EUROPEAN NEW CAR
ASSESSMENT PROGRAMME

Technical Bulletin

Brain Injury Calculation

Version 1.0

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TB 035

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Preface

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EUROPEAN NEW CAR ASSESSMENT PROGRAMME (Euro NCAP)

Table of Contents

1. Introduction 1
2. 2023 Criterion 2
3. 2025 Criterion 5
4. References 6

1. Introduction

Mild traumatic brain injury is a frequent occurrence in vehicle accidents. Over the last five years, the Euro NCAP Frontal Impact Working Group (FIWG) and Brain Injury Working Group (BIJ) have been investigating rotational brain injury metrics. With the adoption of the MPDB frontal impact test and a more capable test tool in the THOR dummy, more measurement possibilities are available upon which to base a brain injury criterion.

The FIWG has reviewed kinematic injury criteria, human brain Finite Element (FE) models along with their associated injury risk curves. A large number of brain injury criteria and injury risk curves are available that are supported by a broad range of injury databases. It is important to ensure that any criterion offers a relevant prediction of brain tissue injury risk. Euro NCAP aims to address reversible brain injuries of AIS2 severity.

Implementation of a brain injury assessment will be applied to Euro NCAP assessments published from the 1st of January 2023 in combination with the existing skull fracture assessment. A more complex FE based assessment will be implemented in 2025.

2. 2023 Criterion

2.1 DAMAGE

2.1.1 Calculation of the Diffuse Axonal Multi-Axis General Evaluation (DAMAGE) criterion is defined in the THOR dummy technical report ISO TR 19222, see Section 4.1.

2.1.2 This criterion is applied to the THOR driver dummy in the MPDB frontal impact for all assessments published from 1st January 2023.

2.1.3 Head rotational velocity, filtered at CFC 60, shall be used to generate rotational acceleration throughout the impact.

2.1.4 DAMAGE is not evaluated for vehicles without frontal airbags. 0 points will be awarded to the head and neck assessment as detailed in the Euro NCAP Adult Occupant Protection Assessment protocol.

2.1.5 Calculation:

$$\begin{bmatrix} m_x & 0 & 0 \\ 0 & m_y & 0 \\ 0 & 0 & m_z \end{bmatrix} \begin{Bmatrix} \ddot{\delta}_x \\ \ddot{\delta}_y \\ \ddot{\delta}_z \end{Bmatrix} +$$

$$\begin{bmatrix} c_{xx}+c_{xy}+c_{xz} & -c_{xy} & -c_{xz} \\ -c_{xy} & c_{xy}+c_{yy}+c_{yz} & -c_{yz} \\ -c_{xz} & -c_{yz} & c_{xz}+c_{yz}+c_{zz} \end{bmatrix} \begin{Bmatrix} \dot{\delta}_x \\ \dot{\delta}_y \\ \dot{\delta}_z \end{Bmatrix} +$$

$$\begin{bmatrix} k_{xx}+k_{xy}+k_{xz} & -k_{xy} & -k_{xz} \\ -k_{xy} & k_{xy}+k_{yy}+k_{yz} & -k_{yz} \\ -k_{xz} & -k_{yz} & k_{xz}+k_{yz}+k_{zz} \end{bmatrix} \begin{Bmatrix} \delta_x \\ \delta_y \\ \delta_z \end{Bmatrix} =$$

$$\begin{bmatrix} m_x & 0 & 0 \\ 0 & m_y & 0 \\ 0 & 0 & m_z \end{bmatrix} \begin{Bmatrix} \ddot{u}_x \\ \ddot{u}_y \\ \ddot{u}_z \end{Bmatrix}$$

$$DAMAGE = \beta max_t\{|\vec{\delta}(t)|\}$$

$$\vec{\delta}(t) = [\delta_x(t) \quad \delta_y(t) \quad \delta_z(t)]^T, \beta = \text{scale factor}$$

$\text{m} = \text{mass}, c_{ij} = \text{damping}, k_{ij} = \text{stiffness}$

$\ddot{\delta}, \dot{\delta}, \delta = acceleration, velocity, displacement$

$\ddot{u} = applied\ angular\ acceleration$

$m_x = 1\ kg, m_y = 1\ kg, m_z = 1\ kg$

$k_{xx} = 32142\ N/m, k_{yy} = 23493\ N/m, k_{zz} = 16935\ N/m,$

$k_{xy} = 0\ N/m, k_{yz} = 0\ N/m, k_{xz} = 1636.3\ N/m, a1 = 5.9148\ ms,$

$\beta = 2.9903\ 1/m$

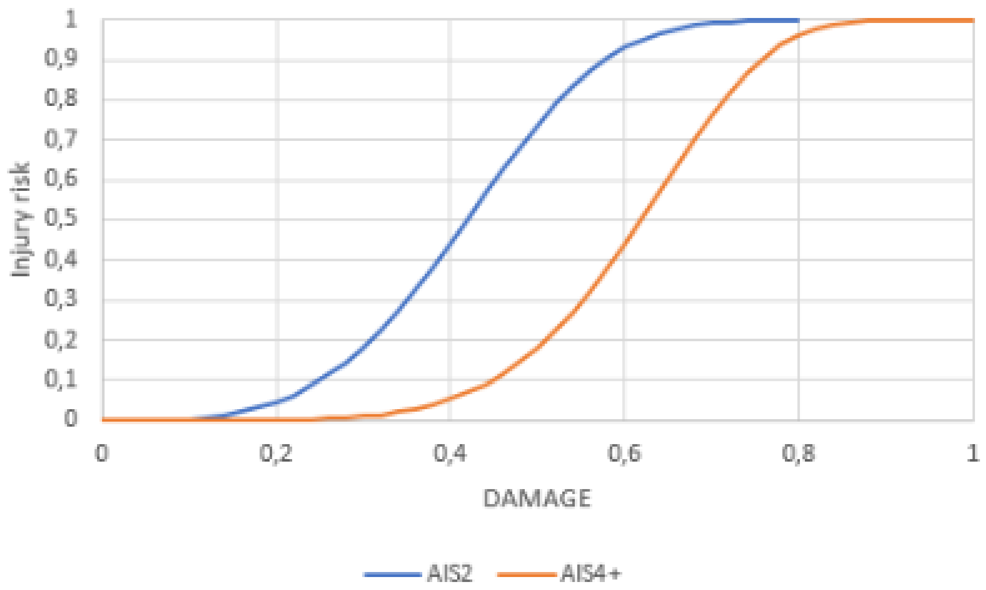
$[c] = a1 \times [k]$

2.2 Assessment

2.2.1 0.47 > DAMAGE ≥ 0.42 (50% risk AIS2) **-1 point** modifier applied to the driver's head assessment.

2.2.2 DAMAGE ≥ 0.47 **-2 point** modifier applied to the driver's head assessment.

2.3 DAMAGE Injury risk curves (AIS2)



$$P_{inj} = 1 - e^{\left(-e^{\left(\frac{1}{b}*\ln(dy+c)-\frac{a}{b}\right)}\right)}$$

With exp(a)= 0,459; 1/b=3,875; c=0,017; D=0,957 (AIS 2)

2.4 Calculation window

2.4.1 When calculating DAMAGE, a time window is specified to exclude certain secondary contacts between the head and vehicle interior. Note, this window does not apply to either HIC or 3ms exceedance calculations.

2.4.2 The exclusion criteria are based upon those used by JNCAP.

2.4.3 This criterion will be evaluated during the loading and early rebound phases of the impact over a max period from T0 up to 200ms.

2.4.4 The time window will be reduced to less than 200ms if, during head rebound, a secondary impact results in an external force on the head drops below -500N.

2.4.5 The external force acting on the head shall be calculated using the head x acceleration and upper neck x force using the formula below.

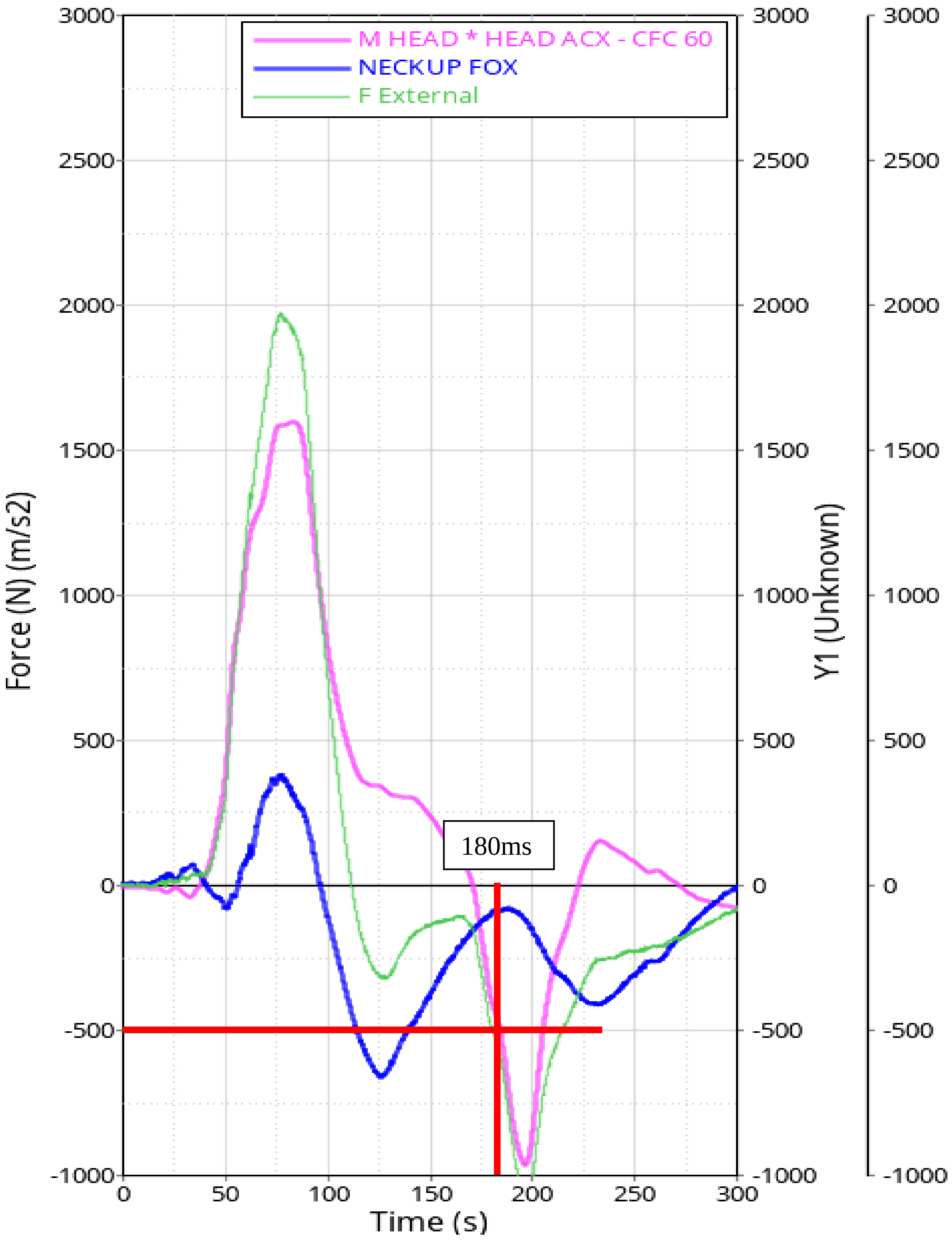
2.4.6 End the calculation when: F external x < -500N

$$F_{external\,x} = -M_{Head} \times a_{Head\,x} + F_{Neck_{upper}x}$$

Where M_{Head} = 4.2kg.

2.4.7 Example:

In the example below, Fexternal x (green line) calculates a force of <-500N (I.e. more negative) at a time of 180ms. The high-speed film confirmed the presence of a secondary contact between the dummy head and vehicle interior. Therefore, the DAMAGE criterion shall be calculated between T0 and 180ms.



3. 2025 Criterion

3.1 Euro NCAP is undertaking accident data analyses and reconstruction via CAE to evaluate predicted brain injury risk of candidate criteria.

3.2 Brain injury numerical simulation tools and associated injury risk curves are currently under review.

3.3 An advanced brain injury criterion will be implemented in 2025.

4. References

4.1 DAMAGE

Development of a Second-Order System for Rapid Estimation of Maximum Brain Strain DAMAGE. Lee F Gabler, Jeff R Crandall, Matthew B Panzer, 2019.

4.2 Injury risk curves

pAIS2+ (BRIC) MPS = 1 EXP(POWER(BRIC/0,602;2,84)) Takhounts 2013
pAIS2+ (BRIC) CDSM = 1 EXP(POWER((BRIC 0,523)/0,324;1,8 Takhounts 2013
pAIS2+ (BRIC) = 1/(1+ 7,82+BRIC*9,1352))) UVA
pAIS2+ (UBRIC) = 1/(1+ 6,4706+UBRIC*17,1171))) Gabler 2018
pAIS2+ (DAMAGE) = 1/(1+ 7,1552+DAMAGE*19,9975))) Gabler 2018

pAIS2+(KTH_strain) = 1/(1+EXP(3,7151 8,0517* KTH_strain Kleiven
pAIS2+(Δω) = 1/(EXP(5,4314 0,0913* Δω)) Kleiven
pAIS2+(SUFEHM_vm_stress))= 1/(1+ 3,178+0,087* SUFEHM_vm_stress Willinger