Chapter 4 – TEST METHODS AND PROCEDURES

The pass/fail of a vehicle in a qualification test is based on the human body loading aspects. In the previous chapter the criteria and the tolerance levels for the human body loading aspects have been described. This chapter gives an overview of the required measurement tools and equipment, and the test procedure. The following topics will be discussed:

Human surrogates in general

- Hybrid III anthropomorphic test device (ATD);
- Positioning of the Hybrid III ATD;
- Measurements with the Hybrid III ATD;
- Pressure measurement device; and
- Additional measurements.

The above topics are also the background for the test protocol which is included in Annex I. This protocol gives detailed information for the preparation and execution of the mine tests concerning the measurements for the injury assessment. The protocol will be part of the mine test procedure of the STANAG 4569.

4.1 HUMAN SURROGATES

To measure the body loads a model or surrogate of the human body is necessary. This surrogate should represent the geometry, the mass and mass distribution to simulate the behaviour (biofidelic response) of the human body. For a geometric surrogate, a simple doll could be used. For a mass surrogate, a sand bag could be used. The combination of a geometric and mass correct surrogate gives the possibility to test safety systems, like a belt. In the last few years, some own developed surrogates, like a steel dummy within the Norwegian Defence, have been used.

The TG-25 stated that the 'sand bag type of dummies' are not appropriate for qualification trials according to STANAG 4569. For mine qualification trials a more sophisticated surrogate, which reports information about leg, spine and neck loads as well as the performance of footrest, seat and restraint systems, is required. The surrogate should not only give satisfying biofidelic response in the initial mine loading phase, but also during the whole motion of vehicle and interior parts.

Because the research area Vehicle Mine Protection is very new and of less economical significance, in comparison to the automotive crash research area, no specific surrogate for the anti-vehicle mine detonation process has been developed. Therefore, the most appropriate existing surrogate has been selected, which is the Hybrid III. In the next section this Hybrid III anthropomorphic test device (ATD) is presented.

4.2 THE HYBRID III 50TH PERCENTILE MALE ANTHROPOMORPHIC TEST DEVICE (ATD)

The Hybrid III 50th percentile male ATD (also called a crash test dummy) was developed for frontal crash tests with cars. The ATD provides facilities to be instrumented with a large number of sensors to measure accelerations, forces, moments and displacements in several body parts. The reusable ATD is a robust measurement device and can withstand extreme loading conditions, but it is also an expensive tool,

so handling the ATD should be done with care. As the ATD has been developed for the frontal loading conditions of car crash tests, its biofidelity is also proven for these loading conditions [Jakobsson, 2005]. However, the ATD can also be used for other loading conditions, like the vertical loads in case of an ejection seat escape.

The ATD is a regulated test device in the USA Code of Federal Regulations (49CFR Part 572, subpart E) for frontal car crash tests. This regulation refers to a General Motors drawing package identified by GM Drawing no. 78051-218, revision U, title "Hybrid III Anthropomorphic Test ATD", date August 30, 1998.

Some other versions of the Hybrid III ATD are available for more specific research purposes. One of them is the FAA-Hybrid III [Gowdy, 1999] for air crashworthiness and ejection seat escape research. This ATD has a straight lumbar spine assembly, which is expected to give a more biofidelic and reproducible response in the vertical loading conditions for pilots sitting in an upright position in their ejection seat and ready to escape.

The standard Hybrid III 50th percentile ATD comes with non-instrumented tibias and for mine vehicle qualification tests, both tibias have to be replaced by instrumented tibias made by the Robert A. Denton, Inc. company and will be referred to as the Denton leg [Denton, 2002; Denton 1984]. The instrumented tibias shall be equipped with a lower tibia load cell that records at least the axial force (Fz). Depending on additional desired instrumentation, different models of the lower tibia load cells and also upper tibia load cells are available (Robert A. Denton, Inc. Drawing Number B-3500-D in Ref. 2).

A new mechanical lower leg model is the Thor-Lx, which is the first developed part of the Thor ATD (see Figure 4.1). This model has been developed to improve the biofidelic response in car crash loading conditions. The Thor-Lx is a more complex leg model as it consists of a damper element in the mid tibia shaft and a simulated Achilles tendon. This makes the model more expensive and probably more vulnerable.

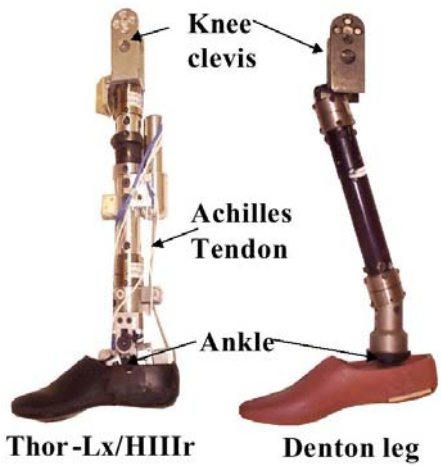

Figure 4.1: Thor-Lx (left) and Denton Leg Model (right).

The Hybrid III 50th percentile male ATD represents the average male of the USA-population between 1970 and 1980 with the following characteristics:

- Stature (standing position): 1.72 m (67.7 inch);
- Weight: 78 kg (172 lb); and
- Erect sitting height: 0.88 m (34.64 inch).

It is clear that these figures may not accurately represent the current population anymore. For example, in the northern part of Europe, the average man is taller. This is an important issue, because risk of head contact in an AV mine incident depends on head clearance and thus mainly on the height of an occupant. The problem is that even the 95th percentile male ATD is not representative. In enclosed figure (Figure 4.2) the size and weights are plotted for a Dutch population in the year 2000 and for the 5th percentile female, 50th percentile male and 95th percentile male ATD. For an equal mixture of Dutch male and female, the original Hybrid III 50th percentile matches very well for both the size and mass. In contradiction to the Dutch situation, the Hybrid III 50th and 95th percentile males are believed representing pretty well the North American 50th and 95th percentile male soldiers based on an anthropomorphic study of the Canadian Land Forces [Chamberland, 1997]. Only large differences are noted between the 5th percentile female soldier and the Hybrid III. Figure 4.3 showed the comparison between Canadian Land Forces anthropomorphic data (in 1997) and different Hybrid III ATDs.

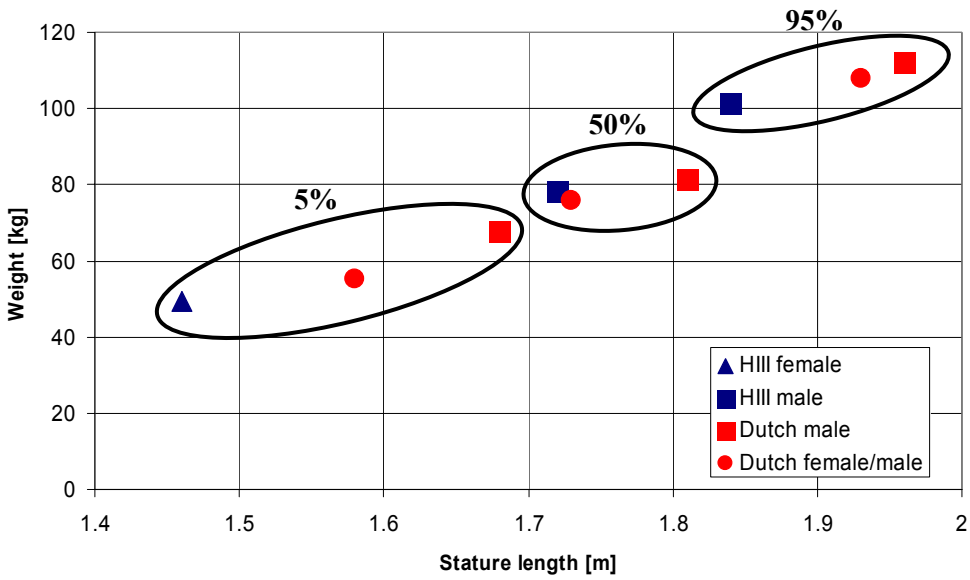

Figure 4.2: Size and Weight for 5th Percentile Female and 50th and 95th Percentile Male Hybrid III ATD and for a Dutch Population in 2000.

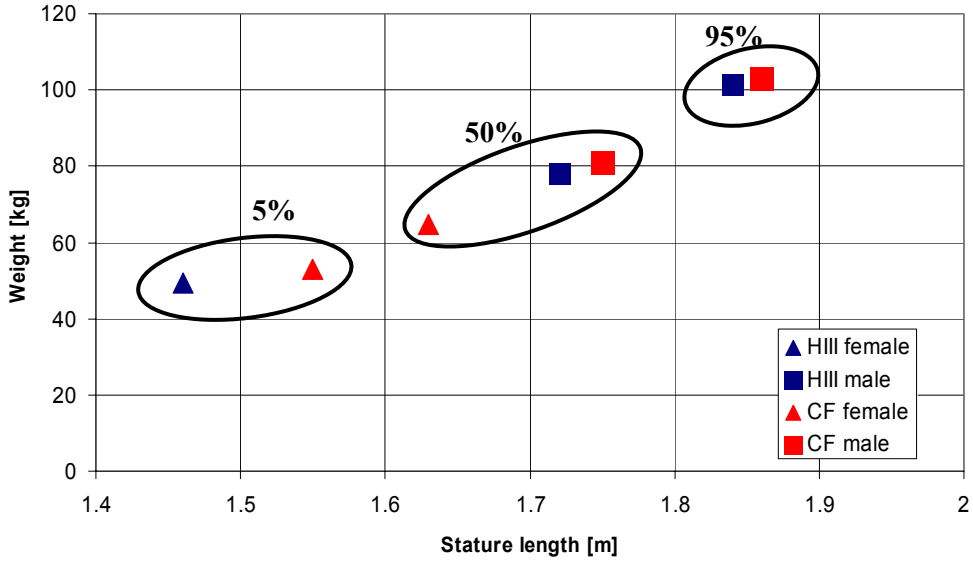

Figure 4.3: Size and Weight for 5th Percentile Female and 50th and 95th Percentile Male Hybrid III ATD and for a Canadian Forces Population in 1997.

A MADYMO study on the difference in response of the 5th percentile female and 50th and 95th percentile male ATDs showed small differences (<10%) in the human body loads for the same input load (both footplate and seat motion) [Horst, 2004]. However, the 5% ATD showed significantly lower human body loads than the 50th percentile dummy.

Summarised, the advantages of the Hybrid III 50th percentile ATD are:

- Complete body inclusive head/neck and extremities;
- Well-defined standardized body dimensions;
- Standard measurement equipment;
- All required measurements for injury assessment available (except for overpressure);
- Sufficient realistic biomechanical response; and
- Can be dressed with clothes, boot, and personnel protective equipments.

Its disadvantages are:

- Complex and expensive;
- Risk of damage after high loads with high repairing costs;
- Required handling experience; and
- ATD proportions may not be representative of current population.

The TG-25 decided to use the 50th percentile standard (seated) Hybrid III ATD (having a curved spine) for a good representation of most common sitting postures in military vehicles during an unexpected mine incident. Second reason for this choice is the fact that this type is more common in world-wide community. Third reason is that a curved or straight spine has no or very limited influence on the DRI-criterion used for the injury assessment of the lumbar-thoracic spine. The TG-25 decided to use the original instrumented Denton leg for lower leg injury assessment. The use of the more complex instrumented Thor-Lx legs need to be further investigated for the AV-mine loading conditions.

If a standing position is required, a conversion kit can be installed on the standard sitting Hybrid III to make the standing posture possible. In Figure 4.4 a picture is given of the ATD inside a military vehicle.

Figure 4.4: Hybrid III ATD in a Truck before the Mine Test.

For a pass/fail test at least one standard Hybrid III 50th percentile male ATD has to be used to measure the human body loads in case of a mine detonation under a vehicle.

4.3 ANTHROPOMORPHIC TEST DEVICE (ATD) POSITIONING

For positioning the ATD(s) inside the vehicle, the following aspects are important:

- The position in the vehicle;
- The seating posture of the ATD; and
- The clothing of the ATD.

4.3.1 The Position in the Vehicle

The ATD has to be placed at one of the original crew positions inside the tested vehicle. This should be the 'worst-case' position: the position that is expected by the 'National Authority' to give the highest loads inside the ATD for a particular mine position under the vehicle.

4.3.2 The Seating Posture

The seating posture of the ATD should be realistic and representative for an occupant with the same sizes as the 50th percentile ATD sitting in an upright position. The straight seating posture should be achieved by placing the pelvis well in the seat cushion and the back of the ATD in contact with the seat back cushion (when available). It should be mentioned that for some seating systems an upright position is not possible for a human. For these cases the most realistic position needs to be checked by a volunteer (preferably with the same sizes as the 50th percentile ATD) and imitated with the ATD.

The feet have to be placed in the same way as for a real sitting or standing person. When footrests or protection measures are available, they have to be used. In case of a driver, the right leg should be placed on the accelerator or breaking pedal – the choice of the pedal must be based on the higher expected risk of the transfer of critical loads via the relevant pedal- and the left one on the resting position. For both legs a realistic body posture has to be achieved. By considering this general requirement, the lower leg longitudinal axis should be as good as possible perpendicular to the foot plate to create a worst-case set-up (see Figure 4.5).

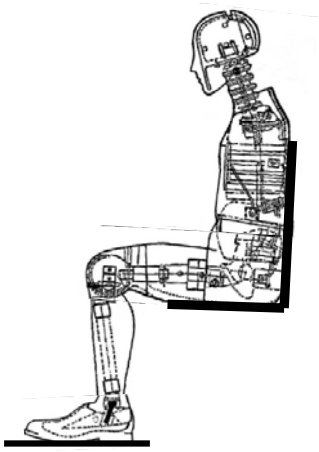

Figure 4.5: Straight Seating Posture.

The hands and arms should be placed in a realistic position. In case of steering wheel or joy sticks, the hands should grip these devices; else the hand should be placed in a resting position on the upper leg. The hands should not be fixed to the steering wheel or legs.

The seat has to be adjusted according to the size and weight of a 50th percentile man. If different seat positions are possible for different functions and scenarios (e.g. combat vs. driving under homologation conditions in peace keeping operations) the worst-case position of the seat has to be tested. In case of the usage of periscopes or other vision tools, the seat has to be adjusted in such a way that the eye-level of the ATD corresponds to these vision systems.

All available protective measures, such as seat belts and head rests, should be used and installed correctly.

When seat belts are available, they have to be used in the original way. Remove slack in the belts and tighten them as realistic as possible. In case of a belt retractor, allow it to retract the belt to remove slack.

In case of repetitive tests or similar tests at other proving grounds, the same seating posture of the ATD should be kept.

4.3.3 The Clothing of the ATD

The clothing of the ATD should correspond to that of a real crew member or passenger of the tested vehicle. For filming purposes, the uniform can be replaced by an overall with a clear visible colour (contrast with background).

The footwear (shoes or boots) should be the same as normally used by the real personnel of that type of vehicle and the footwear should be in good condition, without any damages. For soldiers, combat boots are recommended.

When the occupants wear personnel protective equipment (helmet, vest, etc.) in normal operational conditions, the ATD should wear the same equipment.

4.4 MEASUREMENTS WITH THE HYBRID III ATD

For a pass/fail test, at least the ATD should be instrumented with the following sensors:

- Lower Tibia Load Cell in both legs: axial force (Fz);
- Pelvis Accelerometer: vertical acceleration (Az); and
- Upper Neck Load Cell: shear force (Fx), axial force (Fz), flexion/extension moment (My).

In Figure 4.6 the position of these sensors are shown.

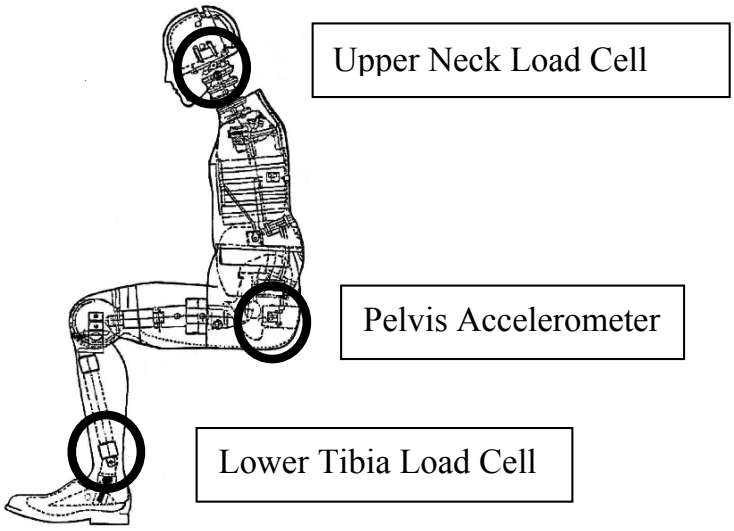

Figure 4.6: Hybrid III ATD with Sensor Positions.

The standard set of instrumentation of the Hybrid III is appropriate for the mine loading conditions.

It is recommended to include more instrumentation to gather additional data about the loading process inside the ATD. This could help to understand the effects and explain unexpected responses observed. When new injury criteria for these additional measured data are available in the future, the injury assessment could be extended.

The following list of additional instrumentation is recommended:

- Five-axis load cell in the lower tibia of both legs (Fx, Fy, Fz, Mx, My);
- Five-axis load cell in the upper tibia of both legs (Fx, Fy, Fz, Mx, My);
- Tri-axis accelerometers on the mid tibia shaft in both lower legs (Ax, Ay, Az);
- One-axis load cell (shear force) in both femurs (Fx);
- Tri-axis accelerometers in pelvis, thorax and head: (Ax, Ay, Az);
- Three or five-axis load cell in the lumbar spine (Fx, Fz, My or Fx, Fy, Fz, Mx, My); and
- Six-axis load cell in the upper neck (Fx, Fy, Fz, Mx, My, Mz).

The way to use and maintain the instrumentation and to record and analyse the channels are well described in the SAE regulation J211/1 from December 2003. This document describes:

- The coordinate system;
- The positive polarities of the sensors;
- The certification and calibration aspects;
- Some boundary condition, like the temperature;
- Data acquisition system settings; and
- Signal processing.

The HFM-090/TG-25 recommends to use this standard for the ATD measurements and the processing of the ATD signals. However, since the loading conditions in a mine strike differ from the car crash loading conditions, some other settings are recommended, which are discussed below. More information about the measurement set-up and settings is given in the Test Protocol in Annex I.

4.4.1 Certification and Calibration

The ATD consists of a steel skeleton and rubber elements, surrounded by rubber and foam material to simulate the skin and soft tissue. The characteristics, like stiffness and damping, have influence on the internal loads in case of impact or loading transfer. Therefore, the characteristics should meet specific requirements, which are verified in a certification test.

The sensors inside the ATD are mechanical devices, which translate the load into an electric signal. The signal is being recorded by the data-acquisition system, which has to be provided with information about the sensitivity of that particular sensor. Each sensor has to be calibrated to give the relation between load and signal amplitude. Due to repetitive loadings, overloads or aging of the mechanical sensor, re-calibration is necessary on a regular schedule. For certification and calibration, refer the ATD user's manual [SAE, 1998].

It is advised that the ATD will be certified and the sensors be calibrated at least every two years. This advice is based on several years of experience with the use of the ATD in the Vehicle Mine Protection research area and valid for 'normal usage'. This means: 15 to 20 tests, loads within the ranges of the sensors, no structural damage to the ATD and the storage of the ATD in a dark room and at a constant temperature of about 20° C. In case of an overload of a sensor, re-calibration of this sensor is mandatory.

4.4.2 Temperature Conditions

Because of the temperature influence on the characteristics of the rubber elements and the skin of the ATD, a constant temperature between 20 and 22° C on the test site is preferred (according to crash test regulations). However, in general, sites for mine tests are outside locations and temperature can hardly be controlled. A temperature of 10° to 30° C inside the vehicle is advised. In winter time, a heater inside the vehicle could prevent too cold conditions and reduce moisture.

4.5 PRESSURE MEASUREMENT DEVICE

Inside the vehicle, the overpressure has to be measured to analyse the effects on non auditory internal organs in the thorax and abdomen. The Chest Wall Velocity Predictor (CWVP) model is used to assess injury to these organs (see Chapter 3). As input for this model the reflected overpressure on the thorax has

to be measured. Originally the measurements should take place using a simple blast test device (cylinder) [Axelsson, 1996]. However from a practical point of view (it is not possible to include the cylinder on the same location as the ATD during one test) the following measurement methods are proposed:

- Using the original cylinder described by Axelsson;
- Using the Hybrid III as reflected area instead of the cylinder; and
- Using a flat plate as reflected area instead of the cylinder.

To measure the reflected pressure it is important to have a correct simulation of the body (equal reflected area) and appropriate transducer fixed on this device. The chest of the Hybrid III ATD represents the body dimensions and thus is proposed as mount of a pressure transducer, in case the pressure needs to be measured on the location where an ATD is placed. Based on blast tunnel tests performed by TNO it was shown that the CWVP is similar for a cylinder or when using the Hybrid III as reflected area [Horst, 2005]. During these tests overpressure effects were measured using different types of models, i.e. a simple plate, a simple cylinder as described by Axelsson and a specific developed pressure measurement device on the chest of the ATD (see Figure 4.7). Four pressure transducers were mounted to the cylinder (also called Blast Test Device: BTD). Special brackets were developed for measuring the pressure on the ATD. The mounted pressure transducers on the ATD showed reliable results, which can be used for injury assessment. When neither the BTD, nor the ATD can be used, then a simple reflected area can be used to measure the overpressure effects for injury assessment. However, it needs to be noted that the reflected area need to be close to the reflected area of the BTD in order to prevent early time rarefaction waves, so representative pressure time records are obtained.

Figure 4.7: BTD (left) and Hybrid III ATD (right) in Blast Tunnel [Horst, 2005].

For blast overpressure, it is hardly possible to define a worst-case location and the position of the ATD is not always the worst-case position for both the mechanical loads and the pressure loads. Therefore, at least two positions for pressure measurements are mandated:

- One on the chest of the Hybrid III ATD; and
- One on a second Hybrid III ATD (when available) or at the crew location where the highest overpressure loads might be expected.

4.5.1 Pressure Measurement Device on the Chest of the ATD

It is recommended to use a flat measurement device strapped on the chest of the ATD as shown in Figure 4.8. The ATD is dressed and the device must be fastened above the clothes. The device should consist of a plate with a flat transducer fixed in or on this plate (see Figure 4.9). To avoid inertia problems for the ATD response, the device should be as light as possible. It is recommended to use hard plastic materials for the mount.

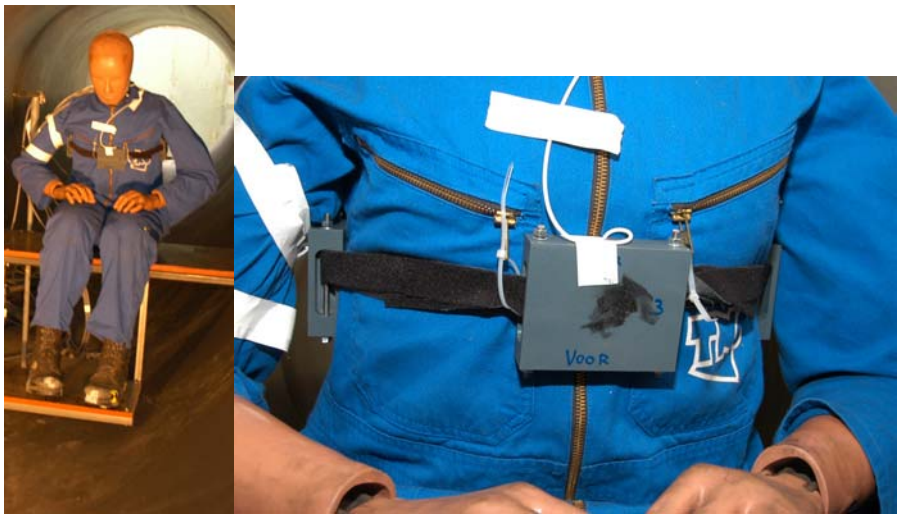

Figure 4.8: Example of Pressure Measurement Device on the Chest of an ATD [Horst, 2005].

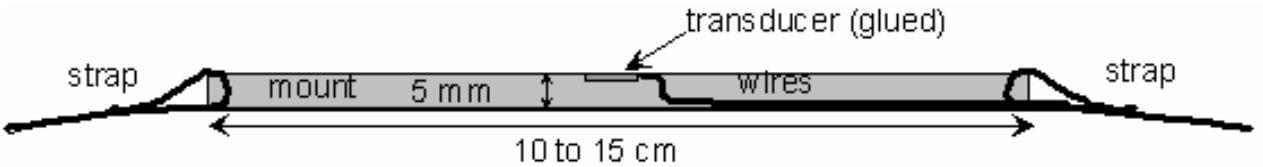

Figure 4.9: Example of a Flat Pressure Measurement Device.

4.5.2 Pressure Measurement Device at Another Position

For another measurement position than the chest of the Hybrid III, it is necessary to have a plane as reflected area at or close to a crew position. This should be the position were the highest overpressure is expected. The back of the seat could be used as reflected area in combination with the same pressure measurement device as described for the ATD. The transducer should be orientated in the same direction as the chest of a human being located on that position.

When no appropriate reflecting plane for the pressure measurement device is available, the original blast test device (cylinder) as described by Axelsson & Yelverton [Axelsson, 1996] can be used (see Figure 4.10).

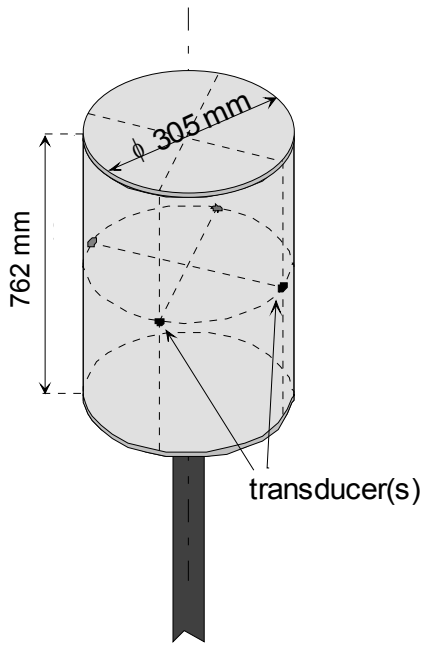

Figure 4.10: Example of a Cylinder for Pressure Measurements.

The dimensions of this cylinder are: height of 762 mm, diameter of 305 mm. Although the human thorax has smaller dimensions it is suggested to follow the original blast test device dimensions and stay as close as possible to the original injury model.

The pressure transducer(s) should be fixed in or at the cylinder at half height. The material for the cylinder should be hard enough to protect the transducer and the wires and to reflect sufficiently the incident pressure.

When the frontal direction (chest direction) for the measurement location is known, at least one single transducer in the cylinder is needed in the same frontal direction (like in case with an ATD).

For a standing position and when the crew member at that position can face any direction, four sensors have to be used. For the conservative approach in the injury assessment, the worst-case sensor in terms of peak velocity must be considered.

Note: This is in contradiction with the original method in which the average value of the four peak velocities (from each sensor) was taken. Additional research is necessary to compare above described methods.

4.5.3 Pressure Transducer Specifications

For fixation on a plate, a flat transducer (< 1 mm) should be used. This could be glued or screwed on that plate. For fixation in a plate or in the cylinder, other transducers could be used as long as the opening of the sensor is flat with the outer surface (flush). To avoid influence of cylinder deformation on the pressure transducer and the signal, the sensor could be placed in rubber mounts in the cylinder wall.

The following specifications are recommended for the pressure transducer:

- Full scale range > 300 kPa; and
- Resonance frequency > 50 kHz.

4.6 ADDITIONAL MEASUREMENTS

In the previous sections the measurement methods have been described for the data, which is required for the mandatory criteria. It is strongly recommended to extend the measurement set-up with extra information, which could be helpful for the assessment.

A list with additional instrumentation in the Hybrid III ATD is already given in Section 4.4. Other additional measurements could consist of belt force measurements, acceleration and displacement measurements on the footrest and seat system or additional pressure measurements.

These measurements are helpful in the understanding of the input loading process. The data is also appropriate for numerical studies of human body loads.

For the assessment of ATD behaviour, normal speed and/or high speed video film recordings give very useful information. For ATD motion only, a high speed recording rate of 1000 frames per second is sufficient. For the high speed video recording of structural response, higher frame rates are recommended.

4.7 SUMMARY

This chapter described the test methods and procedures. The following tools are required for a pass/fail of a qualification test of a vehicle against mine strikes:

- Instrumented Hybrid III 50% male anthropomorphic test device; and
- Pressure measurement device(s).

In Annex I the complete test protocol is presented. In Table 4.1 an overview of the required data for the injury assessment is summarized.

Table 4.1: Overview of Data that Needs to be Measured

Body Region	Required Data	Measurement Device
Lower leg	Axial compression force (Fz) in the tibia	Load cell in the lower tibia of the Hybrid III ATD
Thoraco-lumbar spine	Vertical acceleration (Az) in the pelvis	Accelerometer in the pelvis of the Hybrid III ATD
Head / neck	Shear force (Fx) and axial compression force (Fz) in the neck Flexion/extension bending moment (My) in the neck	Load cell in the upper neck of the Hybrid III ATD Load cell in the upper neck of the Hybrid III ATD
Non-auditory internal organs	Reflected overpressure p(t)	Two pressure gauges (at least one on the chest of the Hybrid III ATD)

4.8 REFERENCES

Axelsson, H. and Yelverton, J.T. (1996), Chest Wall Velocity as a Predictor of Non-Auditory Blast Injury in a Complex Blast Wave Environment, *The Journal of Trauma, Injury*, Infection and Critical Care.

Chamberland, A., Carrier, R., Forest, F. and Hachez, G. (1997), Anthropomorphic Survey of the Land Forces, Final report presented to Defence and Civil Institute of Environmental Medicine (DCIEM), Report number 98-01897, Les Consultants Génicom, Inc., Montréal, Québec, Canada.

Denton, R.A. Inc. (1984), Crash Test Dummy Lower Leg Structure, Patent No. 4, 488, 433.

Denton, R.A. Inc. (2002), Instrumented Lower Leg Assembly.

Gowdy et al. (1999), A lumbar Spine Modification to the Hybrid III ATD for Aircraft Seat Tests, SAE Paper 1999-01-1699.

Horst, van der, M.J. and Maasdam, van, R. (2004), Influence of dummy sizes. Internal TNO memorandum and TNO presentation at third meeting of HFM-090/TG-25, Rijswijk, The Netherlands.

Horst, van der, M.J. and Deursen, van, J.R. (2005), Injury Assessment for Blast Overpressure Effects. TNO DV2 A239 report. TNO Defence, Security and Safety, Rijswijk, The Netherlands.

Jakobsson, L. (2004), Feasibility of Hybrid III for evaluating mine protection of vehicles, TAK report no. TAK2004-018, Volvo Car Corporation, Sponsored by Swedish Defense Materiel Administration, FMV.

NHTSA Title 49 – Transportation Chapter V – National Highway Traffic Safety Administration (NHTSA), Department of Transportation, Part 572 – Anthropomorphic Test Device.

SAE J211/1 (1995), Surface Vehicle Recommended Practice, (R) Instrumentation for Impact Test – Part 1 – Electronic Instrumentation, Rev March.

SAE J1727 (1996), Surface Vehicle Recommended Practice, Injury Calculations Guidelines, Issued August.

SAE (1998), Society of Automotive Engineers, User's Manual for the 50th Percentile Male Hybrid III Test ATD, ATD Testing Equipment Subcommittee, SAE Engineering Aid 23, June.