SOME DESIGN REQUIREMENTS FOR SIDE IMPACT DUMMIES INTENDED FOR LEGISLATIVE TESTING AND RESEARCH

I D Neilson and R W Lowne

Transport and Road Research Laboratory

on behalf of EEVC ad hoc committee on 'Side Impact Dummies'

1. INTRODUCTION

The purpose of this paper is to report the work that has been going on to produce a side impact dummy which meets the requirements of the various groups working in Europe towards the development of protection in cars for their occupants against side impact accidents. The dummy is intended to permit research and development studies to be carried out with a large measure of realism and also to provide a dummy which would be suitable for any regulatory or other test procedure that might be agreed.

The parent body for this work has been the European Experimental Vehicles Committee (EEVC) which set up in 1979 an ad hoc committee to study the side impact dummy situation. Details are given in Appendix 1. The project was able to go ahead because it was accepted by the EEC as a part of its Biomechanics programme. This has now been completed and reported upon. As a result of this a unified European dummy (Eurosid) is now at a late stage of development and it is hoped that further support may be forthcoming to enable the dummy to go into production.

The main intention of this paper is to present the document of the ad hoc EEVC group which states the background requirements which are desirable for any dummy meeting these stated objectives. The document is not the performance specification because these details have been constantly under review as new biomechanic results have become available. However the present paper includes a list of the relevant biomechanics papers including some on acceptable levels of injury tolerance to the various side impact injuries suffered by human beings. The dummy is being prepared to match up with the most appropriate of these findings. Section 2 gives the history of side impact dummies. Section 3 is the discussion of the desirable requirements for side impact dummies prepared by the EEVC ad hoc committee as a basis for European developments. Section 4 is the bit of research sources for biomechanics data which are being used by the committee for the design of Eurosid.

2. HISTORY OF SIDE IMPACT DUMMIES

Possibly the first dummy which was especially designed for side impact studies was the TRRL device of the early 1970s which was strictly speaking not a dummy at all but rather a load-measuring device. It was effectly rigid at its thorax and pelvis, but measured force loads at the pelvis, at four rib levels at the thorax and at the shoulder. It also included pelvic, upper spine and head accelerometers. This was a convenient device to use apart from the multiplicity of measurements and the fact that the force measurements needed interpretation for those dummy components which were unrepresentatively rigid.

HSRI developed for NHTSA a complete side impact dummy with arms integral with the chest moulding. Articulating arms would have increased the variability in the measurement of thoracic loadings. Its particular feature is its modelling of the human thorax and the careful placing of accelerometers on it to give representative readings for particular impact situations with the help of appropriate mass balancing.

As already mentioned the EEVC ad hoc group then met to consider future requirements for side impact dummies. These were gradually developed over a series of meetings up until the summer of 1983 and are those given in Section 3.

The EEC Biomechanics Programme enabled three further side impact dummies to be designed and constructed for comparative evaluation. These were:-

1. ONSER 50 Noteworthy for its representation of flexible parts such as the thorax by foam plastic components.
2. APROD (Association Peugeot-Renault). This has been developed through several versions but includes a thorax which deflects inwards in two parts, an abdomen developed by TNO and detailed development of several other components.
3. MIRA SID. Includes a six component thorax, each of which is load measuring and also a load measuring pelvis.

Cadaver and other biomechanic and accident studies from the EEC programme enabled the designs of the dummies to be refined.

A later part of the EEC Biomechanics programme included an extensive test comparison of these three dummies, with the HSRI (DOT) dummy. After analysis it was concluded that none was entirely satisfactory both because of lack of mechanical development and because the anthropomorphic representation was not quite correct. This has led to the EEVC ad hoc group developing a combined dummy comprising the best features of each and arranging for further mechanical development where necessary. The present stage is the testing of pre-production Eurosid dummies (the name given to the final version) and the tuning of the components to match best the latest ideas about injury tolerance. It is hoped that production will follow in 1985.

3. DESIRABLE REQUIREMENTS FOR SIDE IMPACT DUMMIES

The following is the fifth version prepared by the EEVC ad hoc committee. The dummy is required for two purposes:-

- primarily to use as part of a side impact test procedure for vehicle regulations for the assessment of the protection afforded to car occupants. It should be suitable for both the proposed European requirements and for those being suggested for USA and worldwide.
- Secondly, and as a minor objective, to use for research testing into the problem of side impact into cars and the resulting injuries.

Although the specification is intended to suit testing for regulations, it is expected that most features would be suitable for a research dummy with, at the most, the substitution of a few components.

3.1 Purpose of specification

The purpose of this specification is that it should form a basis for the assessment of any dummies produced for side impact testing. It is not a complete formal specification and it certainly does not include a set of drawings, but rather it lays down a set of desirable features. These should ensure that any dummy meeting this specification should sufficiently represent a typical human being that safety design features in cars can be developed and proved by its use.

3.2 General design features

This specification relates to a dummy to be used for side impact testing, which currently is being planned with impacts perpendicular to the heading of the car under test. However, not all impacts into the dummy are likely to be exactly perpendicular and even in such tests the resultant loadings on the dummy are not always perpendicular. The dummy should generally withstand 50 km/h impacts of a car front into a car side with full measurements and no failures of its components. The dummy should perform correctly for impacts fore and aft of perpendicular to head-on from 30° forwards to 20° rearwards of perpendicular so that impact tests perpendicular to a car can be carried out with the confidence that slight asymmetries of loadings between dummy and car can be accommodated. It may be that the dummy is also suitable for frontal impacts and indeed for all directions of impact, but this capability is not required for regulatory test procedures.

The requirements for the dummy are that:-

- it should reproduce the human being in terms of a selected size and corresponding mass and distribution of mass. The dimensions should be based on those of the USFMVSS 208 Part 572 dummy except where there is evidence for more representative figures.

- the articulation of joints and the flexibility of parts of the dummy should be sufficient so as not to distort the response of the dummy for the intended impact conditions.

- the dummy should interact correctly with the vehicle seat and should sit in the seat in a lifelike manner in whichever seating attitude it is placed.

- the dummy should inflict damage on the vehicle similar to that found from human impacts in accidents.

- the dummy should deform where struck in a representative manner as particularly specified for each body component.

- it should be repeatable in use. It is essential that the dummy should always react to a given repeatable impact in the same way so that the same measurements can be recorded. Ideally measurements should be within 5%–10% under identical impact conditions.

- it should give very similar measurements when impacted in similar but slightly different ways. These differences may arise either from slightly different seated positions from test to test, or when the vehicle impact is slightly different from one occasion to another, or when the structural collapse of the vehicle is slightly different.

- measuring devices should be fitted which are appropriate to each injury situation. For example an impact force may be critical only if spread over a small area of contact, whereas it might be acceptable if distributed over a larger area. Similarly, an acceleration may result from forces along more than one load path and so may not measure critical loadings. Measurements should not prevent the dummy response to each local impact being similar to a human response. In particular, measurements should clearly distinguish between loadings which are just above critical from those just below critical for human beings. In other words, the parameters measured should be such that the rate of change of the measurement on the dummy should not be close to zero at the loading corresponding to the maximum tolerable human loading. For the purpose of these requirements the human response should be reproduced to beyond the level required to produce AIS 3 injuries and preferably to record forces at the AIS 4 level. Frangible components are not to be incorporated in the dummy.

- it should be durable. It is strongly desirable that components should not break or fail during testing, not only because of the resulting delays for obtaining spares and for fitting them, but also because the dummy may need recalibration. The dummy must withstand, without failure or permanent set, an overload equivalent to 50 per cent above the average value required to produce AIS 3 injuries. This overload may be force withstood, extra deflection or energy absorbed as may be appropriate for each component.

- it should be cheap to use. The total cost of using a dummy is made up of capital repayment interest charges, the cost of replacing components, costs for calibration procedures and re-setting, if out of calibration. It is desirable that the total shall be relatively low. A major contribution to this is to use as small a number of measurements as is practicable to check the results of the tests.

3.3 Relationship to Part 572 Dummies

It is desirable that parts of the dummy to the present specification are interchangeable with parts of dummies already built to the Part 572 specification. The interfaces shall be:-

- at the mid femur or alternatively at the knee joint
- at the wrist
- at the top of the lumbar spine.

It is suggested that the design matches the 50th percentile Part 572 male dummy in terms of the general dimensions of each component. In general it is desirable to decrease the dummy structural mass and correspondingly to increase the flesh mass in order to improve the representation of the human.

3.4 Notes on mechanical design

These are suggestions which should help to make the dummy more repeatable. They are not requirements.

The dummy should be stronger than the human which it is representing. This means that generally it should not break or permanently deform under loads or energy input up to at least 50% greater than the specified human tolerance levels for each loading. Up to these levels the load/deflection relation should preferably be linear unless this is inappropriate for some aspects of human performance, in which case further consideration is needed. Stops may be used to prevent excessive deflection. The resulting maximum movements should generally be similar to those of humans. When components are deflected beyond the levels for the tolerance loads, the responses should be similar to those for large or particularly strong people.

It is preferable that flexible components should be built without appreciable damping when they are deformed. Their stiffness should be matched to human responses at approximately the test conditions of the speed of impact. Where damping is essential (eg chest), this should be such that repeated tests give closely similar results and should not rely on the response of components which are subject to variation with changes in temperature or after repeated usage. For example, the dummy flesh should be kept clear of joints so that the response depends on the friction built in to the joint itself rather than on the compression of the flesh.

For the sake of uniformity, the instrument design and data processing of dummy accelerations and other responses shall be to the NHTSA standard specification. Forces shall be recorded according to ISO International Standard 6487-1980, channel class 180. Steps shall be taken in the mechanical design of the dummy to avoid metal to metal contacts, except possibly under severe overload conditions because such contacts give unrepresentative ringing responses which obscure the measurements

3.5 Design of components

Head and neck

In real side impact accidents where the occupant is not ejected, the human head is usually injured by:-

- impacting the cant rail above the door
- impacting the glass of the door
- penetrating the glass and striking the impacting object (car, heavy vehicle, roadside tree or other object)
- the impacting object intrudes into the car and strikes the head
- being thrown out of position in a double or multiple impact and striking almost anything within the car.

In test impacts it is likely that the head strikes the glass of the door and does not receive a severe impact.

The head shall be based on the GM Hybrid III head.

Its dynamic response is critically dependent on the design of the neck and the fact that the shoulder is required to move out of the way so that when struck laterally by a flat impactor, the blow is retarded by the pelvis, the thorax and the head, but not by the shoulder. It is desirable that, when the dummy is decelerated laterally through the thorax and pelvis, the neck allows the head to move in a realistic manner, as seen in human volunteer and cadaver tests. Verification of the head impact response shall be by a whole dummy drop test in which the head strikes a rubber covered rigid plate.

For verification purposes the impact shall be selected to give a HIC of approximately 1,000 using the Hybrid III head from the resultant of triaxial accelerometers fixed in the standard position. The design of the neck shall be based on that of the APROD 82.

Shoulder

When struck laterally the human shoulder can deflect, moving somewhat forwards and upwards and so exposing the thorax to a more direct impact. It is possible to fracture the clavicle, but this is not a frequent or very serious injury and so it is preferable for a dummy shoulder to deflect clear of the thorax, leaving a more uniform impact situation for the thorax. The requirement is for a humanlike and repeatable shrugging action of the shoulder which is well defined by the mechanical linkage. The shoulder should include a representation of the clavicle which should support the diagonal seat belt in a correct manner. This movement of the shoulder shall not be impaired for impacts of up to 30° forward or 20° aft of exactly lateral. The shoulder should return to its neutral position which should be a positive location. The resulting inwards movement should preferably be 70mm with a low resistance to compression and a positive stop at the full compression. The resistance to compression should be closely repeatable with no possibility of the mechanism jamming.

Thorax

In side impact accidents the thorax is injured by direct impact on most occasions. There is not usually any crushing by which the occupant is prevented from moving across the centre of the car as he is struck by the incoming door or side of the car. It is a localised blow to the thorax which causes injury, and this together with loads through the spine, determine the sideways acceleration of the torso. The actual blow is usually from the distorted door, which may be of widely varying stiffness depending on whether the part of the door actually striking the thorax is either just a sheet or panel, or a strengthened edge, or is backed by a latch mechanism, or by the colliding object itself. If the blow is from a flat panel, severe injury only occurs when several ribs fracture at almost the same instant. If the door is more distorted the blow is more localised and penetration of the thorax may occur with one or a few ribs being fractured and displaced into the thorax. There is the possibility of the arm providing an element of padding if it becomes sandwiched between the thorax and the door. However this may not often occur because most side impacts are not exactly perpendicular but rather have a forwards or backwards component. This has two effects. It may displace the arm out of the way. It also means that many parts of the door and frame may strike the occupant and not just the area at the side of the thorax.

For side impact testing for legislative purposes it is necessary that the thorax responds not only to exactly perpendicular impacts but also within the range from 30° forwards to 20° backwards from perpendicular.

The actual measurements taken of impact to the thorax should include the Part 572 accelerometer readings which measure the response at the spine at the height of the thorax. Flat impacts to the thorax itself may be recorded by a suitably placed accelerometer with appropriate weighting and damping to correct its response. There are several possible procedures for recording more localised impacts with their lower critical levels of human tolerance.

As a compromise between the complexity of recording loads on many separate ribs and on having a complete thorax in one unit, it is agreed that the dummy thorax should be divided into three separate regions or ribs and the deflection for each rib or region should be measured.

If the total response of the dummy is to be lifelike, it is important that the thoracic response be set up to match the human one. The complete dummy drop test is used to check the lateral performance of the thorax and pelvis. It may also be desirable to check the response with a lateral impact at 24 km/h of a complete dummy into a rigid wall when placed on a rigid smooth seat and seat back.

The durability of the thorax of a dummy could be assessed by repeating the rigid wall lateral impact at 32 km/h if the dummy design permits this degree of overload.

Arm

Injuries to the arms are sometimes reported in side impact accidents but the mechanism of injury is thought to be highly variable although fractures to the humerus are perhaps the most common. It is not proposed that a side dummy should include measurements to the arm as part of a procedure for checking arm impact. However the design of the dummy arm is important because the arm may shield the thorax, but in a highly variable and uncertain way. The purpose of arm design is therefore to ensure that, when correctly set up before a test, the arm does not interfere with the impact on the thorax. Setting-up procedures are of three main types:-

- the upper arm is held in position to the side of the thorax
- the arm is held well forward in an exaggerated driving position so that most of the thorax is directly exposed to side impact
- the hands are attached to the steering wheel so that in some cars the thorax may be protected by the upper arm where in others it may be exposed.

The presence of arms is important to ensure that the correct mass/inertia effects are transferred to the shoulder and spine. The arms should have light but strong simulated bone and heavy simulated muscle.

Because tests show that an arm directly to the side of the body greatly protects the thorax, it is likely that either the arms will be held forwards out of the way or will be lightly attached to the steering wheel (if in the driving position).

Abdomen

Injury to the abdomen in side impact may occur in three slightly different ways. At relatively high speeds of impact the inertial effects of the contents of the abdomen lead to it being relatively resistant to impact but nevertheless ruptures can occur internally. At low speeds of impact the abdomen is relatively soft and large deflections inwards are possible before injury occurs, but the abdomen is susceptible to penetration by projection of sharp objects.

The abdomen should have a humanlike force/penetration characteristic appropriate to the impact speeds at which testing is to be carried out. Measurement of injury potential will be by the detection of penetrations exceeding a predetermined limit, by means of a contact switch.

Pelvis

The pelvic region is liable to serious injury if the pelvis is fractured or if the socket for the femur is damaged in a violent side impact. An actual impact is likely to be into the iliac crest part of the pelvis and laterally into the greater trochanter which loads the joint directly. The load distribution between the two must critically depend on the shape of the impacting surface and its stiffness as it crushes locally. The loading of the iliac crest, being rigid and firmly attached to the torso, can be specified in relation to a human tolerance load. However, although there is more flexibility as the greater trochanter is impacted inwards, it is considered that force is the appropriate parameter for human tolerance. It is important therefore that the shape of the iliac crest and the great trochanter are represented in the pelvis or pelvis and femur design. This design must have a representative skeletal mass directly attached to the likely points of impact and there must be some flexibility in mounting the pelvis to the dummy spine so that excessive impact responses are avoided. Designs of pelvis are likely to have an excessive skeletal mass because the mass of the contents is included in the dummy pelvic shell. The overall response must be tuned to correct for this. The flesh in the area at the side of the pelvis liable to be struck should be sufficient to comply with the likely requirements and sufficiently durable that it should not deteriorate significantly during many impacts with the impactor. Appropriate design of this portion of dummy flesh and use of a suitable material should enable the overall response to be tuned. Two particular features influence the movement of the pelvis and lower body in a side impact. The two lower projections of the pelvis are covered by muscle and sink into the car seat cushion. This interaction tends to prevent lateral motion during impact and so this region of the body must be correctly reproduced on the dummy. The skeletal shape should be accurately reproduced and given a suitable covering. The thighs are liable to major impact in side impact and are often fractured but because the adduction of the human legs at the pelvis is much greater than for current dummies it is not likely that the human occupant will be twisted round as are some dummies, when the thighs are struck. The human probably has about 40° of abduction and adduction and dummies should approach these amounts.

In summary therefore it is concluded that the pelvis must be representative of the shape of the human pelvis at the points of side impact and at the interaction with the car seat as well as at the iliac crests where the seat belt fits around the pelvis. As well as shape, there must be appropriate simulations of skin covering.

For comparison purposes, a Part 572 accelerometer is to be fitted in its usual position. However it does not measure impacting force and it gives misleadingly low values if the pelvis is trapped and does not move laterally.

Upper legs

As stated above, the upper legs are particularly prone to being fractured in side impact accidents in which the maximum intrusion is forwards of the seat, a not uncommon situation. However because of a lack of research and development work to date it is not yet possible to suggest suitable measurements which should be taken. It is suggested that no changes are made from the Part 572 designs apart from the need to ensure suitable measurements to be made of loadings of the pelvis. Such changes may involve the shape of the upper ends of the upper legs and also the characteristics of the simulated flesh. It may however be also necessary to modify the upper legs as well as the dummy pelvis to give 30° of adduction at the pelvic joints to permit a full articulation without twisting the torso. The shape of the great trochanter should be represented either on the leg or on the pelvis.

Lower legs and feet

Part 572 designs are suitable.

It may be noted that where Part 572 components are mentioned, it is generally sufficient that these items should meet SAE 963, except that in all cases they should interface with the existing adjacent Part 572 components.

Lumbar spine

The part 572 lumbar spine is used.

4. BIOMECHANICAL DATA SOURCES FOR USE IN THE DESIGN AND EVALUATION OF SIDE IMPACT DUMMIES

The following are the data sources used for the three preliminary European side impact dummies and for the combined one - Eurosid.

Body Part	Test basis	Parameters used for evaluation	References
Head	Cadaver drop tests. Subject dropped from 1.2m laterally so that head strikes 5mm rubber sheet.	Peak head acceleration Peak impact force HIC	2
Neck	Sled tests with volunteers and cadavers, 22 kph, 7g.	Kinematics - head angle and displacement neck angle.	3,4 5,6,7
Shoulder	Pendulum impact tests on cadavers. 23.4 Kg impactor, 4.3m/sec.	Force-deflection corridor	2,8
	Volunteers (5 subjects) static loading	Maximum deflection under 200N force	9
Chest	Cadaver drop tests. Subject dropped laterally 1m. onto rigid block and 2m. onto padded block.	Force-deflection and deflection-time corridors.	10,11
	Rigid wall sled tests at 15 and 20 mile/h.	Force-time and acceleration-time (spine and ribs) corridors	6,12
	Pendulum impacts to chests of cadavers.	Pendulum acceleration-time corridor. Force-deflection corridor.	13,14
Abdomen	Cadaver lateral drop tests with abdomen impacting a simulated arm rest.	Force-penetration corridor.	15
Pelvis	Cadaver pelvis impact. 17.2 Kg impactor, velocity 9 m/s onto great trochanter of seated cadaver.	Force-time corridor.	16

5. CONCLUSIONS

A useful anthropomorphic dummy for vehicle safety development work is one which enables its users to make progress in designing safer road vehicles. To this end it must be an appropriate compromise, having to some degree some of the characteristics of features such as biofidelity, repeatability, durability and suitable output measurements. It is hoped that the work described suggests those features that are desirable and indicates by implication where some compromises can best be made.

6. REFERENCES

1. Appropriate papers of "Seminar on the Biomechanics of Impacts in Road Accidents", Commission of European Communities, Borschette Conference Centre, Brussels, 21-23 March 1983.

2. PEUGEOT-RENAULT. "Lateral dummy comparison testing" EEC Biomechanics Programme, Phase IV, Project F11, Final Report 1982.

3. EWING, C L, D J THOMAS, L LUSTIC, W H HUZZY, G C WILLEMS and P MAJEWSKI. "Dynamic response of the human head and neck to Gy impact acceleration" Proc. 21 STAPP Conference 1977.

4. EWING, C L, D J THOMAS, L LUSTIC, W H HUZZY, G C WILLEMS and P MAJEWSKI. "Effect of initial position on the human head and neck response to Y impact acceleration" Proc. 22nd STAPP Conference 1978.

5. PEUGEOT-RENAULT. "Development of a more convenient dummy than the Part 572 one for side collisions" EEC Biomechanics programme, Project F10, Phase III, Final Report 1981.

6. NHTSA. Draft side impact dummy requirements. Unpublished.

7. WISMANS, J, and C H SPENNY. "Performance requirements for mechanical necks in lateral flexion" Proc. 27th STAPP Car Crash Conference 1982. SAE p. 831613.

8. TNO. "EEC Comparison testing of four side impact dummies" EEC Biomechanics Programme, Phase IV, Project NL9, Final Report 1982.

9. TRRL. "Shoulder compression under low load of five volunteers" Unpublished data.

10. FAYON, A, Y C LEUNG, R L STAINAKER, G WALFISCH, M BALTHAZARD and C TARRIERE. "Presentation of a frontal impact and side impact dummy, defined from human data" Proc. 7th ESV Conference 1979.

11. TARRIERE, C, G WALFISCH, A FAYON, J P ROSEY, C GOT, A PATEL and A DELMAS. "Synthesis of human tolerances obtained from lateral impact simulations" Proc. 7th ESV Conference 1979.

12. KALLIERIS, D, R MATTERN, G SCHMIDT and R EPPINGER. "Qualification of Side Impact Responses and Injuries" Proc. 25th STAPP Conference, SAE p. 811009, 1981.

13. MELVIN, J W, D H ROBBINS and J B VENSON. "Experimental application of advanced thoracic instrumentation techniques to anthropomorphic test devices" Proc. 7th ESV Conference 1979.

14. EPPINGER, R. "Personal communication" - original data from Ref. 12 study.

15. WALFISCH, G, A FAYON, C TARRIERE, J P ROSEY, GILLON, GOT, PATEL and STALNAKER. "Designing of a dummy's abdomen for detecting injuries in side impact collisions" Proc. Vth IRCOBI Conference 1980.

16. CESARI, D and M RAMET. "Pelvic tolerance and protection criteria in side impact" Proc. 26th STAPP Conference 1982.

APPENDIX 1

Membership of EEVC ad hoc group on side impact dummy

Dr Ardoino	FIAT
Dr Tarrière Mr Fayon	GIEPR
Mr Glaeser Mr Sievert	BAST
Dr Cesari	ONSER
Mr Maltha	TNO
Miss Haslegrave	MIRA
Mr Benjamin	
Mr Lowne Mr Neilson (Chairman)	TRRL

Contributions were made by other organisations and people including NHTSA and Dr Eppinger.