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Road vehicles — Calculation processes for the neck injury criteria in rear impact

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National foreword

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Road vehicles — Calculation processes for the neck injury criteria in rear impact

Véhicules routiers — Méthodes de calcul des critères lésionnels au cou en choc arrière

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Foreword

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ISO/TR 13330 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems*.

Road vehicles — Calculation processes for the neck injury criteria in rear impact

1 Scope

This Technical Report recommends calculation procedures for several neck performance criteria for low-severity rear impact that are found in the literature. This Technical Report does not recommend any particular criteria or provide injury risk curves since the mechanisms of whiplash injury are neither proven nor validated. Calculations given in this Technical Report apply to mid-size adult male dummies only.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

SAE J211-1:2003, *Instrumentation for Impact Test —Part 1: Electronic Instrumentation*

3 General recommendations

Raw data (unfiltered) must be used as input in the calculation process (including filtering as a first step) described below in this Technical Report.

Sign conventions and the reference frame are those described in SAE J211-1 and shown in Figure 1.

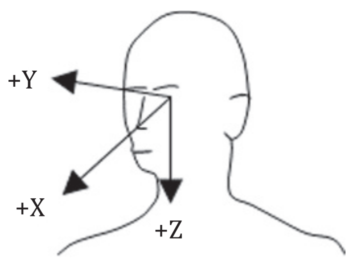


Figure 1 — Reference coordinate system

The positive x-axis will be directed forward.

The positive y-axis will be directed from the dummy's left to its right side.

The positive z-axis will be directed downward from head to toe.

For neck loads, polarities should be checked with the following manipulations:

— Fx > 0: head rearward, chest forward;

— Fy > 0: head leftward, chest rightward;

— Fz > 0: head upward, chest downward;

— Mx > 0: left ear toward left shoulder;

— Mx > 0: left ear toward left shoulder;

— My > 0: chin toward sternum;

— Mz > 0: chin toward left shoulder.

The neck forces and moment can be divided in several portions:

— The anterior portion of the neck force about the x-axis is defined as the positive portion of the neck force about the x-axis measurement. The posterior portion is defined as the negative portion.

— The extension portion of the neck force about the z-axis is defined as the positive portion of the neck force about the z-axis measurement. The compression portion is defined as the negative portion.

— The flexion portion of the neck moment calculated at the occipital condyles about the y-axis is defined as the positive portion of the measurement, while extension portion is considered as the negative portion.

Film or animation video should be available in order to check the main events, such as head contact with the head rest.

4 Calculation process defined for each criterion

4.1 Upper neck loads

4.1.1 Measurements used

$F_{x\_upper\_neck}(t)$: Upper neck force about the x-axis in N.

$F_{z\_upper\_neck}(t)$: Upper neck force about the z-axis in N.

4.1.2 Measurement filtering

The raw data are filtered using the filters as indicated in Table 1.

Table 1 — Filtering of the measurements used in the calculation process of the upper neck loads following ISO 6487 or SAE J211-1

CFC	Measurements	
1000	$F_{x\_upper\_neck}(t)$	$F_{z\_upper\_neck}(t)$

4.1.3 Zero offset measurements

Remove the offset of the filtered channels described in 4.1.1 “Measurements used”. The offset is defined as the mean calculated over the last 10 ms of the measurement before the time of impact, i.e. the last 100 points for a data acquisition of 10 kHz.

4.1.4 Time window to define criteria for maximum/minimum value

The whole time window available is used to determine the minimum and/or maximum values.

4.1.5 Calculation process description

$$F_{x\_upper\_neck\_\max} = \max_{time\_window}[F^{f\&o}_{x\_upper\_neck}(t)]$$

$$F_{z\_upper\_neck\_\max} = \max_{time\_window}[F^{f\&o}_{z\_upper\_neck}(t)]$$

$$F_{x\_upper\_neck\_\min} = \min_{time\_window}[F^{f\&o}_{x\_upper\_neck}(t)]$$

$$F_{z\_upper\_neck\_\min} = \min_{time\_window}[F^{f\&o}_{z\_upper\_neck}(t)]$$

where

$F^{f\&o}_{x\_upper\_neck}(t)$ and $F^{f\&o}_{z\_upper\_neck}(t)$ are the upper neck forces in x and z directions after the filtering and correction of zero offset.

4.1.6 Dummy for which this criterion is calculated

This criterion can be calculated for any dummy for which measurements described above are available.

4.2 NIC[1][2]

4.2.1 Measurements used

$\gamma_{x\_head}(t)$: Head linear acceleration about the x-axis measured at the centre of gravity in m/s[2].

$\gamma_{x\_T1}(t)$: T1 linear acceleration about the x-axis in m/s[2].

4.2.2 Measurement filtering

The raw data are filtered using the filters as indicated in Table 2.

Table 2 — Filtering of the measurements used in the calculation process of the NIC according to ISO 6487 or SAE J211-1

CFC	Measurements
1000	$\gamma_{x\_head}(t)$
180	$\gamma_{x\_T1}(t)$

4.2.3 Zero offset measurements

Remove the offset of the filtered channels described in 4.2.1 “Measurements used”. The offset is defined as the mean calculated over the last 10 ms of the measurement before the time of impact, i.e. the last 100 points for a data acquisition of 10 kHz.

4.2.4 Time window to define criteria for maximum value

The time window to evaluate maximum NIC is until the time of end of head restraint contact.

4.2.5 Calculation process description

$$NIC = \max_{time\_window}\left(0.2 * \left(\gamma^{f\&o}_{x\_T1}(t) - \gamma^{f\&o}_{x\_head}(t)\right) + \left[\int_0^t (\gamma^{f\&o}_{x\_T1}(t) - \gamma^{f\&o}_{x\_head}(t))\right]^2\right)$$

where

$\gamma^{f\&o}_{x\_T1}(t)$ and $\gamma^{f\&o}_{x\_head}(t)$ are the T1 × and head x linear accelerations after the filtering and correction of zero offset.

If T1 × is measured at two locations, e.g. left and right, T1 × is the mean of the two location measurements. Firstly, filter each T1 × channel with CFC180, then calculate an average channel by adding both channels and dividing by 2. Finally, determine the positive maximum between time zero and the time of end of head restraint contact.

Constants of integration at time zero are 0 m/s.

4.2.6 Filtering after calculation process

NIC should not be filtered after calculation.

4.2.7 Dummy for which this criterion is calculated

This criterion can be calculated for any mid-size male dummy for which measurements described above are available.

4.3 Nij [3]

4.3.1 Measurements used

$F_{x\_upper\_neck}(t)$: Upper neck force about the x-axis in N.

$F_{z\_upper\_neck}(t)$: Upper neck force about the z-axis in N.

$M_{y\_upper\_neck}(t)$: Upper neck moment about the y-axis in N.m.

4.3.2 Measurements filtering

The raw data are filtered using the filters as indicated in Table 3.

Table 3 — Filtering of the measurements used in the calculation process of the Nij according to ISO 6487 or SAE J211-1

CFC	Measurements	
1000	$F_{x\_upper\_neck}(t)$	$F_{z\_upper\_neck}(t)$
600	$M_{y\_upper\_neck}(t)$	

4.3.3 Zero offset measurements

Remove the offset of the filtered channels described in 4.3.1 “Measurements used”. The offset is defined as the mean calculated over the last 10 ms of the measurement before the time of impact, i.e. the last 100 points for a data acquisition of 10 kHz.

4.3.4 Time window to define criteria for maximum value

The maximum of the Nij components should be calculated on the whole time window available.

4.3.5 Calculation process description

$$Nij = \max_{time\_window}\left(\frac{F^{f\&o}_{z\_upper\_neck}(t)}{Fzc} + \frac{MOC^{f\&o}_{y}(t)}{Myc}\right)$$

where

$F^{f\&o}_{z\_upper\_neck}(t)$	is the upper neck force about the z-axis either in compression or in tension after the filtering and correction of zero offset;
$MOC^{f\&o}_{y}(t)$	is the moment calculated at the occipital condyles about the y-axis either in flexion or in extension after the filtering and correction of zero offset;
F_{zc} and M_{yc}	are the critical values for upper neck force about the z-axis and for the moment calculated at the occipital condyles about the y-axis.

The critical values (intercepts) used are included in Table 4.

Table 4 — Critical values used in Nij calculation for mid-size male

F_{zc} tension (N)	F_{zc} compression (N)	M_{yc} flexion (Nm)	M_{yc} extension (Nm)
6806	-6160	310	-135

$$MOC^{f\&o}_{y}(t) = M^{f\&o}_{y\_upper\_neck}(t) - \left(D * F^{f\&o}_{x\_upper\_neck}(t)\right)$$

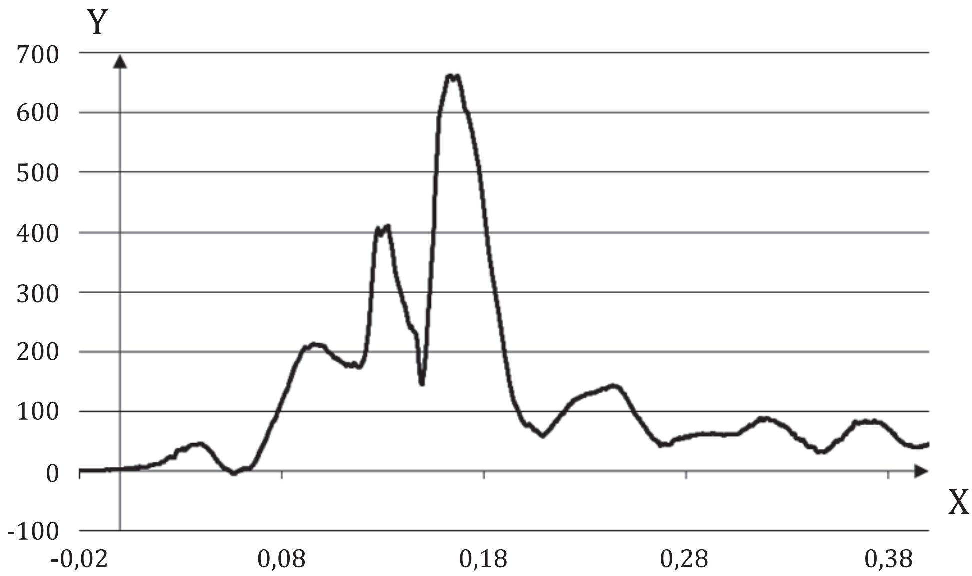
where

$F^{f\&o}_{x\_upper\_neck}(t)$	is the upper neck force about the x-axis after the filtering and correction of zero offset (see Figure 2);
$M^{f\&o}_{y\_upper\_neck}(t)$	is the upper neck moment about the y-axis after the filtering and correction of zero offset (see Figure 3);
D	is the distance between the measurement centre of the upper neck load cell and the occipital condyles about the z-axis.

Checking the value of D distance relevant for the sensor model used with the sensor manufacturer is required.

$MOC^{f\&o}_{y}(t)$ should not be filtered after calculation.

Examples of upper neck forces and upper neck moments are given in Figures 2 and 3.

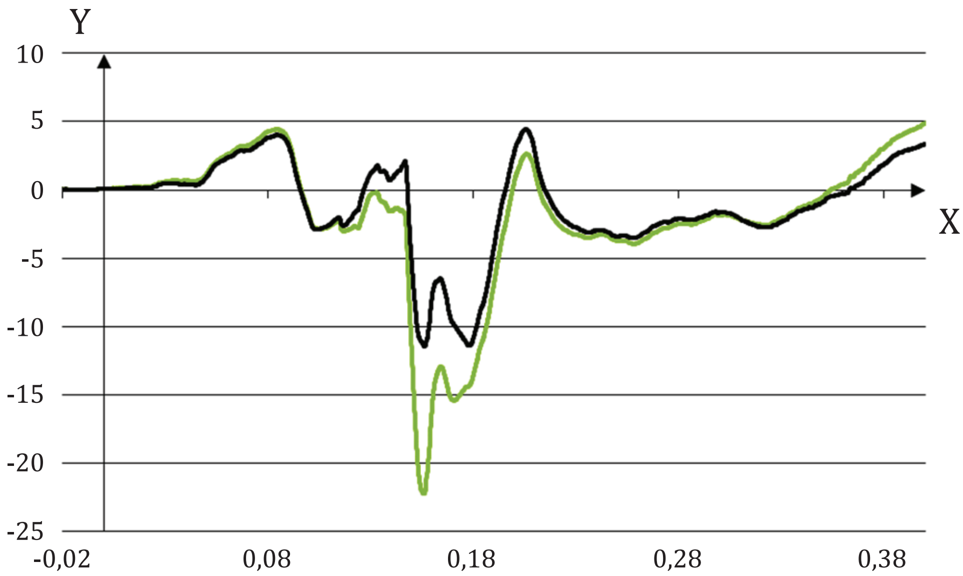


Key

X time in seconds

Y upper neck force

Figure 2 — Example of $F_{z\_upper\_neck}^{f\&o}(t)$ (upper neck force about the z-axis after the filtering and correction of zero offset)



Key

X time in seconds

Y upper neck moment

Figure 3 — Example of $M_{y\_upper\_neck}^{f\&o}(t)$ (upper neck moment about the y-axis after the filtering and correction of zero offset) (black curve) and $MOC_y^{f\&o}(t)$ (moment calculated at the occipital condyles about the y-axis either in flexion or in extension after the filtering and correction of zero offset) (green curve)

To determine the Nij maximum value, four intermediate calculations must be made. These calculations use the upper neck force about the z-axis $F_{z\_upper\_neck}^{f\&o}(t)$ (in tension or in compression) with the moment calculated at the occipital condyles about the y-axis $MOC_y^{f\&o}(t)$ (in flexion or extension). This results in four combinations of the two data channels:

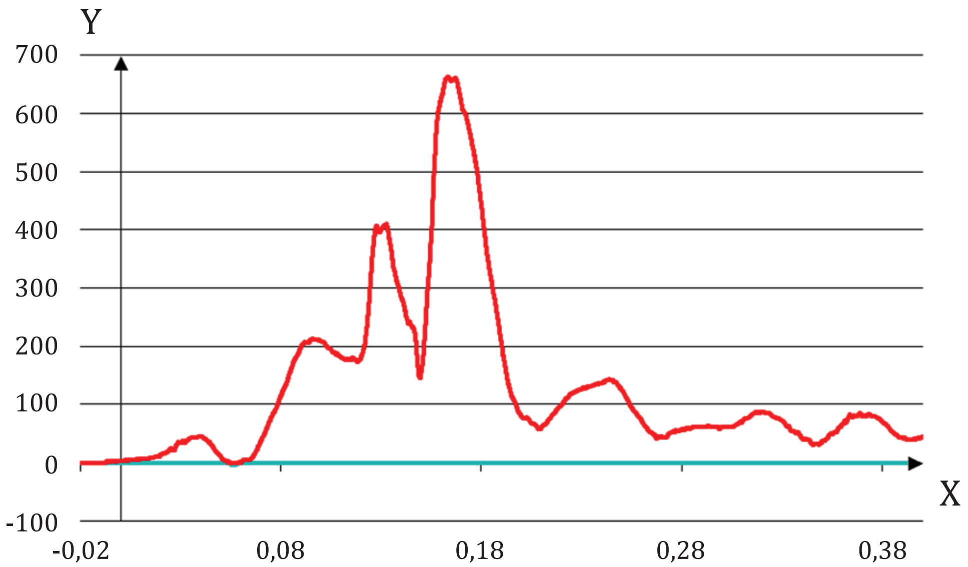
Ncf where $F_{z\_upper\_neck}^{f\&o}(t)$ is in compression and $MOC_y^{f\&o}(t)$ in flexion;

Nce where $F_{z\_upper\_neck}^{f\&o}(t)$ is in compression and $MOC_y^{f\&o}(t)$ in extension;

Ntf where $F_{z\_upper\_neck}^{f\&o}(t)$ is in tension and $MOC_y^{f\&o}(t)$ in flexion;

Nte where $F_{z\_upper\_neck}^{f\&o}(t)$ is in tension and $MOC_y^{f\&o}(t)$ in extension.

The tension portion of the upper neck force about the z-axis is defined as the positive portion of the upper neck force about the z-axis measurement. The compression portion is defined as the negative portion (see example in Figure 4). In the same manner, the flexion portion of the moment calculated at the occipital condyles about the y-axis is defined as the positive portion of the measurement, while the extension portion is considered as the negative portion (see example in Figure 5). In each of these combinations, when a data channel is not in its designated load type its value is to be set to zero. For example, to calculate the Nce (compression – extension) value, all data values of $F_z^{f\&o}(t)$ which do not represent compressive loading are set to zero. Likewise, all data values of $M_y^{f\&o}(t)$ which do not represent an extension loading are set to zero.

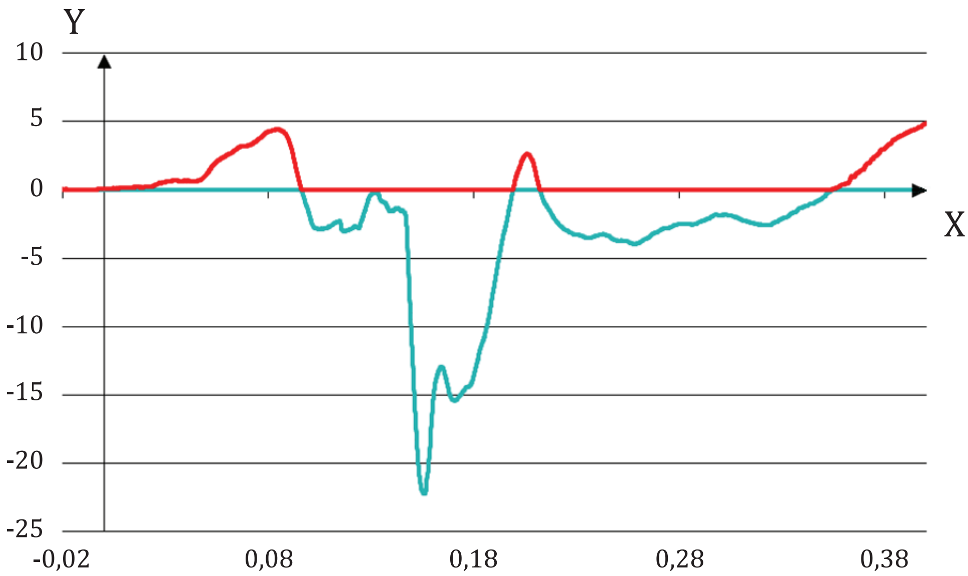


Key

X time in seconds

Y upper neck force

Figure 4 — Example of tension portion of the upper neck force about the z-axis defined as the positive portion (red curve) and compression portion of the upper neck force about the z-axis defined as the negative portion (blue curve)



Key

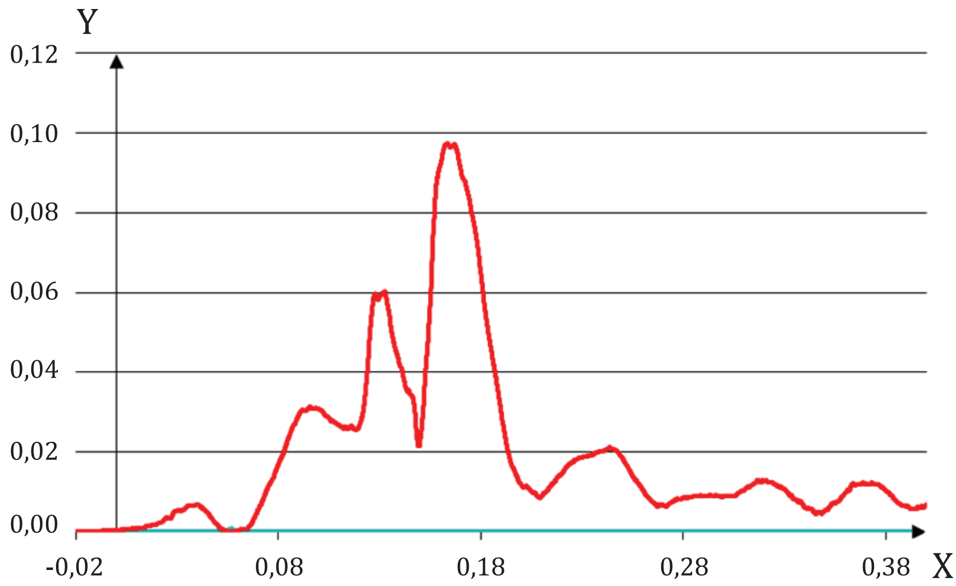
X time in seconds

Y upper neck moment

Figure 5 — Example of flexion portion of the upper neck moment calculated at the occipital condyles about the y-axis defined as the positive portion (red curve) and the extension portion of the upper neck moment calculated at the occipital condyles about the y-axis defined as the negative portion (blue curve)

The force contribution to each Nij component is defined as $\frac{F_{z\_upper\_neck}^{f\&o}(t)}{Fzc}$ (see example in Figure 6 for tension/compression contributions and in Figure 7 for flexion/extension contributions).

The moment contribution to each Nij component is defined as $\frac{MOC_y^{f\&o}(t)}{Myc}$.

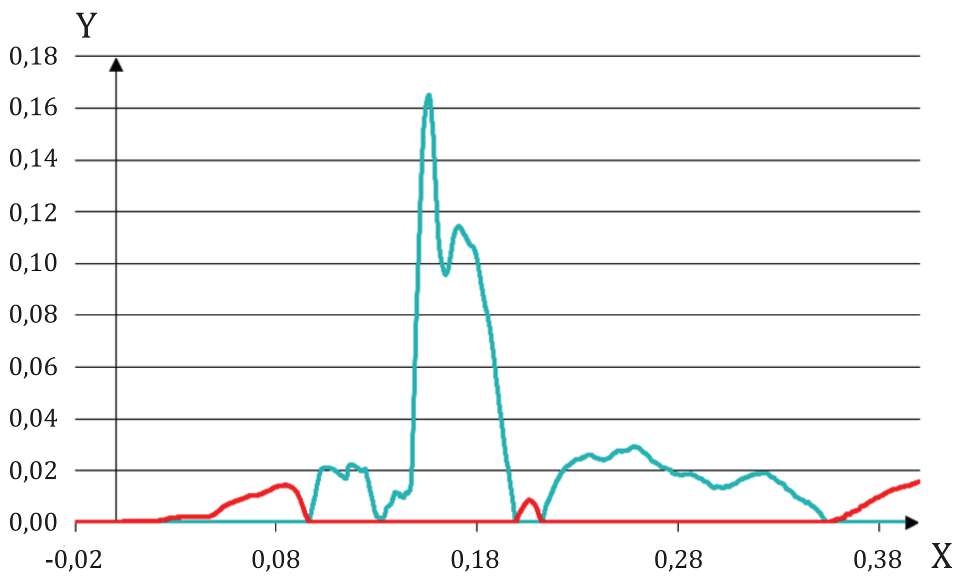


Key

X time in seconds

Y force contributions

Figure 6 — Example of the force contributions for tension (red curve) and for compression (blue curve)



Key

X time in seconds

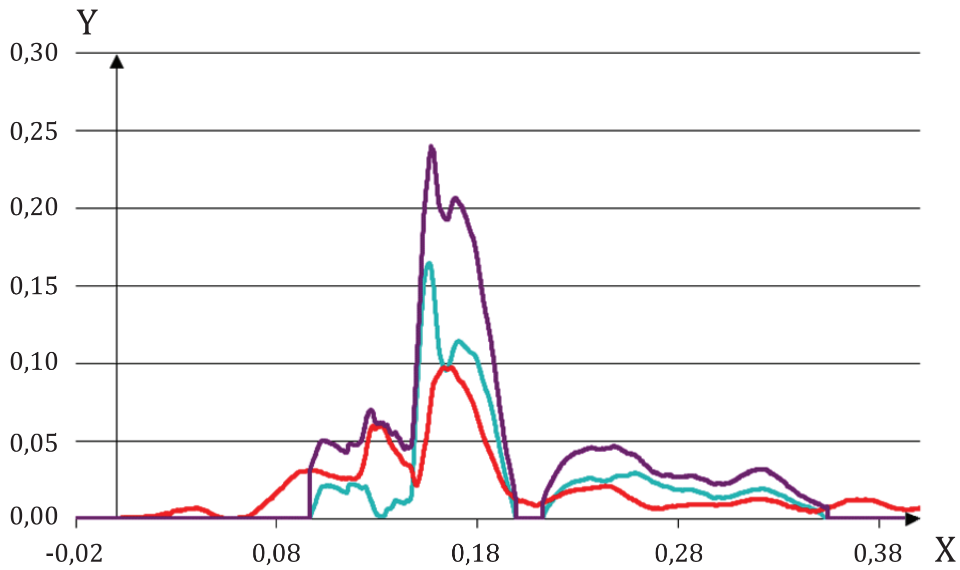
Y moment contributions

Figure 7 — Example of the moment contributions for flexion (red curve) and extension (blue curve)

In case the Nij maximum among the four components is to be calculated, the different portions can be summed using either one of the following processes:

— For each of the four Nij components, if either the force contribution or the moment contribution is null (zero), the Nij component should also be set to null (zero) at that same time (see example in Figures 8 and 9).

— For each of the four Nij components, its value is the sum of the force contribution and the moment contribution even if either contribution is equal to null (zero) (see example in Figures 10 and 11).

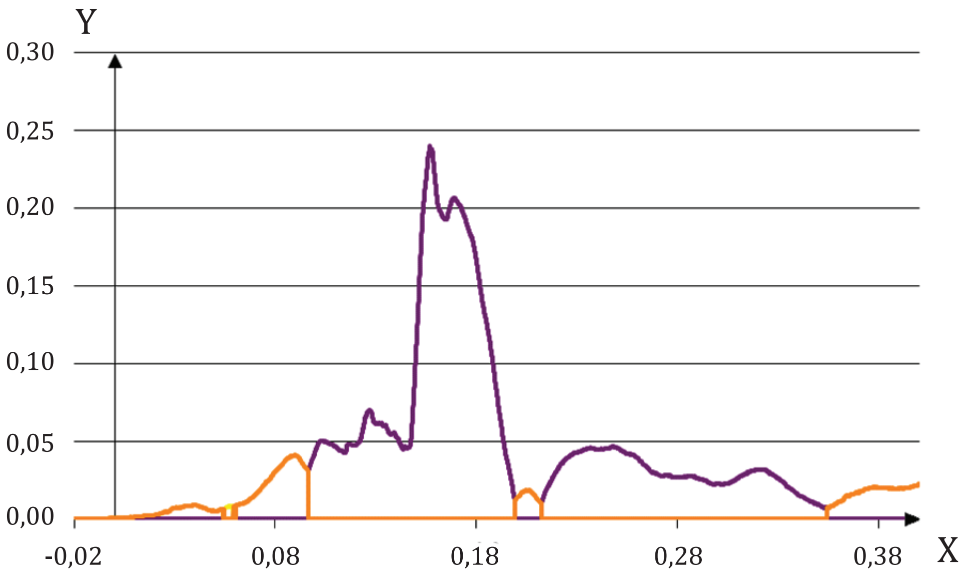


Key

X time in seconds

Y Nte component

Figure 8 — Example of the Nte component (purple curve) summing the tension contribution (red curve) and the extension contribution (blue curve) only if they are both not null simultaneously

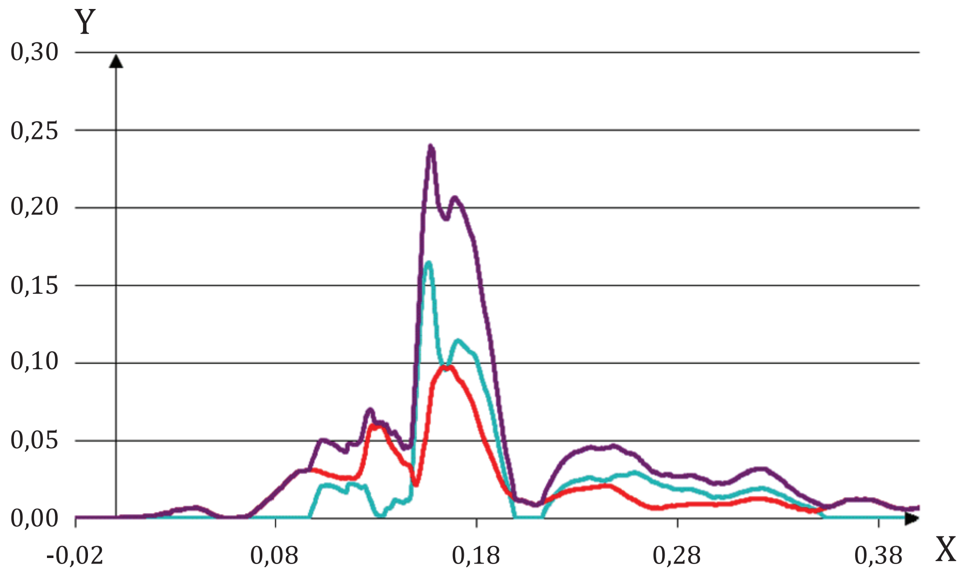


Key

X time in seconds

Y Nce (blue curve), Ncf (yellow curve), Nte (purple curve), Ntf (orange curve) components

Figure 9 — Example of the Nce (blue curve), Ncf (yellow curve), Nte (purple curve), Ntf (orange curve) components summing the relevant force contribution and the moment contribution only if they are both not null simultaneously

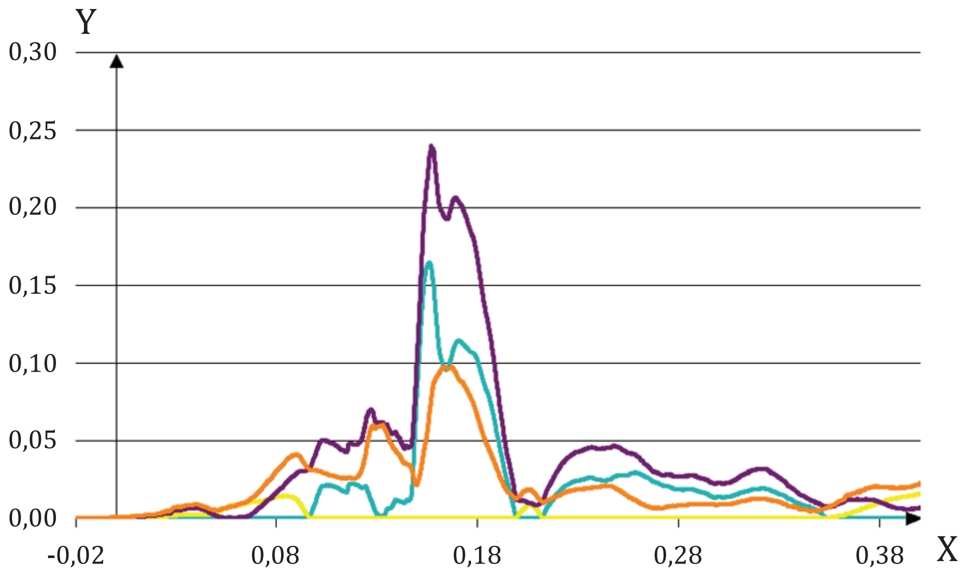


Key

X time in seconds

Y Nte component (purple curve) summing the tension contribution (red curve) and the extension contribution (blue curve)

Figure 10 — Example of Nte component (purple curve) summing the tension contribution (red curve) and the extension contribution (blue curve) regardless if the measurement is positive or negative



Key

X time in seconds

Y Nce (blue curve), Ncf (yellow curve), Nte (purple curve), Ntf (orange curve) components

Figure 11 — Example of the Nce (blue curve), Ncf (yellow curve), Nte (purple curve), Ntf (orange curve) components summing the relevant force contribution and the moment contribution regardless if the measurement is positive or negative

Finally, the Nij maximum value is set to the maximum value of the four combination maximum values.

4.3.6 Filtering after calculation process

Nij should not be filtered after calculation.

4.3.7 Dummy for which this criterion is calculated

This criterion can be calculated for any mid-size male dummy for which measurements described above are available.

WARNING — The intercept values were determined based on pigs/ Hybrid III 3-year-old paired tests and then scaled to adult Hybrid III dummies. It is questionable to use these intercepts values for dummies based on design principles different from the Hybrid III family. However, since there is no information relevant to the other dummies, the intercept values based on Hybrid III design are used for the other dummies.

4.4 Nkm ([4],[5])

4.4.1 Measurements used

$F_{x\_upper\_neck}(t)$: Upper neck force about the x-axis in N.

$M_{y\_upper\_neck}(t)$: Upper neck moment about the y-axis in N.m.

4.4.2 Measurement filtering

The raw data are filtered using the filters as indicated in Table 5.

Table 5 — Filtering of the measurements used in the calculation process of the Nkm

CFC	Measurements
1000	$F_{x\_upper\_neck}(t)$
600	$M_{y\_upper\_neck}(t)$

4.4.3 Zero offset measurements

Remove the offset of the filtered channels described in 4.4.1 “Measurements used”. The offset is defined as the mean calculated over the last 10 ms of the measurement before the time of impact, i.e. the last 100 points for a data acquisition of 10 kHz.

4.4.4 Time window to define criteria for maximum value

The maximum of the Nkm components should be calculated on the whole time window available.

4.4.5 Calculation process description

$$Nkm = \max_{time\_window}\left(\frac{F^{f\&o}_{x\_upper\_neck}(t)}{Fxc} + \frac{MOC^{f\&o}_{y}(t)}{Myc}\right)$$

where

$F^{f\&o}_{x\_upper\_neck}(t)$	is the upper neck force about the x-axis either in anterior or in posterior direction, after the filtering and correction of zero offset;
$MOC^{f\&o}_{y}(t)$	is the moment calculated at the occipital condyles about the y-axis either in flexion or in extension after the filtering and correction of zero offset;
F_{xc} and M_{yc}	are the critical values for upper neck force about the x-axis and for the moment about the y-axis.

The critical values (intercepts) used are included in Table 6.

Table 6 — Critical values used in Nkm calculation for mid-size male

F_{xc} anterior (N)	F_{xc} posterior (N)	M_{yc} flexion (Nm)	M_{yc} extension (Nm)
845	-845	88,1	-47,5

$$MOC^{f\&o}_{y}(t) = M^{f\&o}_{y\_upper\_neck}(t) - \left(D * F^{f\&o}_{x\_upper\_neck}(t)\right)$$

where

$F_{x\_upper\_neck}^{f\&o}(t)$ is the upper neck force about the x-axis after the filtering and correction of zero offset,

$M_{y\_upper\_neck}^{f\&o}(t)$ is the upper neck moment about the y-axis after the filtering and correction of zero offset (see example in Figure 3)

D is the distance between the measurement centre of the upper neck load cell and the occipital condyles about the z-axis.

Checking the value of D distance relevant for the sensor model used with the sensor manufacturer is required.

$MOC_y^{f\&o}(t)$ should not be filtered after calculation.

Considering all the combinations of upper neck force about the x-axis and moment at the occipital condyles about the y-axis, Nkm can be separated into four components:

Nfa where $F_{x\_upper\_neck}^{f\&o}(t)$ is in anterior direction and $MOC_y^{f\&o}(t)$ in flexion;

Nea where $F_{x\_upper\_neck}^{f\&o}(t)$ is in anterior direction and $MOC_y^{f\&o}(t)$ in extension;

Nfp where $F_{x\_upper\_neck}^{f\&o}(t)$ is in posterior direction and $MOC_y^{f\&o}(t)$ in flexion;

Nep where $F_{x\_upper\_neck}^{f\&o}(t)$ is in posterior direction and $MOC_y^{f\&o}(t)$ in extension.

The anterior portion of the upper neck force about the x-axis is defined as the positive portion of the upper neck force about the x-axis measurement. The posterior portion is defined as the negative portion. In the same manner, the flexion portion of the moment calculated at the occipital condyles about the y-axis is defined as the positive portion of the measurement, while the extension portion is considered as the negative portion.

In case the Nkm maximum among the four components is to be calculated, the different portions can be summed with either one of the following two procedures:

— For each of the four Nkm components, if either the force contribution or the moment contribution is null (zero), the Nkm component value should also be set to null (zero) at that same time.

— For each of the four Nkm components, its value is the sum of the force contribution and the moment contribution even if either contribution is equal to null (zero).

4.4.6 Dummy for which this criterion is calculated

This criterion can be calculated for any mid-size male dummy for which measurements described above are available.

WARNING — Intercepts are derived from volunteer tests ([7]) and no intercept specific for dummies are available. Therefore, depending on the biofidelity of the dummy used for testing, they may be more or less appropriate. These are the only values available to calculate the Nkm criterion.

4.5 LNL ([6])

4.5.1 Measurements used

$F_{x\_lower\_neck}(t)$: Lower neck force about the x-axis in N.

$F_{z\_lower\_neck}(t)$: Lower neck force about the z-axis in N.

$M_{y\_lower\_neck}(t)$: Lower neck moment about the y-axis in N.m.

4.5.2 Measurement filtering

The raw data are filtered using the filters as indicated in Table 7.

Table 7 — Filtering of the measurements used in calculation process of the LNL

CFC	Measurements	
1000	$F_{x\_lower\_neck}(t)$	$F_{z\_lower\_neck}(t)$
600	$M_{y\_lower\_neck}(t)$	

4.5.3 Zero offset measurements

Remove the offset of the filtered channels described in 4.5.1 “Measurements used”. The offset is defined as the mean calculated over the last 10 ms of the measurement before the time of impact, i.e. the last 100 points for a data acquisition of 10 kHz.

4.5.4 Time window to define criteria for maximum value

The maximum of the LNL should be calculated on the whole time window available.

4.5.5 Calculation process description

The general formula of LNL is applied for a motion in XZ plane only.

$$LNL = \max_{time\_window}\left(\frac{\left|M^{f\&o}_{y\_lower\_neck}(t)\right|}{Cmoment} + \frac{\left|F^{f\&o}_{x\_lower\_neck}(t)\right|}{Cshear} + \frac{\left|F^{f\&o}_{z\_lower\_neck}(t)\right|}{Caxial}\right)$$

where

$F^{f\&o}_{x\_lower\_neck}(t)$	is the lower neck force about the x-axis, after the filtering and correction of zero offset;
$F^{f\&o}_{z\_lower\_neck}(t)$	is the lower neck force about the z-axis, after the filtering and correction of zero offset;
$M^{f\&o}_{y\_lower\_neck}(t)$	is the lower neck moment about the y-axis, after the filtering and correction of zero offset;
C_{moment}, C_{shear} and C_{axial}	are the critical values for lower neck moment in y direction, for lower neck forces about the x-axis and about the z-axis.

The critical values (intercepts) are included in Table 8.

Table 8 — Critical values used in LNL calculation for mid-size male

C_{moment} (N·m)	C_{shear} (N)	C_{axial}(N)
15	250	900

For dummies for which the lower neck load cell is offset from the T1 location, the lower neck moment about the y-axis $M^{f\&o}_{y\_lower\_neck}(t)$ should be corrected.

$$MOC^{f\&o}_{y\_lower\_neck\_corrected}(t) = M^{f\&o}_{y\_lower\_neck}(t) + \left(D_z * F^{f\&o}_{x\_lower\_neck}(t)\right) + \left(D_x * F^{f\&o}_{x\_lower\_neck}(t)\right)$$

where

$F_{x\_lower\_neck}^{f\&o}(t)$ is the lower neck force about the x-axis after the filtering and correction of zero offset;

$F_{z\_lower\_neck}^{f\&o}(t)$ is the lower neck force about the z-axis after the filtering and correction of zero offset;

$M_{y\_lower\_neck}^{f\&o}(t)$ is the lower neck moment about the y-axis after the filtering and correction of zero offset;

D_X is the distance between the measurement centre of the lower neck load cell and T1 about the x-axis;

D_Z is the distance between the measurement centre of the lower neck load cell and T1 about the z-axis.

Checking the value of D_X and D_Z distances relevant for the sensor model used with the sensor manufacturer is required.

4.5.6 Dummy for which this criterion is calculated

This criterion can be calculated for any mid-size male dummy for which measurements described above can be obtained.

Bibliography

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