EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

EEVC Recommendations on the Future of the Harmonised THOR Dummy: Report on the outcome of the Special Workshop on “Harmonisation of THOR – The Advanced Frontal Dummy”, held 4-5 May 2006 at TRL, UK

EEVC WG12 – Biomechanics
2006

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August 15, 2006

1. Introduction

It is a common experience in developed countries that the road casualty class that contributes most to fatal and serious injuries is car occupants and that the accident configurations responsible for the largest proportion of fatal and serious injuries to car occupants are frontal impacts. This is certainly so for Europe and North America. Consequently the understanding of the mechanisms of frontal impact injuries and how to reduce these is very important in the efforts to reduce overall road accident casualties.

Anticipating the need for a next-generation frontal dummy, NHTSA took the lead by initiating the development of an advanced frontal impact dummy, working with GESAC during 1994 to 2005; this dummy is known as THOR. During this period, NHTSA was in contact with Europe regarding the requirements for the dummy. In Europe, it was recognized that there would be the need in the future for a next generation dummy that would give improved injury risk indications for, for example, the more complex interactions between the chest and seatbelts on their own or in combination with airbags and also the steering wheel and also a better measure for the risk of injury to the feet and legs.

Europe wished to ensure that an advanced frontal impact dummy could interact and respond correctly to the European restraint systems, which are primarily seat belts, normally in association with airbags for front seat occupants. These European airbags act as supplementary restraint systems, rather than the primary restraint system, and often differ significantly to the US airbag design. Thus it was deemed necessary to evaluate the THOR-Alpha, the NHTSA first version, for the European condition. This was undertaken through two EC projects; ADRIA, which evaluated the THOR dummy between 1997 and 1998 and FID (2000 – 2003), which aimed at establishing design improvements. As a result of comments from EEVC and others, NHTSA introduced a revised version, manufactured by GESAC, called THOR–NT. Also FTSS produced a version to the EEVC recommendations, called THOR-FT. This has resulted in two different designs for THOR.

On May 4-5, 2006 a workshop has been held at TRL in the UK with the aim of making recommendations on which of the two designs was preferred by EEVC or, alternatively, if neither version were considered acceptable at this stage, to make recommendations regarding the revisions required. The recommendations from this workshop were discussed within EEVC WG12 and accepted with a few additions.

2. Objectives

The objectives for the Workshop, agreed between those present, were:

- To review all design and anthropometry issues where THOR-NT and THOR-FT differ
- To decide which are the essential and which are preferred options for the EEVC
- Make recommendations if neither of the designs is acceptable
- To prepare a position paper stating the agreed EEVC views on the best options for a harmonised design of THOR which would show significant improvement over Hybrid III

In order to achieve the original aim of THOR, the dummy would have to be demonstrated to be a significant improvement over the current *standard* front impact test dummy, Hybrid III. It was recommended that EEVC WG12 produce a document that identifies the areas of Hybrid III that required improvement in an advanced frontal dummy.

In reviewing the differences between the designs and possible alternatives, the WG categorised the recommendations as:

- Essential
- Highly desirable
- Desirable
- Ambivalent (no preference)

The consensus views of WG12 are shown in **bold** type.

3. General Specifications

3.1 Anthropometry

Both THOR-NT and THOR-FT are based on the anthropometry given by UMTRI [1] although not all components fully meet the specification currently (Anthropometry for Motor Vehicle Occupants - AMVO Dataset, by Moss *et al.* [2]). Currently, THOR-NT is specified in imperial dimensions, THOR-FT is metric.

- **WG12 agrees that it is highly desirable that the advanced frontal dummy should be based on UMTRI dimensions and posture.**

- **Further, WG12 supports the use of Metric dimensions and specifications rather than Imperial (Highly desirable).**

3.2. Biofidelity

Both NHTSA and EEVC have documented the desired biofidelity for the advanced frontal dummy (see Appendix).

- **WG12 believes it to be essential for at least Europe, North America, Australia and Japan to agree on a harmonised set of biofidelity requirements for a frontal impact dummy that takes the needs of all parties into account.**

3.3. Instrumentation

Performance of the dummy must not be affected by the instrumentation or data acquisition system.

- **It is essential to permit the use of the umbilical approach. It is highly desirable if the design could accommodate the use of on-board dummy DAS.**

- **Therefore, the design specification and performance requirements must include the instrumentation (Essential) and data acquisition systems (Essential - if specified).**

3.4 Certification

- **WG12 believes that it is essential that the THOR certification procedures are reviewed and simplified. WG12 proposes that a small group of experts develops necessary and sufficient certification procedures for THOR using, as far as possible, existing certification equipment.**

4. Body Regions

4.1 Head

Although the geometry of the dummy head is correct, the orientation of the dummy head in the in-car seated position when set-up for testing deviates from the UMTRI position in both designs. This is due to the angle of the neck in the test position. The result is that the Frankfort plane in the UMTRI seating position is raised by 3.9° to the horizontal (eyes looking up), whereas the instrumentation plane at the top of the neck is rotated down by about 9° (FT) or 8.5° (NT). The mass of the FT head is 4.14 kg, which is that specified by UMTRI, while the NT head mass is 4.54, the same as Hybrid III (see Table)

	UMTRI (w.r.t. skull bottom)	THOR-NT	THOR-FT	Hybrid III
Mass (kg)	4.14	4.54	4.14	4.54
X-CG (mm)	8.2	7.6	7.6	17.8
Z-CG (mm)	59.9	58.4	58.4	48.3

Both the NT and the FT heads exhibit noisy responses to rigid impacts (head drop test). The first mode of vibration is about 1400 Hz, which is quite low for instrumentation of CFC 1000 where the cut off frequency is 1650 Hz. The head flesh is a two piece construction for the FT and a one piece design for NT.

- **It is essential that the neutral, or test, position for the dummy follows the UMTRI profile.**
- **It is highly desirable to have an instrumentation plane that is horizontal rather than pointing down by about 9° to the horizontal.**
- **It is highly desirable for the head mass to be that specified by UMTRI (4.14 kg).**
- **Head C.G. should be in accordance with UMTRI specification (Highly desirable). The geometrical method for specifying the head C.G. position should be agreed.**
- **It is essential that the head complete with neck attachment system is modified to avoid resonance below 2 kHz. A minimum resonant frequency limit of 4 kHz is suggested.**
- **It is a desirable feature for the head and face skin to be continuous (i.e. one piece).**
- **The WG is ambivalent regarding the method of measuring angular head motion (3-2-2-2 or MHD) provided that the injury criteria can be measured to the same accuracy.**

4.2 Face

Both the FT and the NT designs include similar, but not exactly identical, options for the measurement of force to the face in five locations below the forehead.

- **The WG is ambivalent towards the need for a force measuring face for routine testing. There would be an advantage in removing the discontinuity in the stiffness of the skull (forehead and face) by omitting the force measuring face.**

4.3 Neck

The WG is unhappy with any of the existing designs of neck due to complexity and difficulty in obtaining a reliable measure of neck forces and moments. Uninstrumented load paths and some friction problems with the current spring and wire arrangement mean that errors can appear.

- **WG12 feels that it is highly desirable for this area to be re-designed to remove these problems. Options for an improved design exist for consideration.**

- **In addition, improved biofidelity in extension would be highly desirable.**

4.4 Shoulder

Both NT and FT shoulder design are based on the same concept, however detailed geometrical differences exist in particular in the clavicle region.

- **The WG is ambivalent towards the profiles of the FT and NT clavicle but it would be desirable to have a smooth transition between the clavicle and the acromion.**

There are particular concerns over the interaction of the seat belt with the joint at the outer end of the clavicle. The extent to which this interaction is human-like or not, should be determined and demonstrated.

- **The padding in the shoulder area is not sufficiently robust. Therefore, it is essential to improve the durability of the shoulder padding.**

- **The WG is ambivalent towards the provision of a shoulder (or clavicle) load-cell.**

4.5 Thorax

The lower neck surface of both NT and FT is approximately 57mm below the anatomical T1 position. The location of T1 accelerometers varies between the designs. For the FT, the T1 instrumentation is approximately in the correct anatomical position while for the NT, it is approximately 75 mm lower and 41 mm to the right of the midsaggital plane.

- **It is highly desirable that the vertical location of T1 is close to the anatomically correct position as in the FT design, rather than NT.**

THOR-NT and FT designs differ in the sternum region and in terms of deflection measurement system, yet are following the same anthropometric and biomechanical specification.

- **It is essential that the thorax design should be reconsidered to ensure that there is no non-biofidelic hard contact between the top of the sternum and the base of the neck. Under no foreseeable test conditions should the top of the sternum make contact with the lower neck load-cell. Also, the stiffness of this area should be as biofidelic as possible.**

- **The WG feels that it is highly desirable to avoid the current experience of rib damage due to rib-to-rib contact under high deflection (gouging) and strongly recommends that a small design change is needed to avoid this, such as covering or linking/coupling the ribs together.**

- **The WG has experience that the THOR-Alpha mid-sternum mass had a durability issue. The WG has no preference between the FT and NT design as long as the durability can be guaranteed.**

- **The WG is ambivalent regarding the particular instrumentation chosen for measuring thoracic displacement and believes both the IR-TRACC and CRUX could be acceptable.**

- **The WG believes that it is essential that the precise positions on the sternum and spine between which the motion is to be measured should be defined and fixed and that 3D compression is measured. WG12 experience suggests that if the CRUX systems are to**

be used, a re-design is necessary, in particular to avoid contact during dynamic impacts. It would appear that the IR-TRACC is a more straightforward design solution.

The NT lumbar spine is finely adjustable to a range of posture adjustments while the FT design is limited to three specific orientations. The standard position is used in most passenger cars, but the adjustment may be useful for other conditions such as racing cars or trucks. Probably only three alternative positions are necessary.

- **WG12 feels that it is desirable to adopt the FT, three discrete position, lumbar adjustment as this is less likely to lead to incorrect set-up.**

4.6 Abdomen

Both the THOR-NT and the THOR-FT have a divided two-part abdomen although the design and materials are different. This was needed to allow for the multi-position adjustment of the lumbar to pelvis and also to avoid interference with the lumbar joint movement. The gap between the two abdomen parts and the need for metal plates in the suit to cover this gap concerned the WG12 members. Furthermore the high stiffness in the upper abdomen caused concern regarding the influence on chest compression. If the lumbar with three discreet positions were used, only one of these positions being used for most cars, a divided abdomen would no longer be needed.

- **WG12 believes that it is essential to achieve a significant improvement in the biofidelity of the upper abdomen. It is desirable to maintain a compression measurement in this area but to achieve the improved biofidelity would accept, if necessary, the elimination of the deflection instrumentation in the upper abdomen provided there is improved coupling between the upper abdomen and the lower ribcage.**

- **WG12 believes that it is highly desirable to have a continuous anterior surface to the whole abdomen (upper and lower) which could be achieved by using a single abdominal unit. It remains important to meet the biofidelity of the upper and lower areas of the abdomen.**

- **It is essential that the design of the lower abdomen instrumentation be addressed to avoid the damage in dynamic testing due to restricted range of motion observed, for instance, when the dummy submarines.**

- **It is desirable to maintain the 3D deflection measurement in the lower abdomen particularly as the range of motion will be increased (to avoid the damage) and provided that the maximum compression is not compromised.**

- **WG12 is ambivalent regarding the material from which the abdomen is made provided it is durable and meets the biofidelity requirements.**

4.7 Pelvis

The unloaded pelvis shape of NT was modelled after UMTRI but corrected for flesh compression. The FT was designed according to compressed state that UMTRI specifies, similar to the WorldSID dummy.

- **WG12 prefers the pelvis geometry to follow the UMTRI profile which is already compressed and that the pelvis bone should be based on the Reynolds anthropometry (Highly desirable). From an overall design point of view, WG12 prefers the NT but wishes to see stiffer foam in the seating area to comply with the compressed flesh geometry (UMTRI) while maintaining more human-like flesh stiffness in the lap-belt pelvis interaction zone.**

- **It is essential that both the flesh and skeletal pelvis are durable.**

- **WG12 believes that it is desirable to incorporate realistic interaction between the pelvis and anti submarining devices balanced with the importance of stability in the pelvis flesh for set-up repeatability and convenience.**

- **WG12 feels that it is desirable to improve the load sensing in the iliac crest by, for instance, increasing the number of load-cells in the anterior surface.**

- **It is desirable to have a more human-like bone to flesh mass ratio.**

- **It is desirable to improve the usability of assembly/disassembly of the pelvic bone and flesh.**

4.7 Femur

Both NT and FT have a similar femur design. The compliant element in the mid femur is added to reduce the femur stiffness. Experience in testing has shown that the femur is currently too stiff (Rupp et al. [3]), that the compliant element can lock up and that the mass distribution (between bone and flesh) is incorrect.

- **WG12 considers it to be desirable for the femur compliant element to be modified to enhance the compression and tension performance of the femur and this would permit some bending compliance and also better mass distribution between bone and flesh.**

4.8 Lower leg

Both NT and FT use the so-called THOR-Lx lower legs that are highly advanced but complex in nature.

- **WG12 is aware that NHTSA is considering a revision to the design of the ankle joint stiffness control and can see advantages in a design giving more repeatable performance.**

- **The WG is ambivalent towards the provision of a cheaper, simpler alternative to the THOR-Lx, given that the THOR-Lx is available.**

4.9 Arms

Both the FT and the NT currently use Hybrid III arms. These are not in agreement with the UMTRI specification.

- **As there is no consideration currently being given to assessment of injuries to the upper extremities in frontal impacts within EEVC WG12, it is considered that the use of Hybrid III arms would be suitable.**

5. References

1. Schneider L, Robbins D, Pflüg M and Snyder R (1993). *Anthropometry of Motor Vehicle Occupants. Final Report,* UMTRI-83-53-1. University of Michigan Transportation Research Institute.

2. Moss S, Wang Z, Salloum M, Reed M, van Ratingen M, Cesari D, Scherer R, Uchimura R and Beusenberg M (2000). *Anthropometry for WorldSID A World-Harmonized Midsize Male Side Impact Crash Dummy.* SAE Technical Paper Series 2000-01-2202. Government/Industry Meeting, Washington, D.C..

3. Rupp J, Reed M, Madura N, Miller C, Kuppa S and Schneider L (2005). *Comparison of the inertial response of the THOR-NT, Hybrid III, and unembalmed cadaver to simulated knee-to-knee-bolster impacts.* 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington, DC, USA, 6-9 June, 2005. US Department of Transportation, National Highway Traffic Safety Administration.

6. Summary

[Square brackets show the preferred dummy option NT, FT, both, either or neither]

Anthropometry	–	UMTRI 50th percentile adult male [**Both**]
	–	Specifications to be Metric [**FT**]
Instrumentation:	–	At least equipped for umbilical cord transmission (Essential) [**Both**].
	–	Provision for on-board DAS highly desirable [**FT**]
	–	T1 instrumentation location to be anatomically correct [**FT**]
Biofidelity:	–	EEVC, NHTSA, Transport Canada, Australia and Japan at least to agree requirements. (Essential)
Certification:	–	Small group of experts to propose a necessary and sufficient set of certification procedures.
Head/Face	–	Mass and C.G. to follow UMTRI (Highly desirable) [**FT for mass**]
	–	Instrumentation plane to be horizontal in test condition (highly desirable) [**Neither**]
	–	Head and neck to have resonance frequency >2khz (Essential) [**Neither**]
	–	Head and face skin to be continuous (one piece) (Desirable) [**NT**]
Neck:	–	Redesign required to avoid measurement errors, uninstrumented load paths and setup difficulty (Highly desirable) [**Neither**]
	–	Improved biofidelity in extension (highly desirable) [**Neither**]
Shoulder:	–	Clavicle either straight or bent (ambivalent) [**Either**]
	–	Interaction with shoulder belt humanlike – no unrealistic profile change between clavicle and end bearing (desirable) [**Neither**]
	–	Shoulder padding material durability to be improved (essential) [**Neither**]
Rib cage:	–	Modifications required to avoid non-biofidelic sternum-neck contact (essential) [**Neither**]
	–	Small design change to avoid rib-to-rib contact and damage (highly desirable) [**Neither**]
	–	No preference to sternum mass design [**Either**, provided durable]
	–	IR-TRACC or CRUX acceptable but CRUX would need redesign to avoid test damage and end attachment points must be specified and identical (essential) [**Either**].
Lumbar:	–	Design with just 3 possible angles preferred (highly desirable) [**FT**]
Abdomen:	–	Biofidelity of upper abdomen to be improved (essential) [**Neither**]
	–	Continuous anterior surface, whilst meeting the biofidelity of the upper and lower areas of the abdomen (highly desirable) [**Neither**]
	–	Lower abdomen instrumentation mount to be revised to avoid damage in testing (essential) [**Neither**]
	–	3D measurement in lower abdomen to be retained (desirable) [**Both**]
	–	No preference to construction material (ambivalent) [**Either**]
Pelvis:	–	Profile to follow UMTRI flesh profile, which is already compressed (Highly desirable) [**FT**]
	–	Realistic interaction pelvis to anti-submarining devices to be ensured

	(desirable) [**Unknown**]
	– Human flesh stiffness in lap belt interaction area (highly desirable) [**NT**]
	– Pelvis and flesh to be more durable (essential)[**FT and NT**(hard)]
	– Load sensing at iliac crest anterior surface to be improved (desirable) [**Neither**]
	– More humanlike skeletal/flesh mass ratio (desirable) [**Neither**]
	– Easy assembly of pelvis bone into flesh (desirable) [**Neither**]
Femur:	– Compliant element modified to control extension as well as compression and to allow some bending compliance. (desirable) [**Neither**]
Lower leg	– Improved design of ankle rotation stiffness control (desirable). [**Neither**]
	– No preference for provision of simplified leg design (ambivalent)
Upper extremity	– The use of Hybrid III arms for THOR is acceptable [**NT and FT**]

Appendix A: Comparison of EEVC and NHTSA Biomechanical Requirements

	EEVC Requirements (ESV 2003)	NHTSA Requirements (2001)	Comments
Face	Frontal – Rigid bar - Nyquist (1986)	Frontal - Rigid bar - Nyquist *et al.* (1986)	Identical requirement
	Frontal - Flat disk - Melvin & Shee (1988)	Flat disk - Allsop *et al.*(1988), Melvin and Shee (1989); Nyquist *et al.* (1986)	Identical requirement
	Oblique - ADRIA (1998)	*Proposed* - Oblique - Bermond *et al.* (1999)	Same as tests ADRIA (1998), but different requirements
Head	Melvin (1985) corridors based on UMTRI (Prasad, 1985)	Melvin (1985) corridors based on UMTRI (Prasad, 1985)	Identical requirement
	Melvin (1985) corridors based on Hodgson & Thomas (1975)	Melvin (1985) corridors based on Hodgson and Thomas (1975)	Identical requirement
Neck	Frontal - NBDL 15 g	Frontal - NBDL 15 g - Thunissen (1995)	NHTSA frontal and lateral
	Oblique - NBDL 11 g	Frontal - NBDL - Mertz and Patrick (1971)	WG12 frontal and oblique
		Lateral - NBDL - Klinich (1995)	Same basic data set
		Lateral - NBDL - Patrick and Chou (1971)	
		Proposed - Extension - Ono *et al.* (1999)	
		Proposed - Axial compression - numerous	
		Proposed - Tension - van Ee *et al.* (2000)	
		Proposed - Torsion - Myers *et al.* (1989) and Wismans & Spenny (1983)	
Shoulder	Vezin (2002) - NB: more tests required	None defined	Additional WG12 requirement
Spine	Vezin (2002)	None defined	Additional WG12 requirement
		Numerous tentative proposals	
Thorax	Kroell (1971)	Neathery (1974)	Identical requirements, referenced differently
	Yoganandan (1997)	Yoganandan (1997)	Identical
	Vezin (2002)		Additional WG12 requirement
		Proposed - Q-S thorax regional coupling - Schneider *et al.* (1992)	
		Proposed - Belt loading - Cesari and Bouquet (1990)	
Abdomen	Nusholtz and Kaiker (1994)	Nusholtz and Kaiker (1994)	Identical requirement
	Cavanaugh *et al.* (1986)	Cavanaugh *et al.* (1986)	Identical requirement
	Rouhana *et al.* (1989)		Additional WG12 requirement
		Proposed - Belt impact - Hardy and Schneider (2001)	

		Proposed - Belt impact - Rouhana *et al.* (1989) *Proposed* - Airbag impact - Hardy and Schneider (2001)	
Pelvis	None defined	None defined	
Femur	FID (2000) - Horsch and Patrick (1976) extended with additional data	Horsch and Patrick (1976)	Identical requirement