Report No: GESAC-05-04

THOR CERTIFICATION MANUAL

(Revision 2005.2)

TRAUMA ASSESSMENT DEVICE DEVELOPMENT PROGRAM

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THOR CERTIFICATION MANUAL

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THOR CERTIFICATION MANUAL

1. INTRODUCTION

This manual constitutes part of the final documentation for the NHTSA Advanced Frontal Dummy known as THOR (**T**est device for **H**uman **O**ccupant **R**estraints). It describes the certification procedures for qualifying the different components of the dummy. These are test procedures developed to verify the proper response characteristics of these components, normally under dynamic loading conditions. This manual can be used in conjunction with the document ***Biomechanical Response Requirements of the Thor NHTSA Advanced Frontal Dummy (Revision 2005.1)***. Several of the test procedures described in the latter document and used for evaluating the biofidelity of the Thor dummy are described in greater detail in this document.

2. HEAD CERTIFICATION

Summary

Two standard tests are used for certifying the response of the Thor forehead. The first is a frontal impact to the forehead by a rigid impactor [Melvin, 1985]. The second is an isolated head drop test, similar to that for the Hybrid III head. Either of one or both of these tests can be used to certify the impact performance of the head.

Reference

Melvin, J., Weber, K. 1985. *Task B Final Report.* UMTRI-85-3. University of Michigan Transportation Research Institute, Ann Arbor, MI.

Code of Federal Regulations. 1998. *Title 49, Part 572, Subpart E.*

2.1 Head Impact

Description

This dynamic test is performed to examine the force-time characteristic of the head in an impact with a rigid impactor of mass 23.4 kg. The impact velocity for this certification is 2.0 m/s.

Materials

The parts required for the head frontal impact test are:

1. Fully assembled dummy.

2. Linear impactor or impact pendulum with a mass of 23.4 kg. The impactor should be cylindrical with a circular face of diameter 152 mm. The impactor edge should have a radius of 12 mm.

Instrumentation

The instrumentation required for the test is:

1. Accelerometer or accelerometer / load cell for measuring the impact force.
2. Impact velocity measuring instrumentation.
3. Triaxial accelerometer mounted at the C.G. of the head

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. Filter the pendulum accelerometer or the accelerometer / load cell combination using filter class CFC 180.

Test Procedure

1. Inspect the head assembly for wear, tears, or other damage.
2. Soak dummy in a controlled environment at a temperature between 69° and 72°F for at least 4 hours prior to testing. The test environment should have the same temperature as the soak environment.
3. Seat the dummy on a seating surface with a back support and with the limbs extended horizontally forward (the shoulder and elbow joints can be tightened to the normal 1g level).
4. The impactor should be placed so that its axis is aimed at a point on the forehead on the midsagittal plane and 30 mm above the horizontal line marking the lowest limit of the forehead . The tilt of the dummy head/neck assembly should be adjusted so that the impact area is parallel to the face of the impactor.
5. The motion of the impactor should be constrained so that there is no significant lateral, vertical, or rotational movement.
6. Deliver the impactor at the speeds of 2.0 m/s. Note that at least 60 minutes should pass between two successive tests.

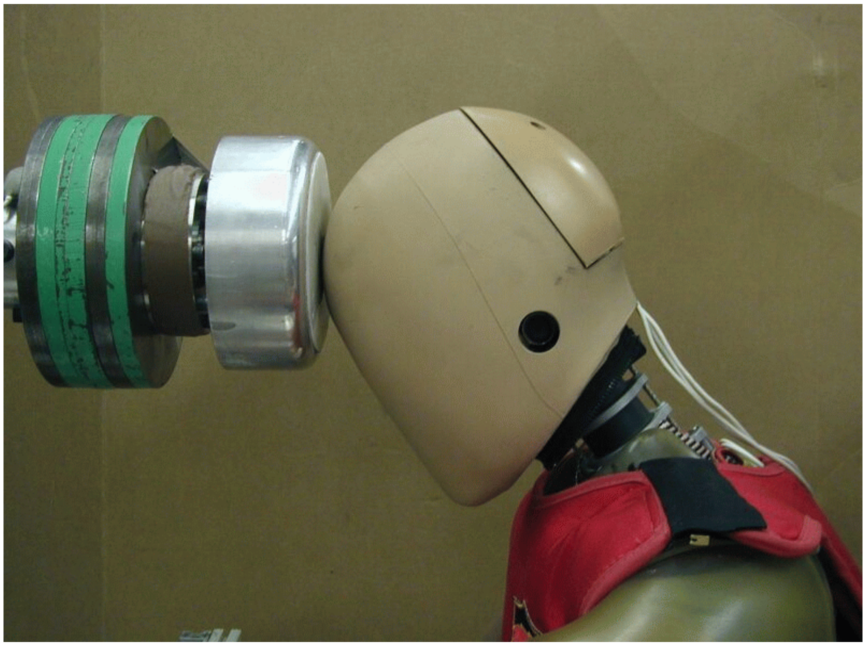

Figure 1. Setup for head impact test using linear impactor.

Performance Specification

The peak force and the time at which the peak force occurs are measured from the impact. These should be within the ranges provided in the table below.

Impact Speed (m/s)	Peak Force (N)	Time for Peak (msec)
2.0 m/s	4980 - 6090	2.0 - 3.0

The specification is shown graphically below.

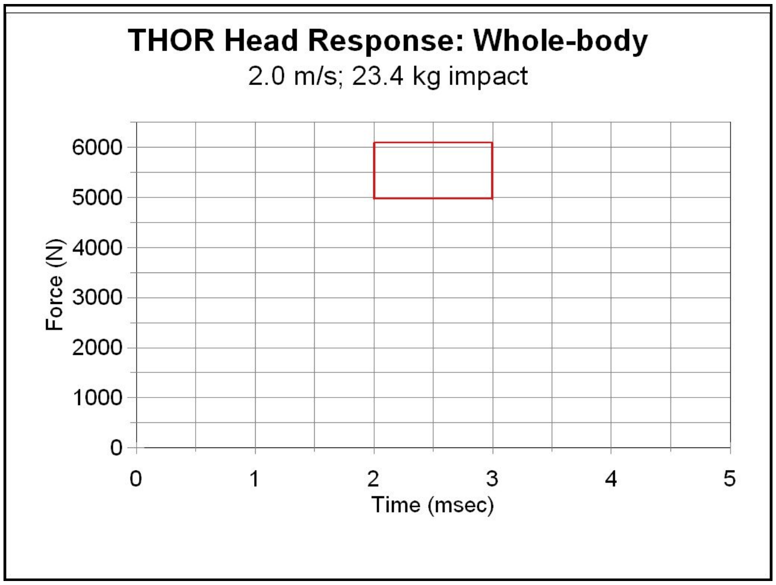

Figure 2. Force vs. time response for THOR head impact.

2.2 Head Drop

Description

A standard isolated head drop test can also be used for certifying the impact response of the THOR head. The procedure for the head drop is similar to that defined in CFR Title 49, Part 572E, Section 32.

Materials

The parts required for the head frontal impact test are:

1. THOR head assembly which includes the face load cell structural replacements (Part T1FCM117) .
2. Head impact plate (according to Part 572E, Section 32).

Instrumentation

The instrumentation required for the test is:

1. Triaxial accelerometer mounted at the C.G. of the head

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. Filter the head C.G. accelerometers using filter class CFC 1000.

Test Procedure

1. Soak the head assembly in a test environment at a temperature between 66° and 78° F for a period of at least four hours prior to its application in a test.
2. Clean the head's skin surface and the surface of the impact plate with 1,1,1 Trichlorethane or equivalent.
3. Suspend the head such that it is oriented symmetrically about its mid-sagittal plane. Using an inclinometer on the flat area of the bottom of the head-neck mounting platform (Part T1NKM210), rotate the head about the lateral axis, till the mounting platform is at 29° from vertical. Lower the head without further rotation, so that the lowest point on the forehead is 376 mm (14.8 in) above the impact plate.
4. Drop the head from the specified height by means that ensure instant release into a rigidly supported flat horizontal steel plate, which is 50.8 mm (2 inches) thick and 61 cm (24 inches) square. The plate shall have a clean, dry surface and any microfinish of not less than .2 micrometers (8 microinches) (rms) and not more than 2 micrometers (80 microinches) (rms).
5. Allow at least 1 hour between successive tests on the same head.

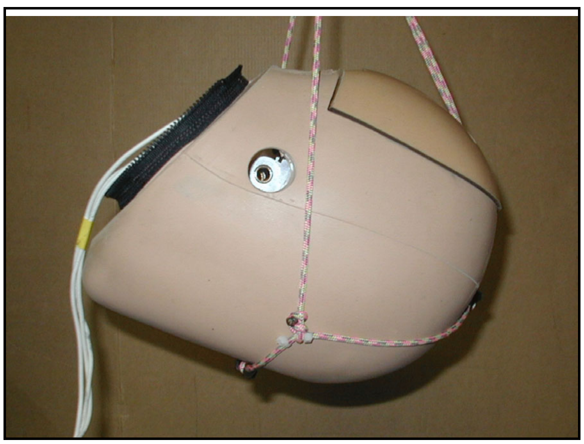

Figure 3. Setup for head drop test.

Performance Specification

The peak resultant acceleration of the head C.G. should be within the ranges provided in the table below.

Impact height (mm)	Peak acceleration (g)
376	225 - 275

The specification is shown graphically below.

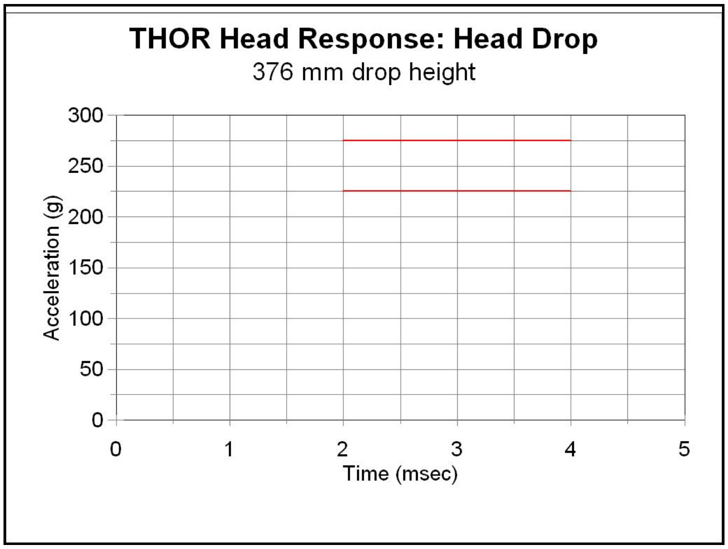

Figure 4. Acceleration vs time response for THOR head drop impact.

3. NECK CERTIFICATION

Summary

The standard test used for certifying the response of the Thor neck is with the neck and head assembly attached to the standard head-neck pendulum as defined in CFR Title 49, Part 572.

Reference

Code of Federal Regulations. 1998. *Title 49, Part 572, Subpart E.*

3.1 Neck Dynamic Response with Pendulum

Description

The test resembles the current test for the 50th percentile male head-neck assembly. The head/neck assembly is attached rigidly to the bottom of the head-neck pendulum. The pendulum test is used to define dynamic response in all three directions, namely: frontal, lateral, and extension.

Materials

The parts required for the head/neck pendulum test are:

1. Head and neck assembly, including all neck spring hardware
2. Head-neck pendulum (as defined in CFR Title 49, Part 572, Subpart E)
3. Foam padding used for decelerating the pendulum.

Instrumentation

The instrumentation required for the test is:

1. Upper neck 6-axis load cell.
2. Front and rear neck spring load cells.
3. Rotary potentiometer at the occipital condyle.
4. Pendulum accelerometer.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. Filter the pendulum accelerometer using filter class CFC 60, the load cell data channels using filter class CFC 600 and the rotary potentiometer using filter class CFC 180.

Test Procedure

1. Inspect the neck assembly for wear, tears, or other damage and for any debonding between the rubber pucks and metal plates. Inspect the front and rear springs (including the inserted rubber tubes) within the head assembly for any wear or other damage. Inspect the front and rear stops at the bottom of the head also for wear and damage.

2. Attach the neck assembly to the head and ensure that the O.C. potentiometer and housing are properly inserted.

3. Soak the head and neck assembly in a controlled environment at a temperature between 69° and 72°F for at least four hours prior to testing. The test environment should have the same temperature as the soak environment.

4. Mount the bottom of the neck assembly rigidly to the end plate of the head/neck pendulum. For the frontal flexion test, the neck is placed such that the mid-sagittal plane of the head is vertical and anterior-posterior direction of the assembly is pointing in the direction of travel of the pendulum. For the extension test, the direction is reversed. For the lateral flexion test, the base of the neck is rotated by 90° from the above.

5. Attach a rectangular section of Ensolite SCC High Performance foam to the impact area of the frame of the head-neck pendulum. The dimensions of the foam are:
   length = 136.5 mm; width = 101.6 mm; thickness = 76.2 mm.
   The foam can be attached by double-sided tape to the frame. It should be ensured that the contact area of the foam pad will completely cover the impactor plate on the pendulum upon impact.

   The response characteristics of the foam are determined from a quasi-static force-deflection test on a cubic specimen of dimensions of 50.8 mm x 50.8 mm x 50.8 mm. These are shown in the following table.

Compression Characteristics of Ensolite SCC Foam

Deflection (mm)	Compression (%)	Force Range (N)
15	.30	240 - 270
25	.50	470 - 520

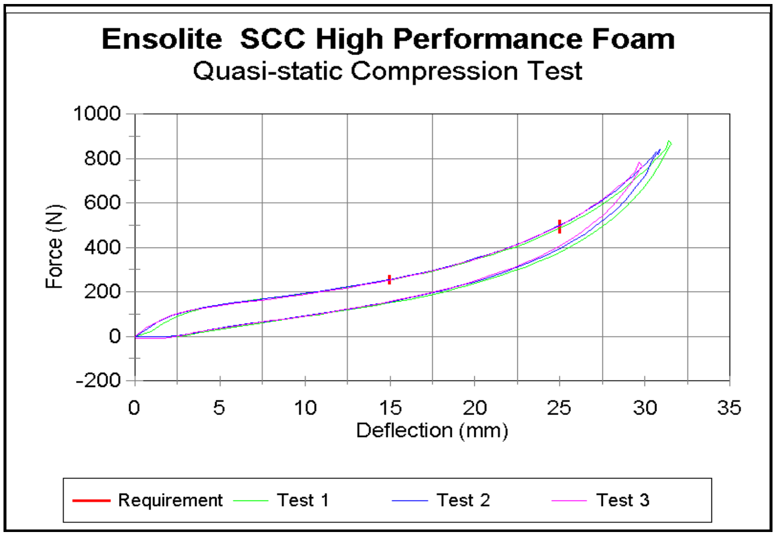

Figure 3. Force-deflection response of Ensolite SCC High Performance foam in quasi-static compression.

6. For the frontal flexion test, the pendulum should be released from a height to generate a 3.8 ± .1 m/s velocity at impact (equivalent to pendulum drop angle of 54.1°) . For the extension test, the pendulum should be released from a height to generate a 3.7 ± .1 m/s velocity at impact (equivalent to pendulum drop angle of 53.6°). For the lateral flexion test, the pendulum should be released from a height to generate a 2.9 ± .1 m/s velocity at impact (equivalent to pendulum drop angle of 40.3°).

7. Collect the time histories of the instrumentation channels above. The calculation procedure for the total moment at the O.C. is shown below and can also be determined using the accompanying THORTEST program. Using either method, compute the time history of the total neck moment (My) at the O.C.

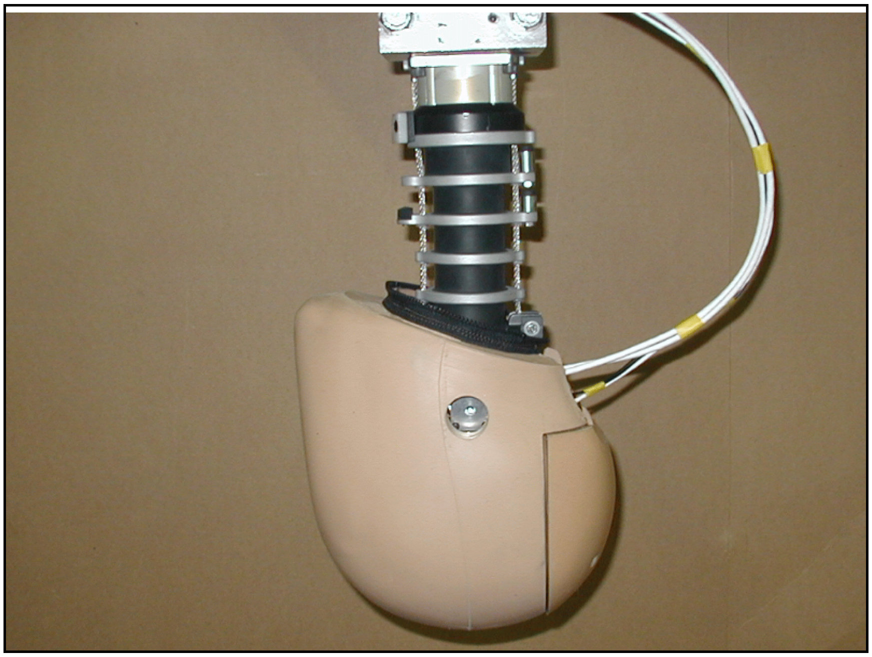

Figure 6. Setup for the neck pendulum test (flexion).

Data Processing

The moment at the O.C. is computed from the relation:

$$M_{OC} = M_y + a.F_x - r_f \times f_f + r_r \times f_r$$

where: F_x, M_y = shear X force and Y moment measured at load cell
a = offset of center of load cell from center of occipital condyle (O.C.) pin
r_f, r_r = vector location of front and rear neck spring cables relative to O.C. (from measurements on the head and neck)
f_f, f_r = vector forces along front and rear neck spring cables (from neck spring load cells)

Performance Specifications

Frontal Flexion

The response of the neck in frontal flexion is given by the following:

Pendulum Acceleration

Quantity	Units	Specification
Peak acceleration	g	24.0 - 28.0
Time for peak acceleration	msec	18.5 - 21.5
Duration	msec	35.1 - 40.8

Moment at O.C.

Quantity	Units	Specification
1st peak moment	Nm	46.6 - 57.0
Time for 1st peak moment	msec	58.0 - 71.0

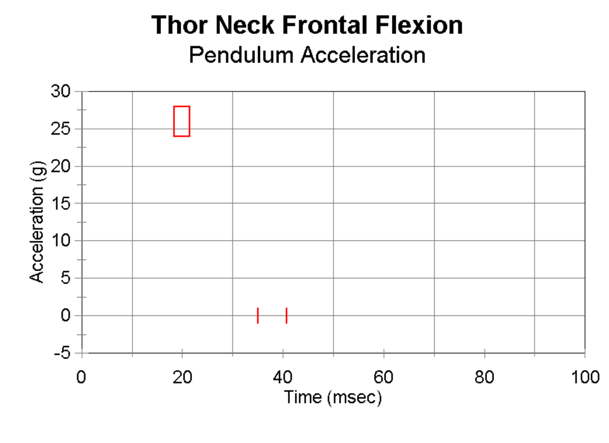

Figure 7. Pendulum acceleration response with head/neck pendulum in frontal flexion.

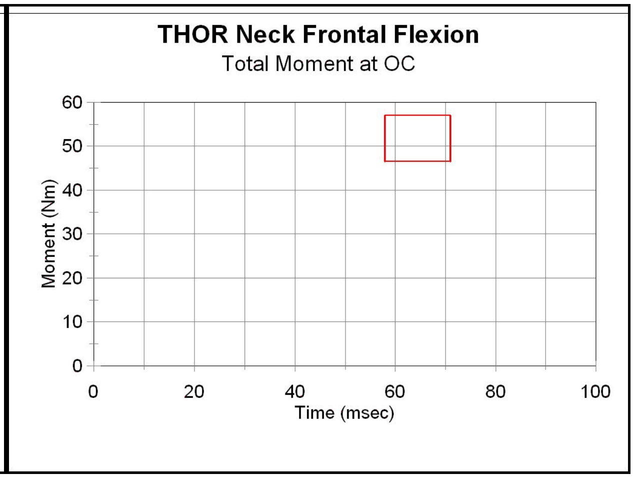

Figure 8. Neck My moment response at O.C. with head/neck pendulum in frontal flexion.

Extension

The response of the neck in extension is given by the following:

Pendulum Acceleration

Quantity	Units	Specification
Peak acceleration	g	23.1 - 26.9
Time for peak acceleration	msec	18.5 - 21.5
Duration	msec	36.1 - 41.9

Moment at O.C.

Quantity	Units	Specification
1st peak moment	Nm	-81.1 - -99.2
Time for 1st peak moment	msec	48.0 - 59.0

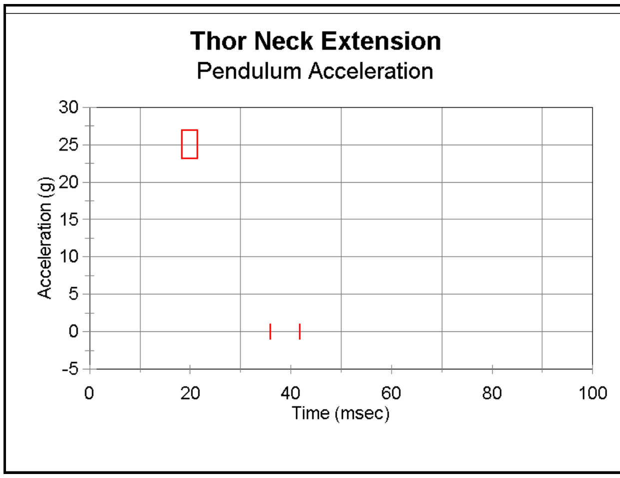

Figure 9. Pendulum acceleration response with head/neck pendulum in extension.

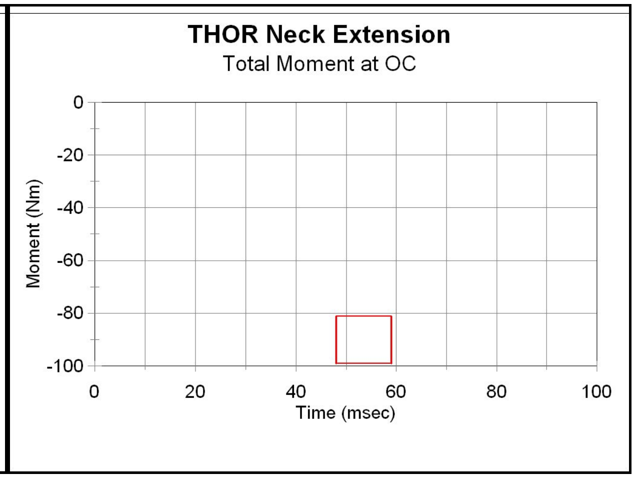

Figure 10. Neck My moment response at O.C. with head/neck pendulum in extension.

Lateral Flexion

The response of the neck in lateral flexion is given by the following:

Pendulum Acceleration

Quantity	Units	Specification
Peak acceleration	g	15.0 - 17.2
Time for peak acceleration	msec	20.2 - 23.4
Duration	msec	40.7 - 47.3

Moment at O.C.

Quantity	Units	Specification
1st peak moment	Nm	29.6 - 36.2
Time for 1st peak moment	msec	59.0 - 72.0

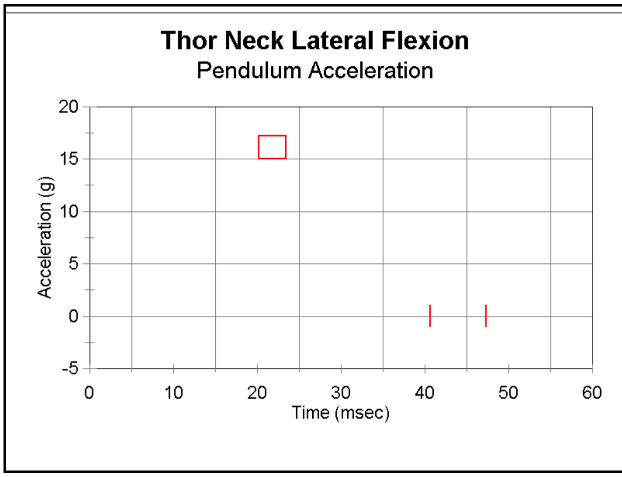

Figure 11. Pendulum acceleraton response for head/neck pendulum in lateral flexion.

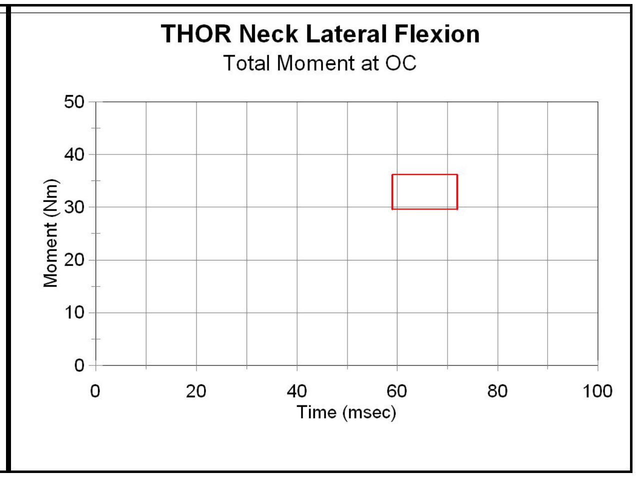

Figure 12. Neck Mx moment response at O.C. with head/neck pendulum in lateral flexion.

3.2 Neck Occipital Condyle Joint Quasi-Static Rotation Response

Description

The response of the occipital condyle (OC) joint between the head and the neck is verified using a quasi-static test using the isolated joint assembly.

Materials

The parts required for the OC joint test are:

1. Head-neck mounting platform (Part T1NKM210), occipital condyle cam (Part T1NKM043), occipital condyle bolt (Part T1NKM010) along with the necessary washers, neck rotary potentiometer along with the potentiometer housing.
2. Fixture allowing for performing quasi-static rotation at the OC joint. A representative fixture is shown in the figure below.

Instrumentation

The instrumentation required for the test is:

1. Upper neck 6-axis load cell.
2. Rotary potentiometer at the occipital condyle.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. The laboratory can follow any standard procedure for reducing the data collected from the above sensors, including any low-pass filtering that is generally used by the lab for quasi-static testing.

Test Procedure

1. Inspect the flexion and extension soft stops for wear, tears, or other damage and for any debonding with the stop plate.
2. Mount the head-neck mounting plate rigidly to the base plate of the test fixture and then mount the deflection rod to the bottom of the upper neck load cell. Ensure that the initial starting position of the neck is 0° ± 1° .
4. Slowly rotate (at about 1 - 2 ° / second) the top rod from the initial starting position to about 20° in flexion. Bring back the rod to a vertical position and continue rotation in extension to about 30° and then return back to vertical.
5. Record the M_y moment from the upper neck load cell.

Data Processing

Only the M_y moment from the upper neck load cell is required for certifying the response of the OC joint.

Performance Specifications

The response of the OC joint in flexion and extension is given by the following:

OC Joint Moment

Quantity	Units	Specification
Peak Flexion Moment	Nm	8.7 - 11.7
Peak Extension Moment	Nm	-8.7 - -11.7

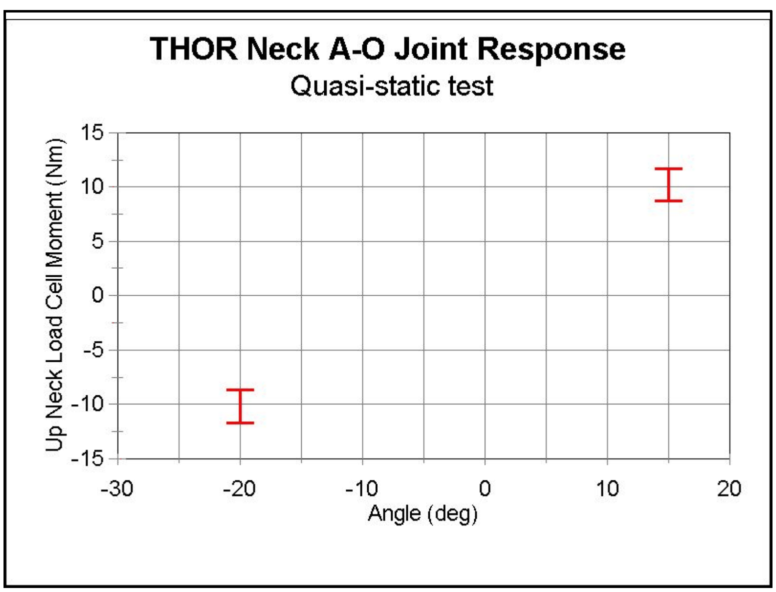

Figure 13. Quasi-static A-O joint response in flexion/extension.

4. THORAX CERTIFICATION

Summary

The standard tests for certifying the response of the Thor thorax are the Kroell central impact tests to the sternum at 4.3 and 6.7 m/s [Neathery, 1974] and an oblique impact to the lower ribcage [Yoganandan, 1997]. The biomechanical corridor for the 4.3 m/s Kroell impact has been modified from the original values by lowering the force by 667 N [GESAC, 2005].

References

GESAC, Inc. 2005. *Biomechanical Response Requirements of the Thor NHTSA Advanced Frontal Dummy (Revision 2005.1).*

Neathery, R. 1974. *Analysis of Chest Impact Response Data and Scaled Performance Recommendations.* Proceedings of the 18th Stapp Car Crash Conference.

Yoganandan, N., Pintar, F., Kumaresan, S., Haffner, M., Kuppa, S. 1997. *Impact biomechanics of the human thorax-abdomen complex*. International Journal of Crash, Vol 2, No. 2, pp 219-228

4.1 Upper Ribcage Central Impact Test

Description

The principal response corridors required to be met by THOR for thoracic impact are the traditional Kroell corridors for rigid disk impacts to the mid-sternum at 4.3 m/s and 6.7 m/s. The normalized curves, showing the impact force vs. chest deflection define the appropriate response requirements for these types of impacts for a 50th percentile U.S. male.

Materials

The parts required for performing the Kroell test are:

1. Fully assembled Thor dummy with internal Crux units
2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2. Four Crux units attached to the standard upper and lower thorax locations.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. All instrumentation should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10 ksamples/sec

Test Procedure

The test configuration for performing the Kroell tests using the 50th percentile male THOR ATD consists of:

1. Inspect the ribcage, bibs, and jacket for wear, tears, or other damage. Prior to assembly the profiles of the ribs should be examined to determine if they have been permanently deformed.
2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
   NOTE: Care should be taken to ensure the ambient temperature is well controlled within the above limits since the rib material is very temperature sensitive.
3. The impactor should be rigid and flat with a 152 mm diameter and mass of 23.4 kg. The edge of the impactor face should have a radius of 12.5 mm.
4. The lumbar spine pitch change mechanism is kept in the slouch position.
5. The dummy is set up in a sitting position, with no back support and its legs horizontal and the arms raised (may be taped lightly to a support bar).
6. Dummy is positioned in front of impactor such that the center line of the impactor is at the vertical level of the middle of dummy rib #3, and positioned over the mid-line of the sternum. This position would be at the middle of the line connecting the attachment nuts of the two upper chest deflection measurement systems (Crux). The impactor face should be approximately parallel to the chest at this location. This requires the lower thoracic spine to be 0° - 4° bent forward relative to vertical.
7. Two impact speeds are tested: one at 4.3 m/s (+/- 0.1 m/s) and one at 6.7 m/s (+/- 0.1 m/s).
8. The measurements include the impact force measured at the impactor and deflections measured by the two upper Crux systems. The average of the right and left X deflections should be used as the measure for chest skeletal deflection.

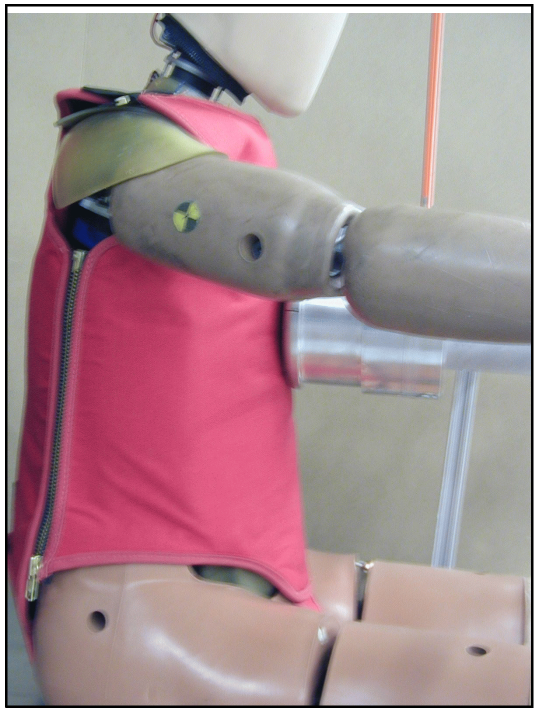

Figure 14. Setup of sternal impact test for measuring upper ribcage response.

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry.

The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

2. Upper left and right Crux measurements: These comprise the potentiometer data from each of the Crux units. Process the Crux potentiometer data using the supplied THORTEST program to determine the X, Y, and Z deflections.

Performance Specifications

The specifications for the Kroell impact are:

Table 1. 4.3 m/s Sternal Impact

Parameter	**Value**
Initial Peak @ 5 mm Deflection	Force (N): 1900 - 2400
Max. Force	Force (N): 2450 - 2950
Max. X Deflection	Defl (mm): 49.0 - 59.0
Hysteresis	71% - 87%

Table 2. 6.7 m/s Sternal Impact

Parameter	**Value**
Initial Peak @ 5 mm Deflection	Force (N): 3800 - 4700
Max. Force	Force (N): 5630 - 6870
Max. X Deflection	Defl (mm): 65.0 - 79.0
Hysteresis	71% - 87%

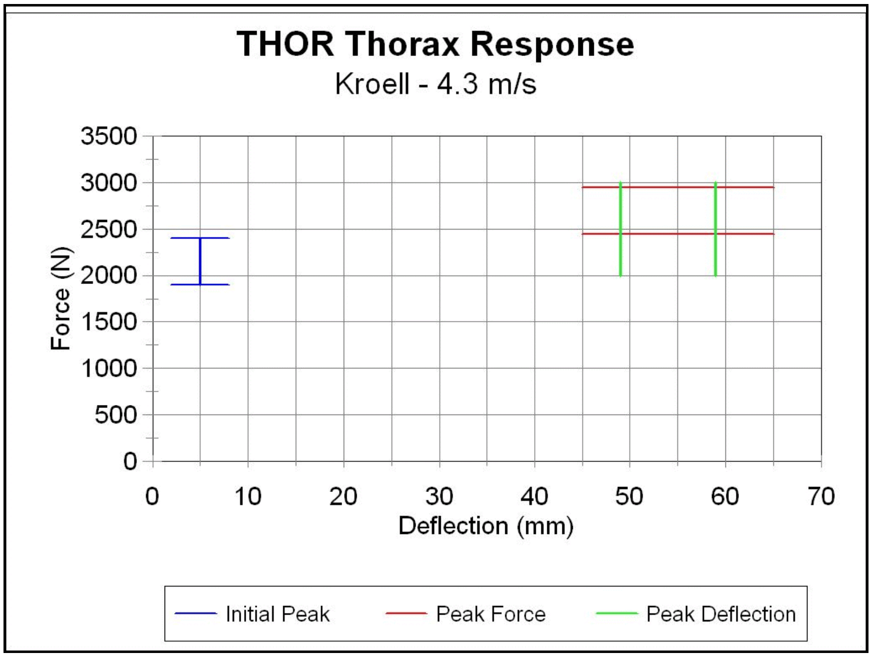

Figure 15. Force-deflection corridor for 4.3 m/s sternal impact (from Neathery).

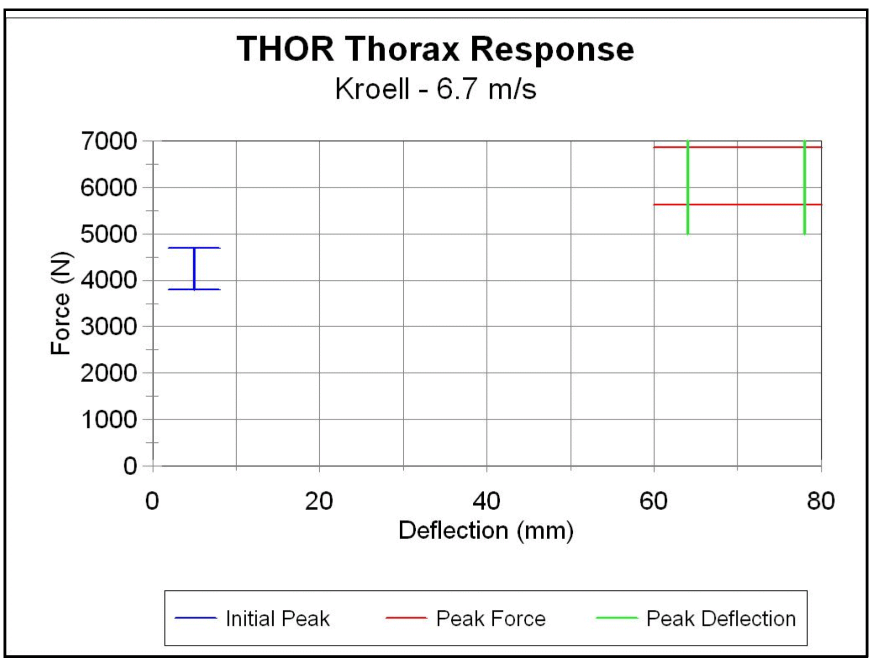

Figure 16. Force-deflection corridor for 6.7 m/s sternal impact (from Neathery).

4.2 Lower Ribcage Oblique Impact Test

Description

This test is based on oblique impacts at the lower ribcage performed by Medical College of Wisconsin (MCW) [Yoganandan, 1997]. In these tests, the torso was initially rotated from right to left by 15°, such that the impact occurred on the right antero-lateral thorax. The instrumentation in the MCW tests consisted of a load cell and uniaxial accelerometer attached to the pendulum to measure the impact forces. The chest deflection was measured with a chest band which measures the external deformation of the thorax. The response characteristics of the lower ribcage are shown as a force-time corridor, a deflection-time corridor and a combined force-deflection corridor.

Materials

The parts required for performing the lower ribcage oblique impact test are:

1. Fully assembled Thor dummy with internal Crux units
2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2. Four Crux units attached to the standard upper and lower thorax locations.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. All instrumentation should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

1. Inspect the ribcage, bibs, and jacket for wear, tears, or other damage. Prior to assembly the profiles of the ribs should be examined to determine if they have been permanently deformed.

2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
   NOTE: Care should be taken to ensure the ambient temperature is well controlled within the above limits since the rib material is very temperature sensitive.

3. The lower extremities are stretched horizontally and the upper extremities are extended forward to allow positioning of the torso. The back of the torso is unsupported.
4. Impact loading is applied at the level of the sixth rib in the anterior region on the right side.
5. The moving impactor mass is approximately 23.5 kg. and the impacting surface is a rigid (aluminum) disk of 152 mm. The impact surface is covered with 2 pieces of 9.5 mm thick and 152 mm diameter Rubatex foam ® 451N). The force-deflection characteristics of the padding, in quasi-static compression, are shown in the graph below.

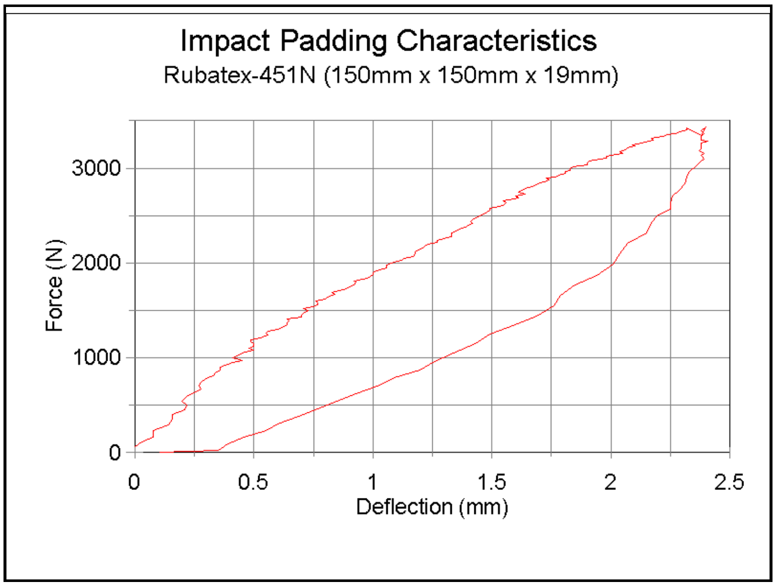

Figure 17. Quasi-static force-deflections characteristics of padding used in oblique impacts of lower ribcage.

6. The impact velocity is 4.3 m/s (+/- 0.1 m/s).
7. The lumbar spine pitch change mechanism is adjusted to the slouch position to keep the setting consistent with Kroell test setup.
8. Long underwear is placed on the dummy to provide realistic seat interaction.
9. The dummy is seated facing the impactor on a thin Teflon sheet. The teflon sheet is free to move relative to the wooden board attached to the test bed.
10. A clear acrylic plate with markings at +/-15 degrees relative to a center line may be used to adjust the orientation of the dummy about the vertical axis. The plate is attached to the top of the test bed. The center of the plate or 0 degree mark is oriented such that when viewed from above (through the acrylic), it is in line with the posterior most point on the base aluminum neck plate. This point is selected to allow rotation of the dummy about its spine. The dummy is rotated 15° from left to right about the spine to impact the left lower ribcage and rotated 15° from right to left to impact the right lower ribcage . Impacts should be performed on both sides to ensure symmetry.

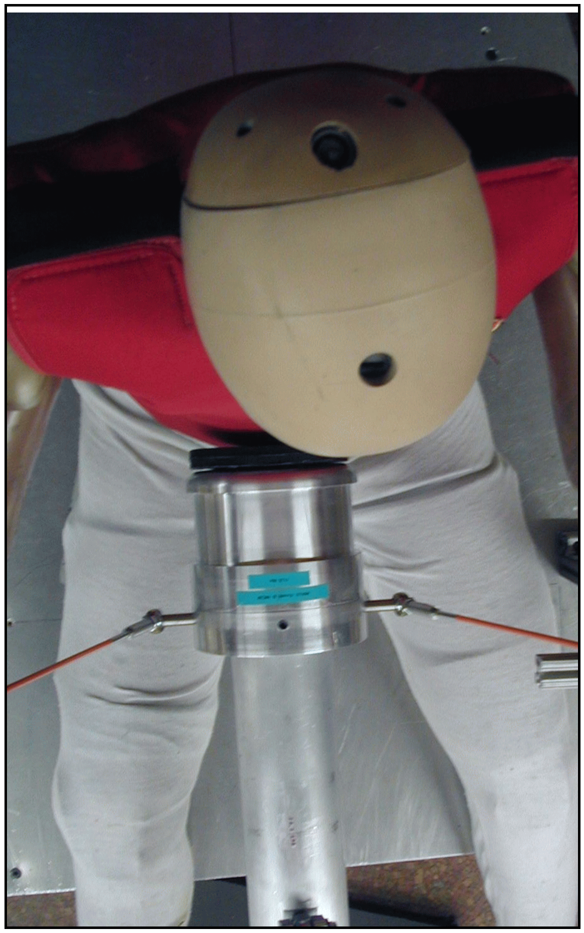
Figure 18. Setup of lower ribcage oblique impact

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

2. Both lower Crux units are installed. Process the Crux potentiometer data using the supplied THORTEST program to determine the X, Y, and Z deflections. Calculate the effective deflection of the ribcage by combining the X and Y deflections from the Crux on the impacted side by the formula:

$$d = X\cos\theta + Y\sin\theta$$

Find the maximum value of d and the maximum value for F_i

Performance Specifications

The specifications for the lower ribcage oblique impact are given by the peak force and peak internal deflection as computed above.

Table 3. MCW Lower ribcage response requirement

Quantity	Units	Specification
Peak Force	N	3390 - 4140
Peak Displacement	mm	41 - 51

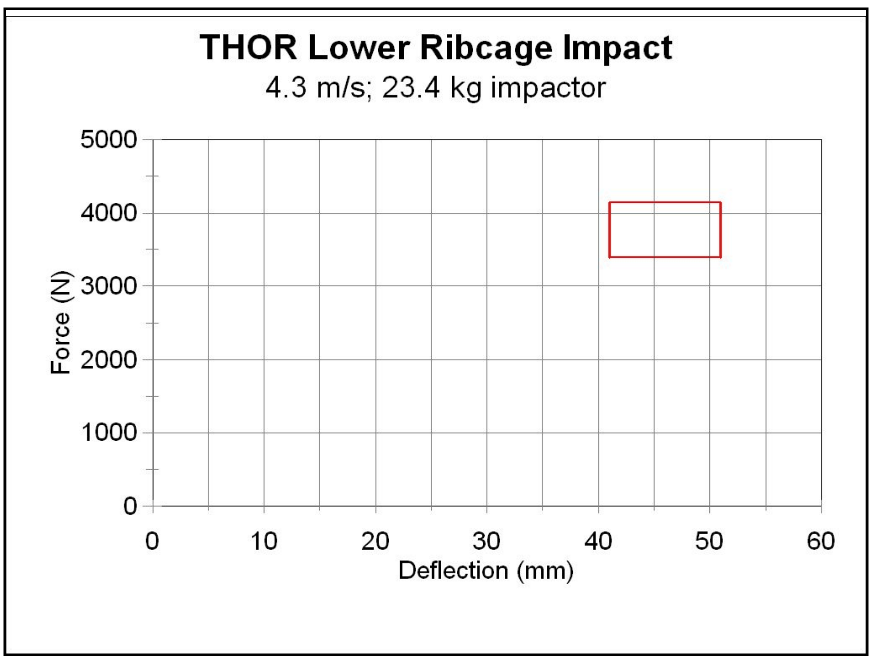

Figure 19. Force-deflection specification for oblique impact to lower ribcage at 4.3 m/s.

5. ABDOMEN CERTIFICATION

Summary

The standard tests used for certifying the response of the abdomen consist of an impact test with a cylindrical rod against the lower abdomen [Cavanaugh, 1986] and a steering wheel shaped impactor against the upper abdomen [Nusholtz, 1992].

References

Cavanaugh, J., Nyquist, G., Goldberg, S., and King, A. 1986. *Lower Abdominal Tolerance and Response.* Proceedings of the 30th Stapp Car Crash Conference.

Nusholtz, G., and Kaiker, P. 1994. *Abdominal Response to Steering Wheel Loading.* Proceedings of the 14th International Conference on Experimental Safety Vehicles.

5.1 Upper Abdomen Dynamic Impact Test

Description

The response requirement for upper abdomen impact has been derived from data developed by Nusholtz [1994] based on steering wheel impacts with engagement at region L2. The requirement is in the form of a force vs penetration corridor. Six tests were performed with impact speeds of 3.9 m/s to 10.8 m/s with an average speed of 8.0 m/s.

Materials

The parts required for performing the upper abdomen impact test are:

1. Fully assembled Thor dummy with left and right internal DGSP units in the abdomen.
2. Impact fixture: either impact pendulum or linear impactor with rigid, steering wheel shaped impact face. A sketch of the steering wheel geometry is shown in the following figure.

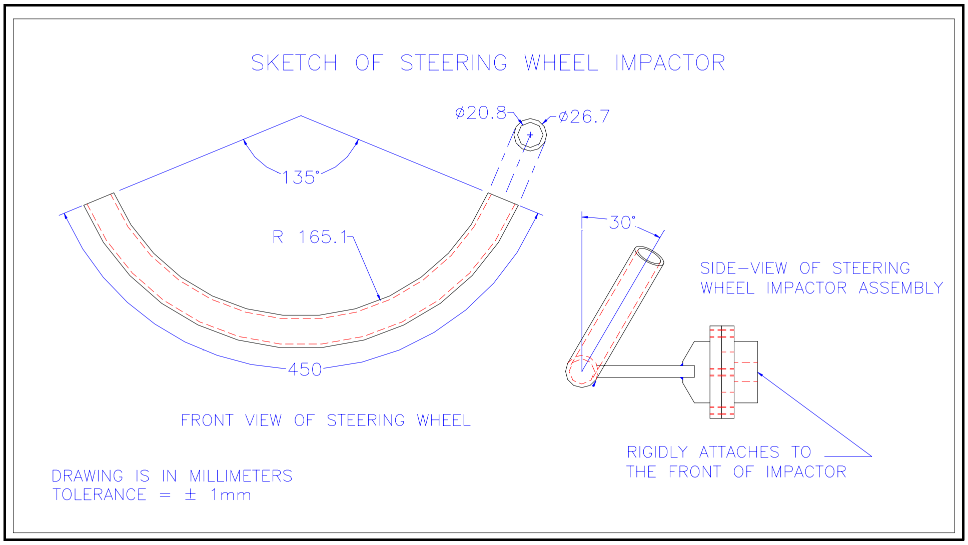

Figure 20. Dimensions and geometry of steering wheel impactor.

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination).
2. Upper abdomen string potentiometer.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. All instrumentation should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

1. Inspect the abdomen foam and the outer Cordura covering for wear, tears, or other damage. Prior to assembly the abdomen should also be inspected for any permanent set.
2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
3. The dummy is dressed in long thermal type pants. The dummy is seated on a thin plastic sheet. The lower extremities are stretched horizontally and the upper extremities are extended forward to allow positioning of the torso. The back of the torso is unsupported.
4. The lumbar spine pitch change is adjusted to the slouch position. The lower thoracic spine is maintained in a vertical position.
5. Impactor is in the shape of a steering wheel, mounted at an angle of 30° to the vertical axis with a mass of 18 kg.
6. The leading edge of the steering wheel is lined up with the center of the seventh rib.
7. The impact velocity is 8.0 m/s (+/- 0.1 m/s).

8. The normal certification procedure will be to determine the penetration directly from the maximum displacement measured by the upper abdomen string potentiometer, and the maximum force measured from the impactor.

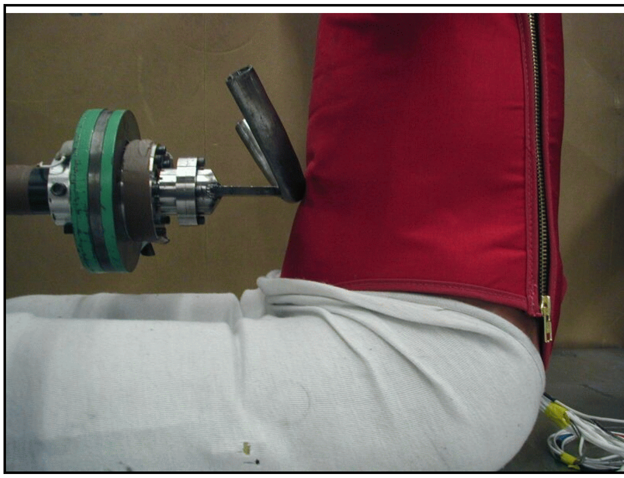

Figure 21. Setup of upper abdomen test (side view)

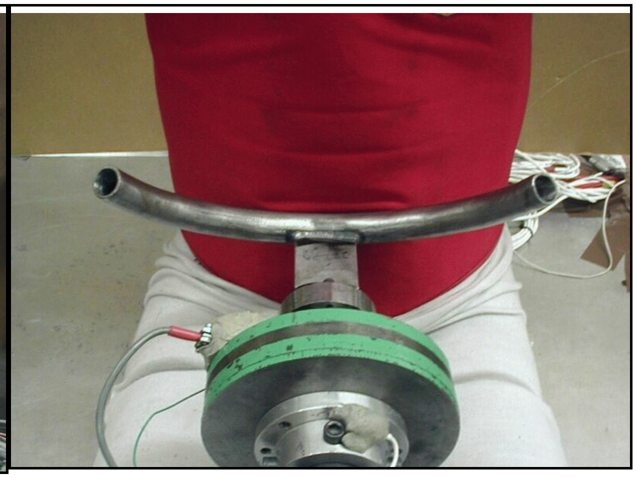

Figure 22. Setup of upper abdomen test (front view)

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: \This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

2. Upper abdomen string potentiometer measurement: (CFC: 180)

Performance Specifications

The specifications for the upper abdomen impact are given by:

Table 4. Upper abdomen response requirement (8.0 m/s)

Quantity	Units	Specification
Peak Force	N	5220 - 6380
Peak Displacement	mm	41 - 50

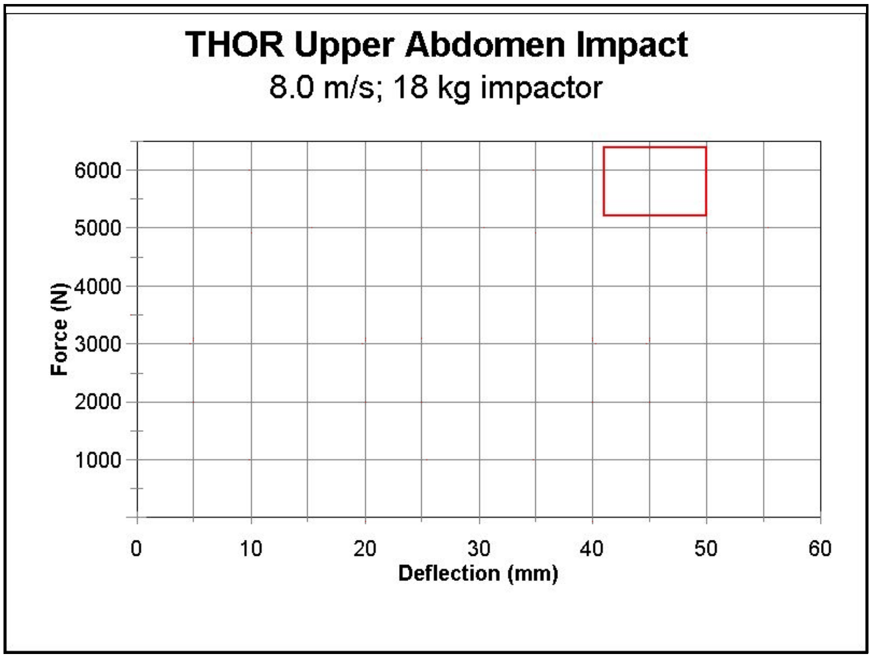

Figure 23. Force-penetration corridor for upper abdomen impact at 8.0 m/s.

5.2 Lower Abdomen Dynamic Impact Test

Description

The response requirement for lower abdomen impact has been derived from the low severity tests performed by Cavanaugh [1986]. The requirement is in the form of a force vs penetration corridor. The tests were conducted using a 25 mm diameter rigid bar of length 30 cm and mass 32 kg, impacting perpendicularly the abdomen of cadavers at vertical location of approximately L3. Five tests were performed in the speed range of 4.9 to 7.2 m/s with an average impact speed of 6.1 m/s.

Materials

The parts required for performing the lower abdomen impact test are:

1. Fully assembled Thor dummy with left and right internal DGSP units in the abdomen.

2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2. The two DGSP units attached to the lower abdomen.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. All instrumentation should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

1. Inspect the abdomen foam and the outer Cordura covering for wear, tears, or other damage. Prior to assembly the abdomen should also be inspected for any permanent set.
2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
3. The lower extremities are stretched horizontally and the upper extremities are extended forward to allow positioning of the torso. The back of the torso was unsupported.
4. The lower thoracic spine is maintained in a vertical position and the center line of the impactor should be at the vertical level of the line joining the centers of the attachment nuts of the right and left DGSPs and aimed at the mid-point of this line.
5. Impactor is a 25 mm diameter, 30 cm long rigid cylindrical rod with mass of 32 kg
6. The impact velocity is 6.1 m/s (+/- 0.1 m/s).
7. The normal certification procedure will be to determine the penetration directly from average of the X component of the deflection measured by the two DGSPs within the abdomen and the external impactor force. A corresponding external measurement may be obtained using a linear displacement transducer.

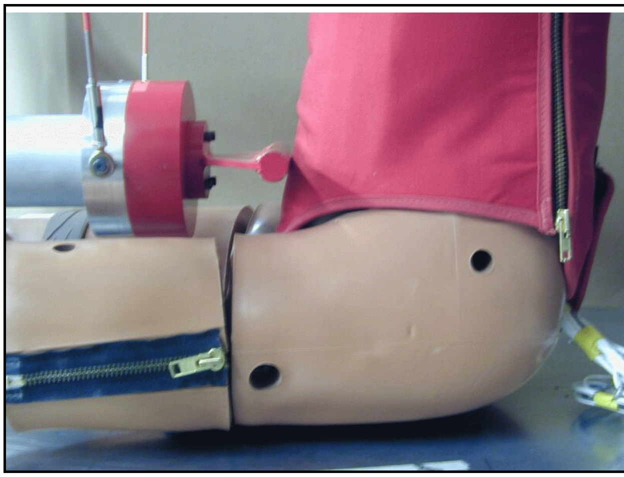

Figure 24. Setup of lower abdomen rod impact test (side view)

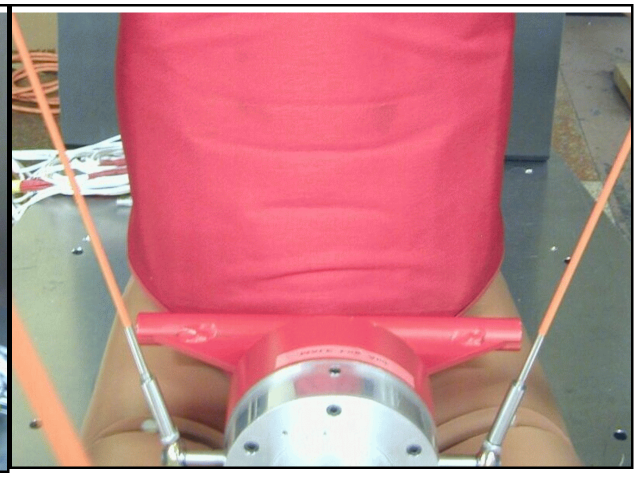

Figure 25. Setup of lower abdomen rod impact test (front view)

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

    $$F_i = -F_{LC} + m_f a$$

    where: F_{LC} = load cell measurement
    m_f = mass in front of load cell
    a = impactor acceleration

2. Left and right DGSP measurements: These comprise the potentiometer data from each of the DGSP units. (CFC: 180)

Performance Specifications

The specification for the lower abdomen impact at 6.1 m/s is given by the impact force corridor for an internal deflection of 50 mm (as computed from the average of the X displacements measured by the left and right DGSPs).

Table 5. Lower abdomen response requirement (6.1 m/s)

Quantity	Units	Specification
Peak Force	N	2200 - 2700
Peak Displacement	mm	49 - 60

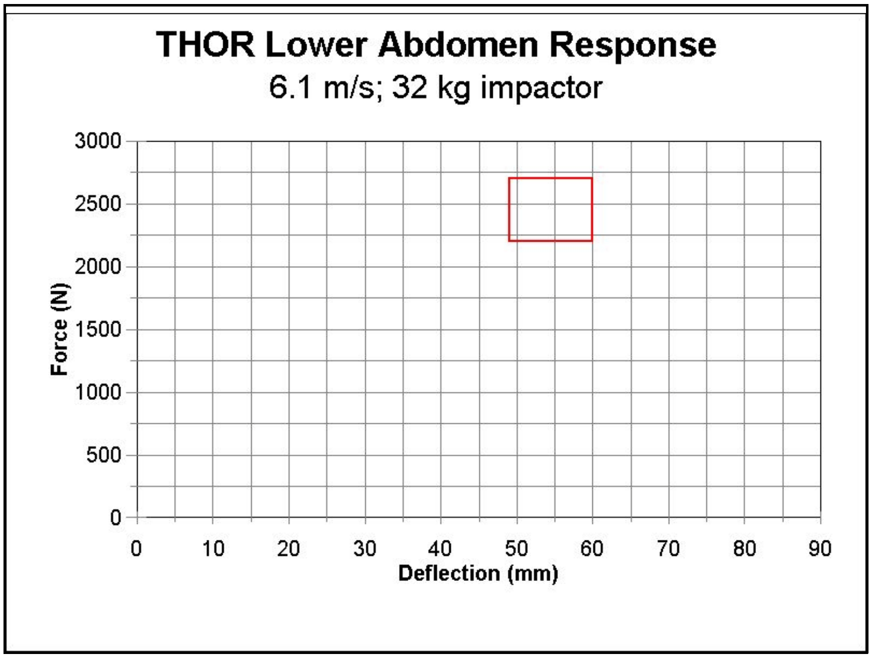

Figure 26. Force response for lower abdomen impact with rigid rod at 6.1 m/s.

6. FEMUR CERTIFICATION

Summary
The standard dynamic test for certifying the response of the Thor femur is the whole body knee impact test at specified initial impact energies [Horsch, 1976].

References

Horsch, J., and Patrick, L. 1976. *Cadaver and Dummy Knee Impact Response.* Proceedings of the 20th Stapp Car Crash Conference. SAE Paper # 760799.

6.1 Knee Impact Tests

Description

This test examines the response of the femur to axial impacts at the knee. The test uses a whole dummy seated in a chair. Peak impactor force and impact velocity are recorded to find whether the peak force is within the corridor.

Test Set-up

The parts required for performing the knee impact test are:

1. Fully assembled Thor dummy
2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity.

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2. Instrumentation to measure the initial impact velocity.

The polarity conventions and data acquisition system must conform to requirements of SAE Recommended Practice J211. All instrumentation should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

1. Inspect the knee skin, knee insert and femur puck for wear, tears, or other damage. Prior to assembly the femur puck should also be inspected for any significant permanent set. A small radial bulge is usual after the femur puck has been in service for some time.

2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
3. The dummy is seated on a horizontal, flat, rigid surface, with the lower legs placed over the edge of the surface, flexed at an angle of 20° from vertical. The torso is unsupported and the arms may be placed along the side of the body.
4. The impactor is rigid with a diameter of 76 mm and mass of 5 kg.
5. The impactor is aligned with the center of the knee, such that it is collinear with the femur axis.
6. Impact velocity is at 2.6 m/s (+/- 0.1 m/s).
7 The impact force is measured and the normal certification procedure will be to determine the peak force.

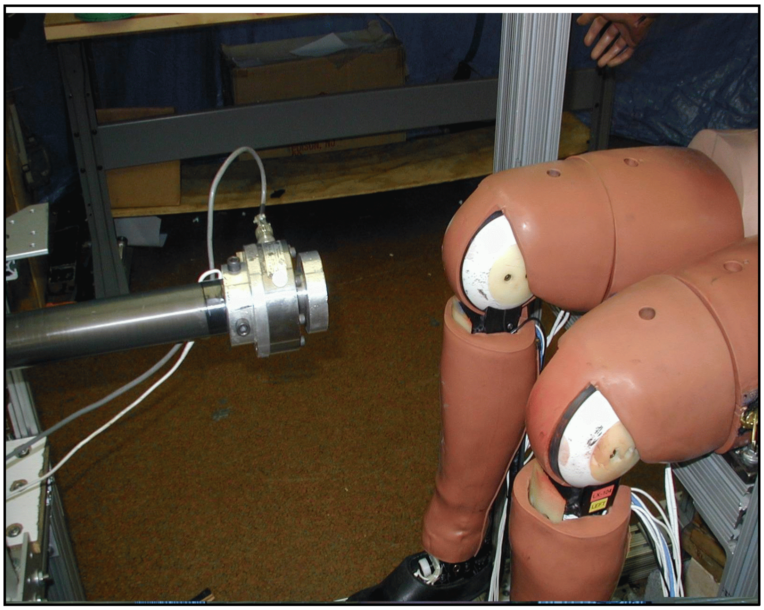

Figure 27. Setup for performing whole body knee impact.

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:

    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

Performance Specifications

Table 6. Knee impact response requirement

Impact speed (m/s)	Force (N)
2.6	3510 - 4290

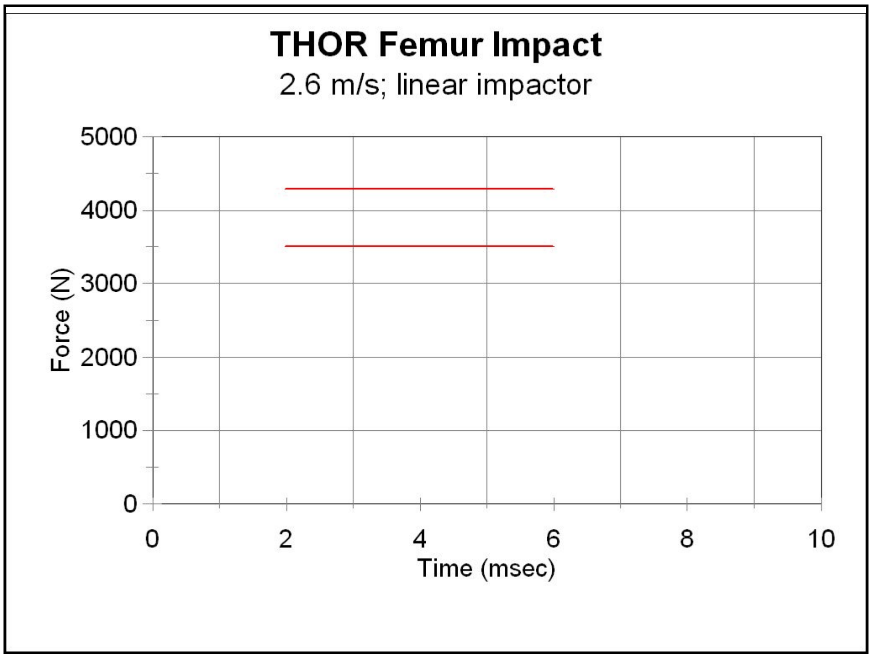

Figure 28. Knee impact response in whole body configuration for varying impactor mass and velocity.

7. FACE CERTIFICATION

Summary

There are two standard dynamic tests for certifying the response of the Thor face. The first is an impact test with a rigid rod at 3.6 m/s, and the second is an impact test with a 152 mm rigid disk at 6.7 m/s [Melvin, 1988].

References

Melvin, J., and Shee, T. 1989. *Facial Injury Assessment Techniques.* Proceedings of the 12th International Conference on Experimental Safety Vehicles.

7.1 Rigid Bar Impact

Description

This test examines the response of the face to impact load across a strip located horizontally below the eyes.

Test Set-up

The parts required for performing the rod impact test are:

1. Fully assembled Thor dummy
2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity.

Instrumentation

The required instrumentation for this test is:

1 Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2 Instrumentation to measure the initial impact velocity.

The polarity conventions and data acquisition system must conform to requirements of the 1996 revision of SAE Recommended Practice J211. The impactor load cell and accelerometer should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

For the rod impact test to the face, the configuration is defined as:

1. Inspect the face skin, the face foam, and the head skin for wear, tears, or other damage.
2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
3. The torso of the subject is maintained straight and the head vertical, with the legs kept horizontal and arms raised. The head and neck should be aligned (bottom of the head/neck mounting plate parallel to the upper neck load cell). The dummy is seated on a horizontal, flat, rigid surface and is left unsupported at the back.
4. The impactor assembly, including the rod, has a total mass of 32 kg.
5. The cylindrical impactor is rigid with a diameter of 25 mm and length of 30 cm.
6. The rod is configured to impact along the mid-line of the left and right maxilla plates on face. The face load cell plates (under the head skin) should be perpendicular to the impact direction.
7. Impact velocity is at 3.6 m/s (+/- 0.1 m/s).
8. The impact force is measured and the normal certification procedure will be to determine the peak force and the time at which peak force is reached.

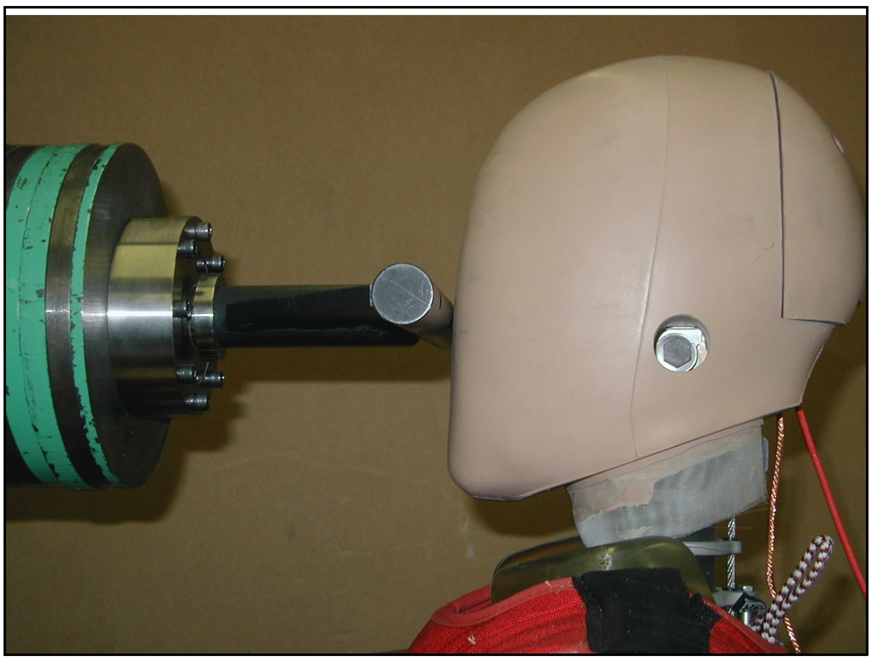

Figure 29. Setup of face impact test with rigid rod.

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half

the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

Performance Specifications

The specification for the face impact with rigid rod is given by:

Table 7. Face impact with rod response requirement (3.6 m/s)

Quantity	Units	Spec
Peak Force	N	2750 - 3360
Peak Time	msec	6.8 - 8.8

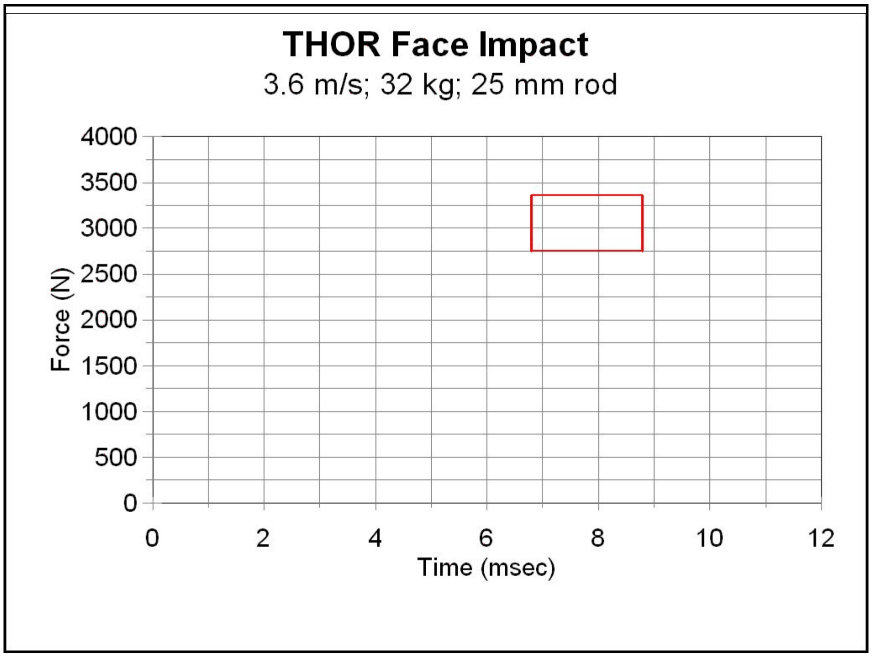

Figure 30. Force vs. time response for facial impact with rigid rod

7.2 Rigid Disk Impact

Description

This test examines the response of the face to a distributed load across the whole face. The test is performed using a disk impactor with a diameter of 152 mm and mass of 13 kg.

Materials

The parts required for performing the disk impact test are:

1. Fully assembled Thor dummy
2. Impact fixture: either impact pendulum or linear impactor with appropriate mass and velocity.

Instrumentation

The required instrumentation for this test is:

1. Instrumentation to measure impact force (impact accelerometer on impactor or load cell / accelerometer combination)
2. Instrumentation to measure the initial impact velocity.

The polarity conventions and data acquisition system must conform to requirements of the 1996 revision of SAE Recommended Practice J211. The impactor load cell and accelerometer should be filtered with CFC 180. Suggested sampling rates for the A/D conversion is 10ksamples/sec

Test Procedure

For the disk impact test to the face, the configuration is defined as:

1. Inspect the face skin, the face foam, and the head skin for wear, tears, or other damage.
2. Soak the dummy in a controlled environment at a temperature between 69° and 72°F overnight prior to testing. The test environment should have the same temperature as the soak environment.
3. The torso of the subject is maintained straight and the head vertical, with the legs kept horizontal and arms raised. The head and neck should be aligned (bottom of the head/neck mounting plate parallel to the upper neck load cell). The dummy is seated on a horizontal, flat, rigid surface and is left unsupported at the back.
4. The impactor assembly, including the disk, has a total mass of 13 kg.
5. The disk impactor is rigid with a diameter of 152 mm, with an edge radius of 12 mm.
6. The center of the disk is configured to impact between the cheek and chin plates on the face. The face load cells should be parallel to the disk
7. Impact velocity is at 6.7 m/s (+/- 0.1 m/s).

8. The impact force is measured and the normal certification procedure will be to determine the peak force and the time at which peak force is reached.

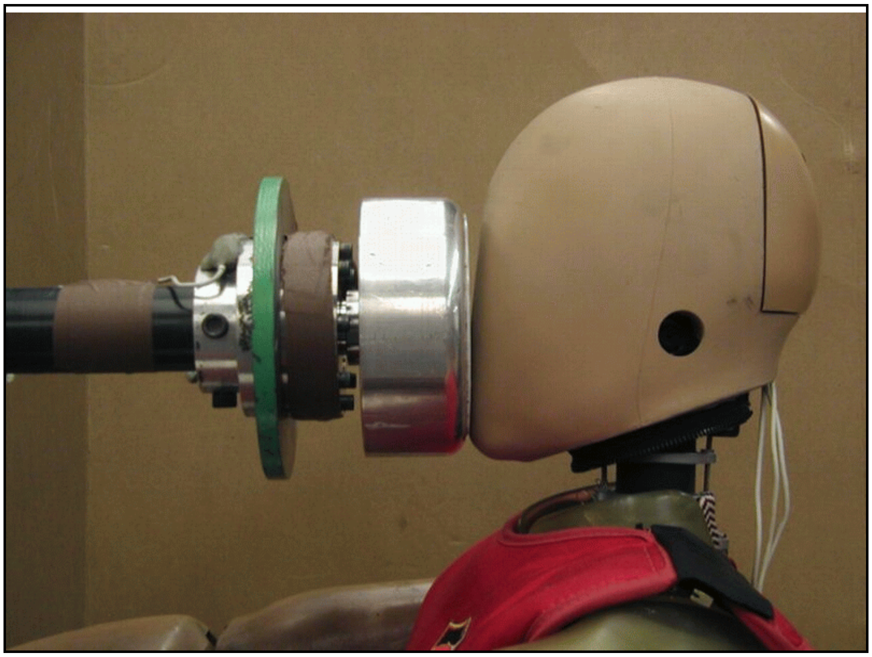

Figure 31. Setup for face impact test with rigid disk.

Data Processing

The impactor can either be a pendulum or a linear impactor with the desired mass and geometry. The measurements include:

1. Impact force at the contact face: This can be measured in either of two ways:
    1. With a single linear accelerometer along the line of impact
    2. With an in-line load cell measuring axial force and a linear accelerometer along the line of impact. In this case, the mass in front of the load cell, including half the load cell mass should be recorded to determine the inertial correction to the load cell reading. The impact force is given by:

$$F_i = -F_{LC} + m_f a$$

where: F_{LC} = load cell measurement
m_f = mass in front of load cell
a = impactor acceleration

Performance Specifications

The specification for the face impact with rigid disk is given by:

Table 8. Face impact with disk response requirement (6.7 m/s)

Quantity	Units	Spec
Peak Force	N	8390 - 9750
Peak Time	msec	3.9 - 5.1

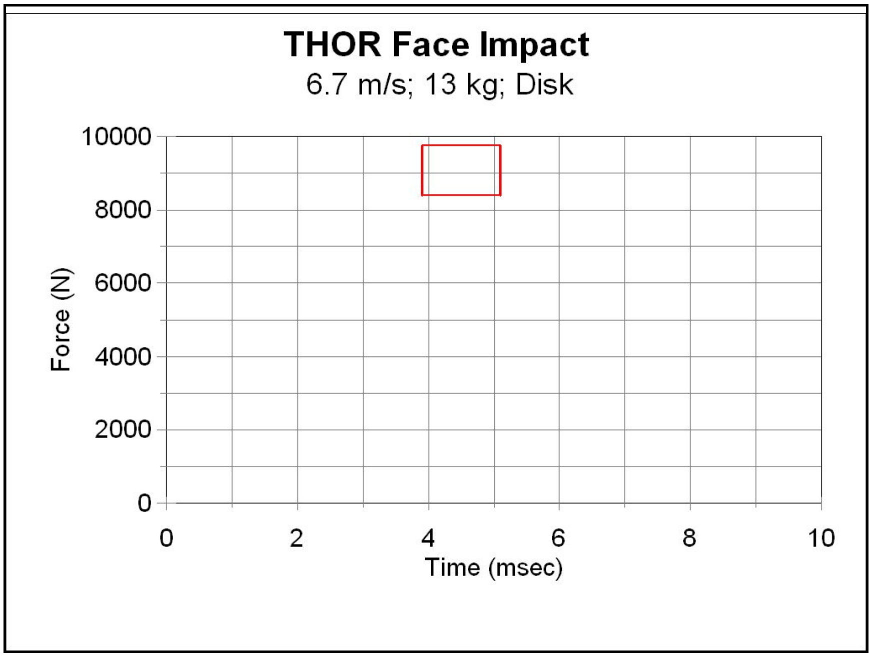

Figure 32. Force vs. time response for facial impact with rigid disk.

8. LOWER LEG/ANKLE/FOOT CERTIFICATION

Summary

The certification tests for the lower leg assembly include quasi-static ankle motion in inversion and eversion, and impacts to the ball and heel of the foot. Detailed description of the certification procedures are given in the document: ***Certification Procedures for the Thor-LX/Hybrid III Retrofit Version 3.2-October, 2001***. Most of the description in the above document is reproduced here to make this certification document complete.

Reference

VRTC. 2001. *Certification Procedures for the Thor-LX/Hybrid III Retrofit Version 3.2-October, 2001*

8.1 Quasi-static Inversion and EversionTests

Description

The quasi-static inversion and eversion tests examine the range of motion and resistance of the ankle joint soft stops in inversion and eversion.

Materials

The equipment and fixtures utilized in this test are:

1. Machine capable of vertical travel with application of load (e.g. Universal Testing Machine)
2. Steel cable
3. Rigid fixture to horizontally mount lower leg to universal testing machine
4. Ankle Moment Arm
5. Cable Attachment Bracket
6. Lower leg/ankle/foot assembly below the compressible tibia element.

Instrumentation

The instrumentation required for the quasi-static tests is:

1. Lower leg assembly including the following parts, ankle assembly, Achilles assembly, tibia assembly, and X, Y, and Z-axis rotary potentiometers.
2. Instrument to measure moment and force.

Test Procedure

1. Inspect the dorsiflexion/plantarflexion and inversion/eversion soft stop assemblies for uneven wear, tears, or other damage. Check for smooth rotation of the ankle about all three axes.
2. Soak the ankle, foot, and tibia assemblies in a controlled environment at a temperature between 69 °F and 72 °F for at least four hours prior to testing. The test environment should have the same temperature as the soak environment.
3. Rigidly mount the tibia and align the foot at zero position (0° dorsiflexion, plantarflexion, inversion, and eversion, 0° rotation about Z-axis).
   Since the lower leg naturally rests at 15° plantarflexion, an external device will be necessary to hold the foot at 0° plantarflexion for the inversion/eversion tests. (Note: Rotation about the Z-axis is undesirable during the quasi-static tests and should be prevented.)
4. Do not attach the tendon during the testing. Also, the potentiometer channels should be set according to calibration values provided by the manufacturer and verified for accuracy.
5. Rotate the ankle from the initial starting position to 37-38° inversion or eversion at a rate of 1-2°/second. (Note: Do not rotate beyond 38° to avoid damage as this angle is near the joint mechanical limit.)
6. Calculate the torque at the ankle joint.

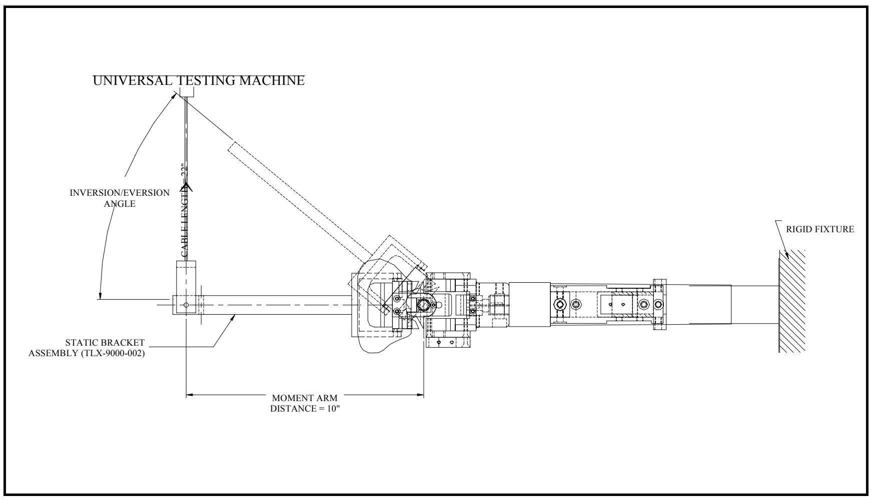

Figure 33. Setup for quasi-static inversion/eversion test of Thor lower leg.

Data Processing

The polarity conventions must conform to requirements of the 1996 revision of SAE Recommended Practice J211. The laboratory can follow any standard procedure for reducing the data collected from the above sensors, including any low-pass filtering that is generally used by the lab.

The torque at the ankle joint is determined as follows (referring to Figure 34):

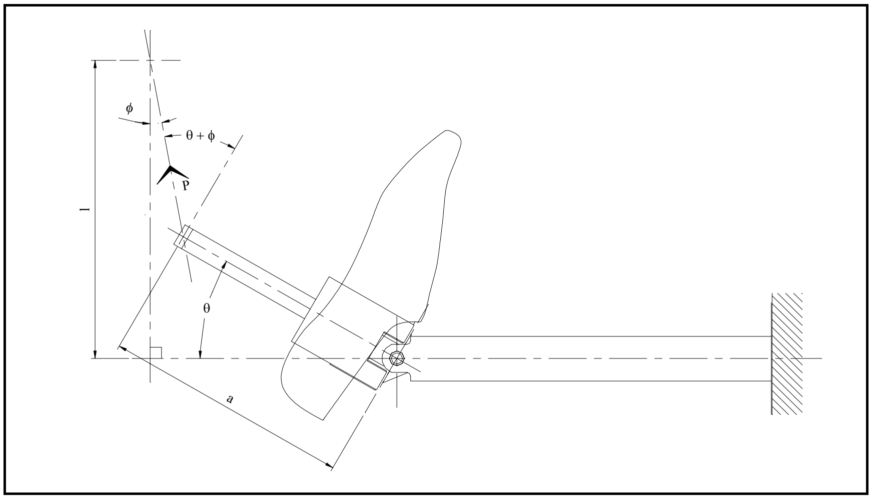

Figure 34. Setup for calculation procedure.

The angle made by the cable to the vertical is first computed:

$$\sin\phi = \frac{a - a\cos\phi}{l}$$

$$\phi = \sin^{-1}\left(\frac{a - a\cos\phi}{l}\right)$$

where: a = length of arm between cable attachment point and point of rotation
l = length of cable between attachment point on foot and to attachment point on load platform
ϕ = angle made by cable with vertical

The effective moment acting about the joint is then:

$$T = Fa\cos(\theta + \phi)$$

where: T = torque acting about ankle joint
F = force measured by load cell attached to cable

Performance Specifications

The angle at which the following torque values are measured should be within the corresponding ranges:

Inversion/Eversion	6 N.m:	17.5 - 21.3°
	23 N.m:	29.3 - 35.9°

The certification specifications are shown as a function of angle in the following graphs.

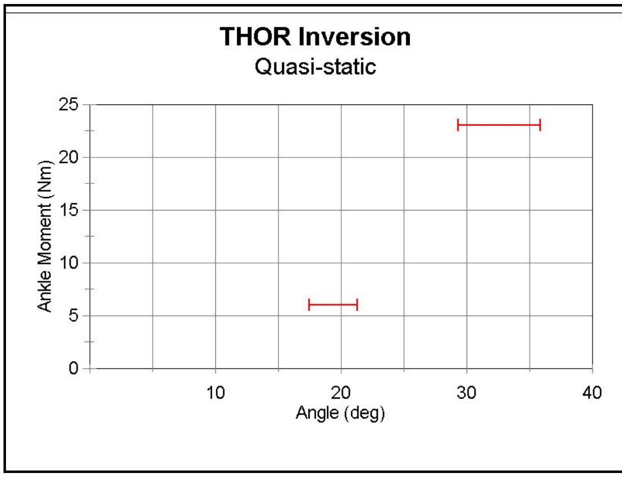

Figure 35. Quasi-static inversion response.

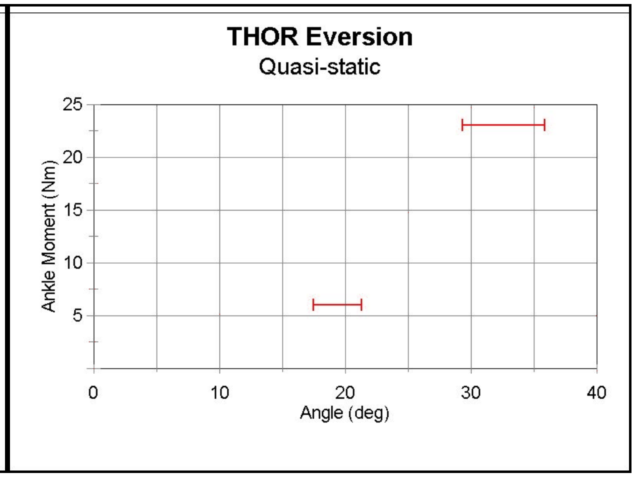

Figure 36. Quasi-static eversion response.

8.2 Dynamic Dorsiflexion Test

Description

This dynamic impact test validates the performance of the ankle and the compliant elements in the foot and tibia. The anatomical areas of pendulum impact are the ball of foot. The test velocity is 5.0 m/s.

Materials

The required parts for this test are:

1. NHTSA Dynamic Impactor (described in VRTC document: Certification Procedures for the Thor-LX/Hybrid III Retrofit Version 3.0). The combined mass of the impactor face, ballast, and 1/3 of the supporting tube is 5kg. Because the densities and weights of some materials may vary, slight adjustment of the dimensions may be needed to achieve the same 5kg mass. The supporting structure for the NHTSA Dynamic Impactor is determined by the test facility.
2. Tibia Mounting Fixture
3. Lower leg/ankle/foot assembly below compressible tibia element.

The setup for the test is shown in the following figure.

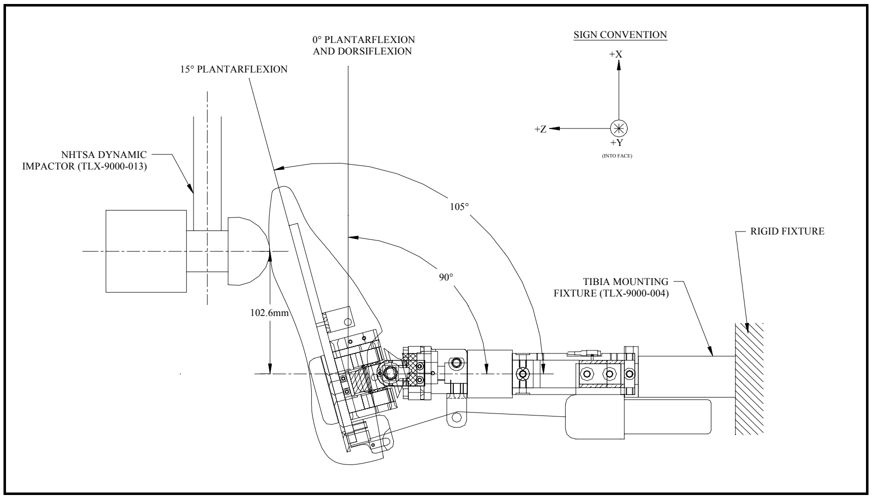

Figure 37. Setup of pendulum fixture for dynamic dorsiflexion test.

Instrumentation

The instrumentations used for this test is:

1. Lower leg assembly, including foot assembly, ankle assembly, tibia assembly, Achilles assembly, five channel lower tibia load cell , four channel upper tibia load cell (heel of foot test only), and X, Y, and Z- axis ankle rotary potentiometers
2. Instrumentation to measure impactor velocity

Test Procedure

1. Inspect the ankle soft stops for tears, permanent deformations, or separation from the soft stop brackets. Inspect the foot skin for wear and tears.
2. Soak the ankle, foot, and tibia assemblies in a controlled environment at a temperature between 69°F and 72°F for at least four hours prior to a test. The test environment should have the same temperature as the soak environment.
3. Remove the Tibia Compliant Bushing Assembly and mount the leg to the Tibia Mounting Fixture at the lower flange, with the toe pointing upward. The test fixture must be rigidly secured so that it does not move during impact.
4. Verify that the Achilles spring cable tension is correctly adjusted. (See Thor-Lx/HIIIr User's Manual).
5. Allow the foot to rest in neutral position (15° plantarflexion, 0° inversion and eversion, 0° rotation about the Z-axis) and zero all instrumentation channels except the rotary potentiometers. Potentiometer channels should be set according to calibration values provided by the manufacturer and verified for accuracy (See Thor-Lx/HIIIr User's Manual). Leave the foot in neutral position for impact.
6. Adjust the fixture so that the longitudinal centerline of the pendulum arm is vertical at impact, and the point of impact is 102.6 mm (4.04 in) above the ankle Y-axis pivot point.

7. Release the pendulum and allow it to fall freely from a height to achieve an impact velocity of 5 ± 0.1 m/s (16.4 ± 0.3 ft/s). Time-zero is defined as the time of initial contact between the pendulum impactor and the ball of the foot.
8. Record data from the following channels:
   Lower Tibia Load Cell - Fx, Fy, Fz, Mx, My
   X, Y, Z-axis Rotary Potentiometers
   Pendulum acceleration
9. Wait at least 30 minutes between successive impacts to the same foot.

Data Processing

The polarity conventions and data acquisition system must conform to requirements of the 1996 revision of SAE Recommended Practice J211. The lower tibia load cell and accelerometer should be filtered with CFC 600. The rotary potentiometers should be filtered at CFC 180. Suggested sampling rates for the A/D conversion is 10 ksamples/sec

The ankle moment is computed using the formula:

$$M_{ankle} = M_y - aF_x$$

where:
- M_y = moment about Y-axis measured by lower tibia load cell
- F_x = force along X-axis measured by lower tibia load cell
- a = distance between center of lower tibia load cell and dorsiflexion joint (.0907m)

The angle is measured with the Y rotary potentiometer. The appropriate offset should be subtracted so that when the foot is perpendicular to the tibia, the angle is computed as zero.

Performance Specification

The certification corridors for the ball of foot impact tests are defined as follows.
   Peak Lower Tibia Compressive Force 3058 - 3738 N
   Peak Ankle Resistive Moment 76.2 - 93.2 Nm

The certification corridors are shown in the following graphs.

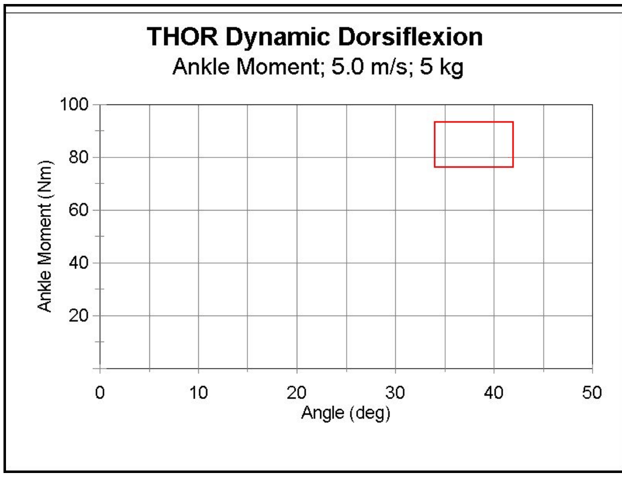

Figure 38. Peak ankle moment response for dynamic dorsiflexion.

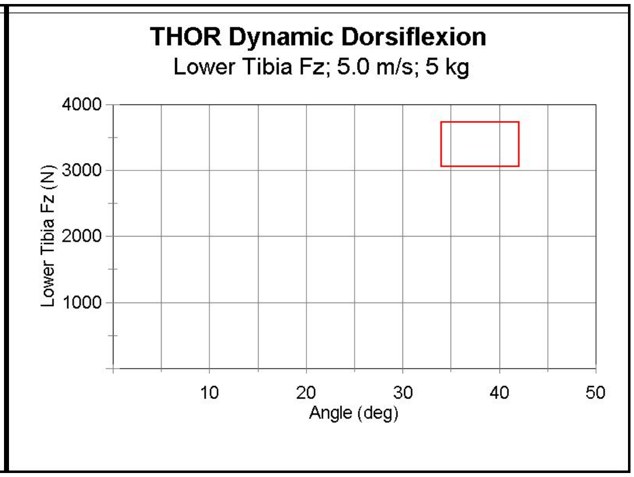

Figure 39. Peak lower tibia Fz response for dynamic dorsiflexion.

8.3 Dynamic Heel Impact Test

Description

This dynamic impact test validates the performance of the ankle and the compliant elements in the foot and tibia. The anatomical areas of pendulum impact are the heel of foot. The test velocity is 4.0 m/s.

Materials

The required fixture for this test is:

NHTSA Dynamic Impactor (see Dynamic Dorsiflexion)). The combined mass of the impactor face, ballast, and 1/3 of the supporting tube is 5kg (11 lbs). Because the densities and weights of some materials may vary, slight adjustment of the dimensions may be needed to achieve the same 5kg (11 lbs) mass. The supporting structure for the NHTSA Dynamic Impactor is determined by the test facility.

The setup of the test is shown in the following figure.

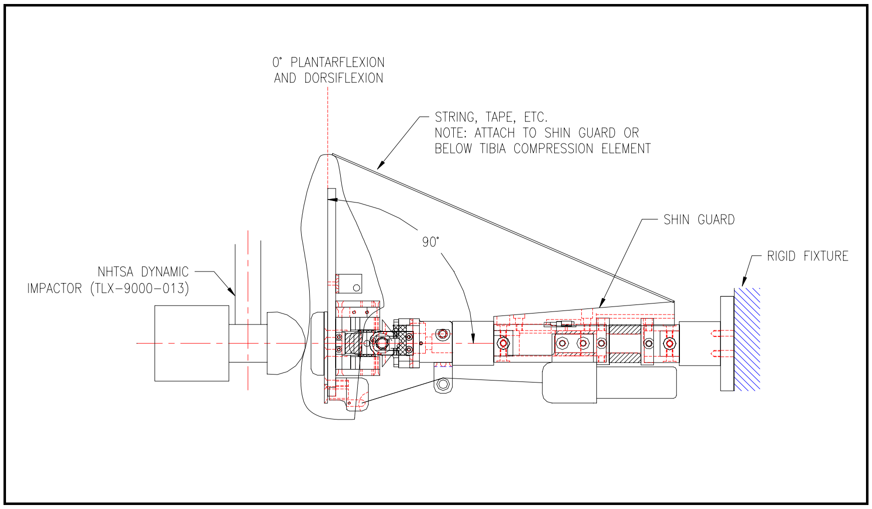

Figure 40. Setup of impact pendulum for dynamic heel impact test.

Instrumentation

The instrumentations used for this test are:

1. Lower leg assembly, including foot assembly, ankle assembly, tibia assembly, Achilles assembly, five channel lower tibia load cell , four channel upper tibia load cell (heel of foot test only), and X, Y, and Z- axis ankle rotary potentiometers
2. Instrumentation to measure impactor velocity

Test Procedure

1. Soak the ankle, foot, and tibia assemblies in a controlled environment at a temperature between 69° and 72° F for at least four hours prior to a test. The test environment should have the same temperature as the soak environment.
2. Inspect the tibia compliant bushing assembly for fatigue and deformation. Check the plunger retaining bolts for wear.
3. Remove the knee clevis and mount the tibia to the test fixture at the proximal end of the upper tibia load cell with the toe pointing upward. The test fixture must be rigidly secured so that it does not move during impact.
4. Zero the instrumentation channels, excluding the rotary potentiometers, with the foot resting in neutral position (15° plantarflexion, 0° inversion and eversion, 0° rotation about the Z-axis). Rotary potentiometer channels should be set according to the calibration sheets provided by the manufacturer and verified for accuracy. (See Thor-Lx/HIIIr User's Manual)
5. Impact the heel at 0° plantarflexion. A piece of tape, string, or wire, etc. extending from the toe to the shin guard or another area below the tibia compressive element will be required to hold the foot at this position. (Note: Attaching the tape, string, etc. to areas on the leg proximal to the tibia compressive element may significantly alter the foot from 0° plantarflexion during heel impact and is not desirable).

6. Adjust the fixture so that the longitudinal centerline of the pendulum arm is vertical at impact, and the impact point is aligned with the tibia centerline.
7. Release the pendulum and allow it to fall freely from a height to achieve an initial impact velocity of 4 ± 0.1 m/s (13.1 ± 0.3 ft/s). Time-zero is defined as the time of initial contact between the pendulum impactor and the heel of the foot.
8. Record the following data channels.
   Lower Tibia Load Cell - Fx, Fy, Fz, Mx, My
   Upper Tibia Load Cell - Fx, Fz, Mx, My
   X, Y, Z-axis Rotary Potentiometers
9. Wait at least 30 minutes between successive impacts to the same foot.

Performance Specification

The peak compressive force measured by the lower tibia load cell should be within the range of 2694 - 3292 N. The performance requirement is shown in the following graph.

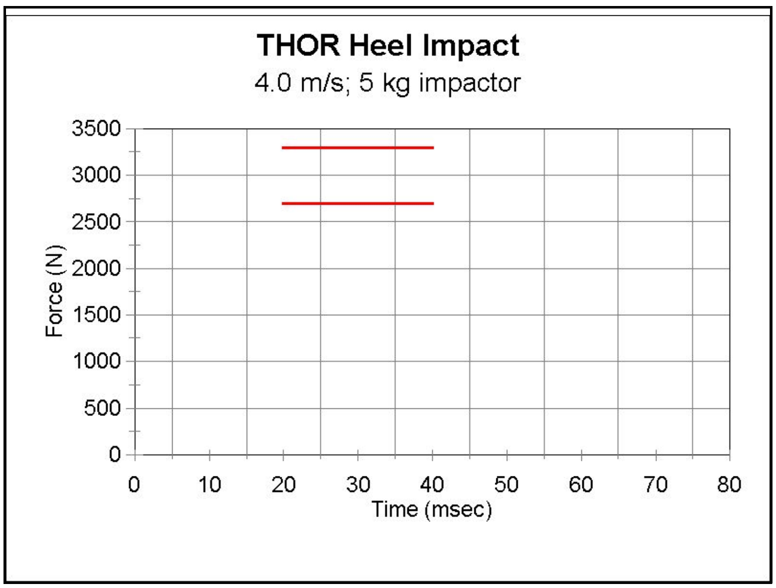

Figure 41. Peak lower tibia Fz under dynamic heel impact.