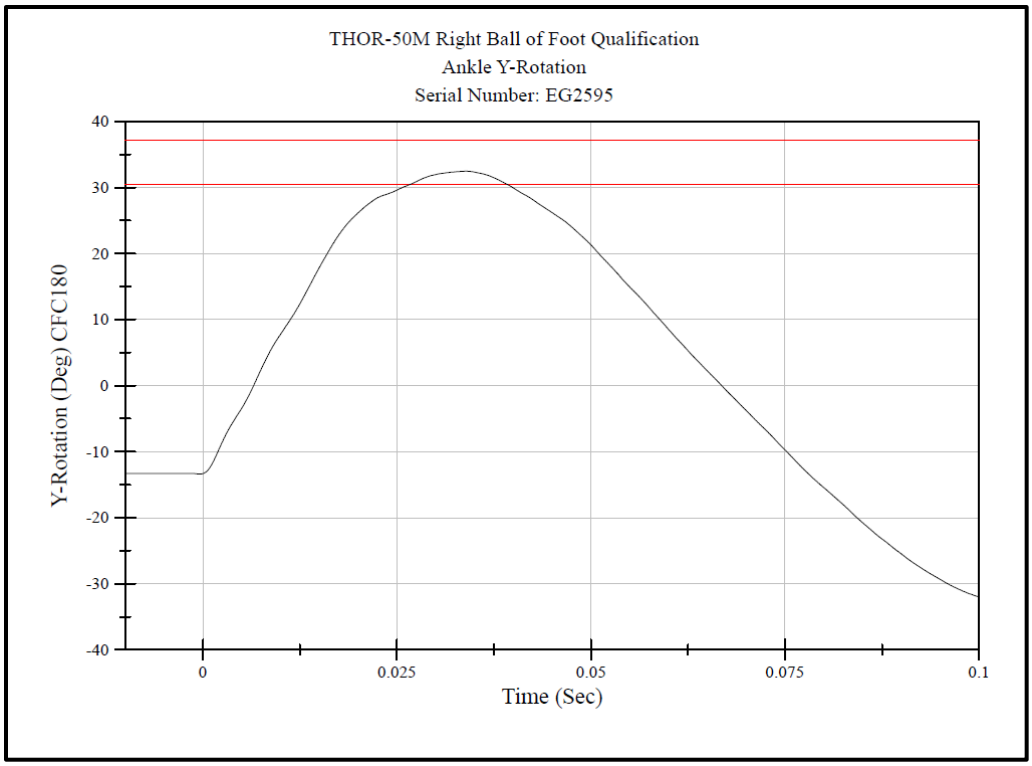


*Figure B-68. Right ball of foot: Ankle Y-axis rotation for in-dummy DAS EG2595 (2023 version)*

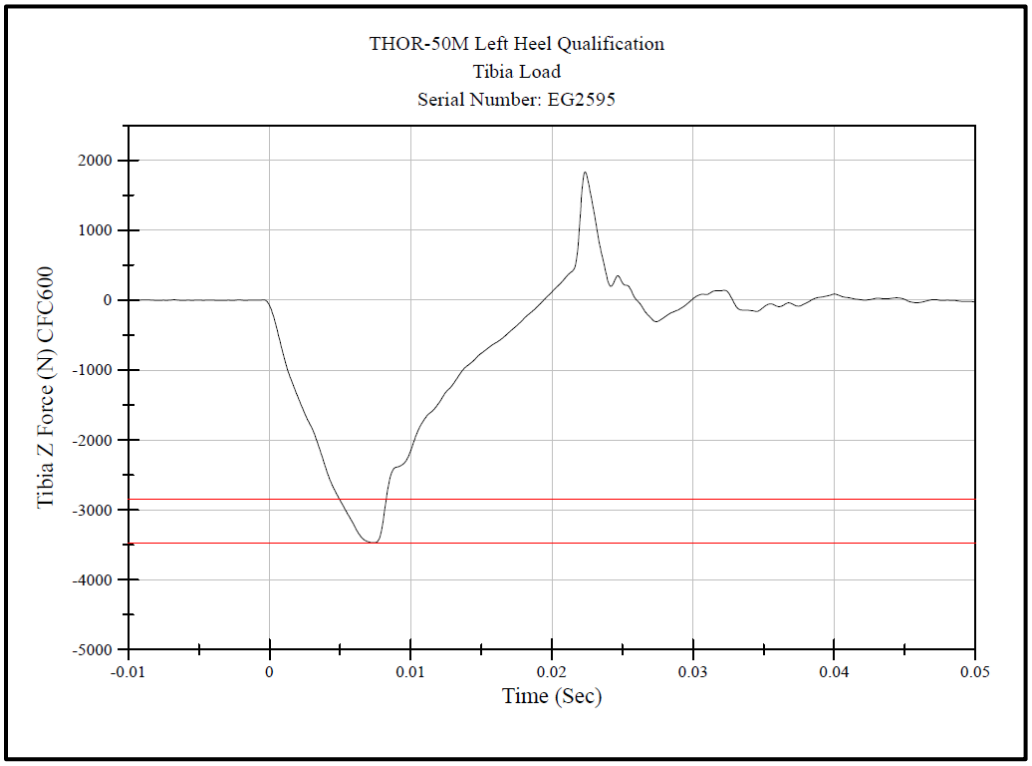


*Figure B-69. Left heel: Tibia Fz for external and in-dummy DAS EG2595*

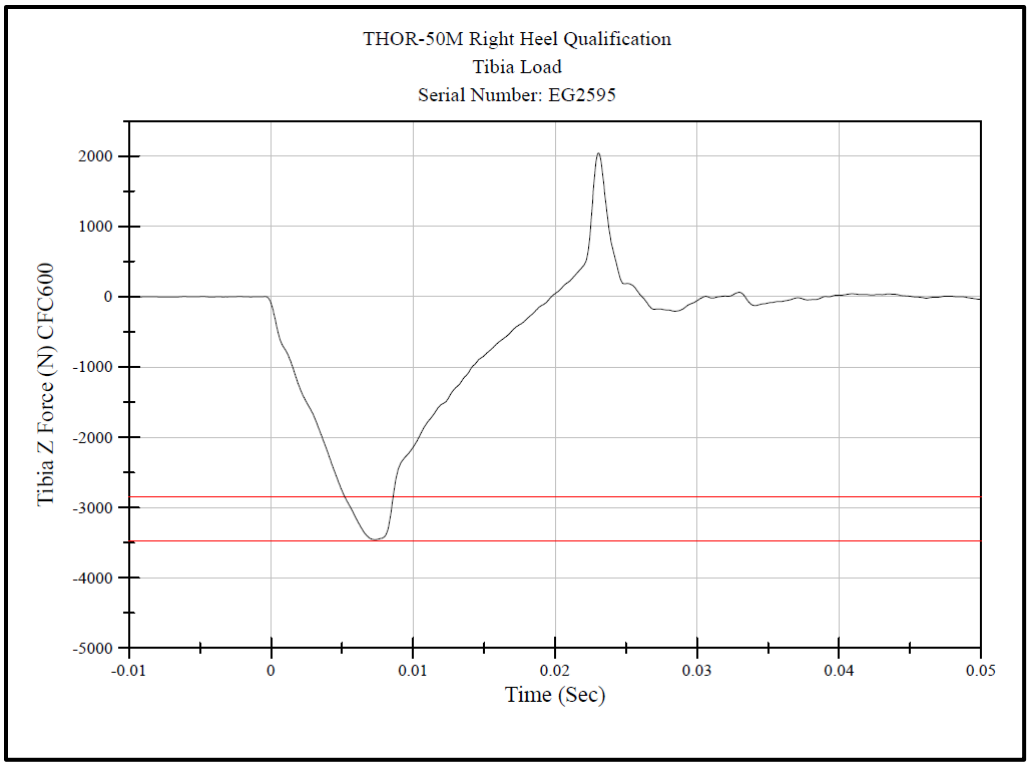


*Figure B-70. Right heel: Tibia Fz for external and in-dummy DAS EG2595*

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