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MOTORCYCLISTS' HELMETS AND VISORS - TEST METHODS AND NEW TECHNOLOGIES

Version: Final report

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Abstract

As the number of motorcycle accidents increase in the UK, an impact to the head continues to be the most significant cause of fatal and serious injuries. Some 80% of all fatalities during motorcycle accidents are caused by head injuries.

The European COST 327 research Action concluded that if helmets could be improved to provide 24% more protection, some 20% of AIS 5-6 casualties could be reduced to AIS 3-4. New test methodologies and limit values were proposed, including performing linear impact tests at an increased speed of 8.5m/s compared with 7.5m/s for the European Regulation ECE 22-05 - an increase in energy of 30%.

A concurrent UK Department for Transport (DfT) funded project, S100L/VF, developed a helmet prototype which was aligned with the COST 327 objectives and achieved more than 60% improved protection during both linear and oblique impacts. It was concluded that if all riders wore helmets with equivalent safety performance, up to 100 lives a year could be saved in the UK.

In response to the findings of COST 327 and S100L/VF, the DfT has funded a research programme with TRL which has overall objectives to improve helmet and visor test methods, evaluate new helmet concepts and devise a consumer information scheme so as to facilitate worthwhile improvements in helmet and visor design to reduce fatal head injuries and mitigate environmental factors.

Given the potential for reducing the number of motorcycle fatalities, the project has considered various mechanisms to delivery safer helmets to the market place. A regulatory impact assessment reviewed three options:

1. Do nothing;
2. Introduce legislation for safer helmets to COST 327 recommendations; and
3. Introduce a Consumer Information Scheme to encourage safer helmets to COST 327 recommendations

It was concluded that a consumer information scheme would provide the most rapid delivery to the market of helmets offering improved head protection and that this could be the first step towards improved regulations in the future.

Executive Summary

From 1995 to 2004 motorcycle fatalities in Great Britain rose from 416 per annum to 585 (40% increase) and serious injuries rose from 5,672 to 6,063 (7%). Consequently motorcycle casualties are an increasingly large proportion of road casualties. Typically 70% of the serious injuries are from head impacts increasing to 80% of the fatality injured motorcyclists. There has also been a 40% increase in motorcycle traffic from 1995 to 2004 compared with a 16% increase in overall traffic for all modes over the same period.

TRL has been contracted by the Department for Transport (DfT) to investigate ways of improving helmet performance. This is the final report of the project S0232VF Motorcyclists' Helmets and Visors - Test Methods and New Technologies.

Previous to this research there had been an EC research Action, COST 327 'Motorcycle Safety Helmets', to investigate motorcyclists' head and neck injuries. The results were used as the basis for this project. A detailed investigation of some 253 motorcycle casualties from the UK, Germany and Finland as part of COST 327 determined that:

- 67% of casualties had head injuries, 73% leg injuries, 57% thorax injuries, and 27% neck injuries.
- Helmet damage was found to be fairly evenly distributed around the helmet with 53.2% being lateral impacts, 23.6% frontal and 21.0% rear. The crown received only 2.2% of the impacts.
- Rotational motion was found to be the cause of 60% of AIS 2 and above injuries and linear motion the cause of 30%.
- An increase in energy absorption of some 24% would reduce 20% of AIS 5 - 6 casualties to AIS 2 - 4.

These findings were used to develop a COST 327 test specification for improved helmet performance.

The DfT objective for the S0232VF project was: "To improve helmet and visor test methods, evaluate new helmet concepts and devise a possible consumer information scheme, so as to facilitate worthwhile improvements in helmet and visor design to reduce fatal head injuries and mitigate environmental factors."

An International Workshop, hosted by the DfT, was held in London to discuss the most effective ways of improving helmet designs and delivering safer helmets to the market place. A consensus was reached on short, medium and long term principal objectives as follows:

Short (2yr):

- Linear impact to include high and low speed tests
- More stringent requirements for the oblique impact test
- Evaluate helmet retention
- Devise a specification for light reactive visor materials
- Implement COST 327 recommendations for an improved Standard

Medium (5yr):

- Accident simulation
- Investigate advanced test tools and headforms including the Bimass
- FE simulation
- Ventilation and noise research.

Long (10yr):

- Research advanced "smart" materials
- Standards to require include ventilation and noise assessment.

On 1st July 2000, helmets conforming to UN ECE Regulation 22.05 became legal for sale in the UK in addition to those meeting BS 6658-1985. Part of this project involved examining the effectiveness of current test methods and in particular those within Reg22.05. Methods prescribed to assess friction and projection (method A vs B), impact site sensitivity, the difference between guided and free-motion headforms and the chin-guard test were examined. All relate to the test methods currently prescribed by Reg22.05 and the enhanced test methods proposed by COST 327.

Test method A is an oblique impact test (based upon BS6658) and B is a new method developed for Reg22.05 that uses a carriage accelerated by a drop weight. The test work showed that Methods A and B do not give equivalent results. Method A is currently the more stringent, particularly for the abrasion test and is representative of accident mechanisms. Method B does not represent the real world since the force normal to the helmet is only 400N when in reality the load is typically 4kN. Of concern is the fact that helmets with an advanced, low friction, outer membrane that slides relative to the shell to reduce rotational motion gave values typically less than 30% of the permitted maximum for method A, yet failed method B.

Reg22.05 specifies impacts at specific sites. Tests away from those sites showed that the permitted value of HIC (Head Injury Criterion) could be exceeded by over 20%. It was concluded that impacts should be specified by test area rather than specific location, which could be achieved by introducing an additional number of impact tests with the test sites chosen by the test house. The prescription for helmet orientation and alignment during the Reg22.05 impact tests has encouraged helmets with sculptured shell geometries, particularly at the rear. Tests showed that this can create a misalignment between the headform centre of gravity and the impact anvil thereby generating falsely reduced linear accelerations during the test, but potentially high rotational head accelerations during accidents. For relatively low linear impact accelerations of 100g the rotational accelerations may exceed 12,500rad/s^2 at which there is a greater than 35% risk of serious or fatal (AIS 3-6) head injury. Test sites specified by area, with addition prescriptions of head centre of gravity relative to the anvil geometric centre would help. In addition, carefully specified design restrictions may also be needed to solve the problem.

It is specified (within Reg22.05) that during the freefall drop test onto the chinguard, the chinstrap may be fully tightened. In many current helmets there is a large gap between the chin and the inner surface of the chinguard and the load may be transmitted to the headform via the neck through the strap rather than through the chin as intended by the regulation. Many helmets failed the test when tested with the chinstrap not fastened. It is proposed that the test specification should be revised to prevent the triumph of fashion over safety. Such helmets could be responsible for many of the 13% (COST 327) and 9% (UK) helmets that research has shown came off the head during an accident.

Investigation using ten subjects showed that if the chinstrap could be pulled over the chin when fastened correctly, the helmet could be ejected during a simulated roll off test; facial geometry determined the outcome. It was concluded that a headform with a better likeness to the human head could be developed for the retention test but, importantly, the end users should be encouraged to assess helmet fit and stability before purchasing a helmet.

Results of tests showed that the twin-wire guided-headform linear impact test method is generally more stringent than the free-motion headform method, with results approximately 4g higher during tests onto an MEP (a reference material). Rotation of the free-motion headform may have contributed to the difference. Furthermore, the guided headform was found to be more repeatable during MEP testing. The variance was 0.94% for the guided headform compared with 2.31% for the free motion headform. In terms of peak linear acceleration, the accuracy of the guided method was ± 4.5g compared with ±10g for the free motion method.

An assessment of the Bimass headform using a finite element simulation showed that helmets optimised for enhanced safety would align with the recommendations of COST 327 and provide good impact performance at both high and low impact speeds. Although Bimass would be suitable for the evaluation of enhanced safety helmets, the assessment did not identify any advances over existing test methods for the optimisation of helmets to COST 327. Due to the limitations, additional cost and complexity of the headform, it is inappropriate to recommend the Bimass as a test tool for immediate use in Regulation or a consumer information scheme.

Low angle sun and sun glare are known to cause discomfort, distraction and loss of clear vision for motorcycle riders. Light-reactive visors may be offered by the industry to solve the problem and although advanced photo-reactive and electro-chromic visors may satisfy the requirements of current Standards this may not be adequate to prevent such visors from becoming hazardous during certain other conditions. For example they could become opaque if the power failed.

TRL experimental results showed that incident light could vary from 100,000 Lux in bright sunlight, to 200 Lux at dawn dusk and less than 1 Lux during night time riding. TRL has developed a range of criteria that should be incorporated into the visor Standard to ensure satisfactory performance. In particular the reaction time should be no greater than 5 s for the transmittance to reach 95% of the final value, for both darkening and lightening, and not less than 80% light transmittance in the event of power failure.

Protocols based upon the above findings have been developed for the Consumer Information Scheme (CIS) referred to as MHAP (Motorcycle Helmet Assessment Programme). Helmets will be tested at velocities up to 9.5m/s, a value at which current helmets are known to exceed the maximum permitted acceleration and HIC (275g, 2400 HIC). The scheme has been evaluated with three current and three advanced prototype helmets. The results have demonstrated that up to 100 lives per year may be saved with advanced helmet designs that achieve high ratings in the CIS.

Within this project it was not possible to consider all scientific opinion and evidence which may influence the integrity of the consumer information scheme protocols. The authors have therefore presented a reasoned rationale for each technical inclusion where possible. The CIS protocols are based on considered scientific evidence and best practice, but TRL could not anticipate all contrasting and determined views which may be held by external organisations. Consequently, the proposed CIS is ready for implementation as a trial scheme thus enabling feedback from interested stakeholders. The credibility of the protocols will be strengthened by this influence and would further the success of a full test programme and publication of the results.

1 Introduction

Between 1980 and 1995, the number of motorcyclist fatalities in the UK fell from approximately 1,000 to 400 per annum. A similar trend was seen for serious injuries reducing from almost 20,000 to less than 6,000 over this period. These figures have since been rising and in the year 2000 there were 572 fatal and 6,312 seriously injured motorcyclists. Although this is somewhat a consequence of increased motorcycle usage, fatal and serious injuries to motorcyclists are an increasingly large proportion of road accident casualties and this is likely to grow further with increased motorcycle popularity. Between 1995 and 2000, the number of licensed motorcycles increased from 594,000 to 825,000 and rose again to 1,060,000 in 2004, (Department for Transport, 2006). Similarly, according to Transport Statistics UK, the level of motorcycle traffic increased from 3.7 billion vehicle kms in 1995 to 4.6 in 2000 and 5.2 in 2004. This shows a 40% increase in motorcycle traffic from 1995 to 2004 compared with a 16% increase in overall traffic for all modes over the same period.

In response to this trend, TRL was commissioned by UK Department for Transport to investigate improved helmet and visor test methods, evaluate new helmet concepts and devise a possible consumer information scheme, so as to deliver improved helmets and visors to the market place, to help meet these targets.

The final report from COST 327, a European Research Action project was a primary reference for this project. The COST action identified important trends in motorcycle accident and injury mechanisms through a detailed analysis of more than 250 motorcycle accidents including experimental replication and mathematical modelling. Amongst the many findings, it was estimated that a 30% increase in energy absorbing characteristics of the protective helmet would reduce 50% of AIS 5 - 6 casualties to AIS 2 – 4. A test specification was recommended which could reduce fatal and serious head injuries by an estimated 20%, based on a 24% increase in impact energy.

A UK research project entitled 'The Protective Helmets: Motorcycle, Pedal Cycle and Human Head Tolerance,' (Chinn et al, 1993), and known as S100L/VF, advanced the work of COST 327. Completed alongside COST 327, this project demonstrated that the proposed improvements in helmet performance could be exceeded using advanced helmet technologies. This project concluded that, with 100% market penetration, this level of improvement in helmet safety would potentially save 100 lives per year in Great Britain alone. The final report for S100L/VF provided a substantial technical reference for this project.

This report details the research conducted to investigate how improved test methods could be used to promote improved helmet designs. The project aims to provide a mechanism for delivering safer helmets to the market place, thus helping the Government achieve published safety targets. The proposed test methodologies are complementary to the recommendations made by both COST 327 and S100L/VF.

A review of current test methods, in particular the European standard UN-ECE Regulation 22.05, has been completed to ensure compatibility with enhanced helmet designs. The principal objective of this project was the development of a consumer information scheme, which could be introduced to facilitate consumer awareness and encourage industry to produce safer helmets.

An essential part of delivering safer helmets to the market place is the involvement of industry. This project was therefore initiated with a workshop in order to liaise and consult with the industry and gain support for the programme to deliver new test tools and, thereafter, safer helmets.

The research programme incorporated a partial Regulatory Impact Assessment (RIA) to validate the potential benefits of safer helmets and to assess the impact on major stakeholders within the helmet industry. It was concluded that a scheme to improve consumer information may be the most effective option for the rapid delivery of enhanced safety helmets to the market place. The cost benefit, of such a scheme was projected to be 3.5 times the initial investment over the first five years. It was further understood that a consumer information scheme could lead to improved regulations in the future.

2 Background

2.1 COST 327

COST 327 was a European research Action on motorcycle safety helmets that brought together the expertise of France, Germany, Hungary, Italy, the Netherlands, Switzerland, Finland and the United Kingdom. The main objective of this work was to establish the tolerance of the human head and neck to the main injuries sustained by motorcyclists and, based on this, to propose a specification for testing the next generation of motorcycle helmets. It was estimated that helmets which meet this standard could reduce motorcycle fatalities by 20% (almost 1000 riders per annum across the European Union).

Accident and injury mechanisms were determined through the detailed analysis of accident data and head and brain injuries. Some of these accidents were also reconstructed experimentally in laboratory conditions, and by way of mathematical modelling. The relevance of criteria used to determine human tolerance to injury e.g. peak linear acceleration, was then be assessed. Appropriate test methods were developed and a test specification suggested based on the findings of the research.

Amongst the many findings, the research action found that nationally, whilst 20% of riders admitted to hospital suffered a head injury (indicating that current helmets offer good protection), 16% sustained a head injury of Abbreviated Injury Scale (AIS) 2-4 suggesting that improvements to helmets could offer worthwhile injury savings.

From some 253 head/neck injury accident cases, the key observations made were;

- 67% of casualties had head injuries, 73% leg injuries, 57% thorax injuries, and 27% neck injuries.
- Helmet damage was found to be fairly evenly distributed around the helmet with 53.2% being lateral impacts, 23.6% frontal and 21.0% rear. The crown received only 2.2% of the impacts.
- Rotational motion was found to be the cause of 60% of AIS 2 and above injuries and linear motion the cause of 30%.
- 12.9% of motorcyclists lost their helmets during the accident sequence.
- Hybrid II and Hybrid III dummy headforms gave better repeatability than the rigid aluminium and wooden headforms. A novel Bimass Hybrid headform gave the most realistic injury prediction.
- When correlating injury severity against test parameters, Head Injury Criteria (HIC) was the most accurate followed by skull-brain relative linear and rotational acceleration as measured by the Bimass headform.
- The peak tangential anvil force recorded during oblique anvil tests using a Hybrid II headform had a linear correlation with rotational acceleration (r=0.97).
- An increase in energy absorption of some 24% would reduce 20% of AIS 5 - 6 casualties to AIS 2 - 4.

These findings were used to develop a test specification for improved helmet performance which is detailed in Appendix B (i).

2.2 Protective helmets: motorcycle, pedal cycle and human head tolerance (S100L/VF)

This project, commissioned by the DfT, was complementary to the COST 327 action. The project recommended revised performance criteria and limit values for the testing of motor and pedal cycle helmets in view of improved understanding of the tolerance of the human head and brain to injury. The work included a study of brain injuries and the reconstruction of helmet damage to establish better tolerance criteria; dynamic tests and mathematical modelling of existing and new materials to aid helmet design.

The development of a prototype helmet demonstrator was a significant output of this project. The helmet, which utilised novel design concepts including an advanced composite shell with low friction layer, was demonstrated to provide improved head protection. Furthermore, it was projected that almost 100 fatalities could be saved in the UK alone. This fatality reduction became a key delivery target of the Governments' Road Safety Strategy for safer motorcycles.

2.3 Project objectives

This project builds upon the work of COST 327 and the previous work for the Department for Transport in project S100L/VF. The aim of this project was set by the DfT in the Invitation to Tender as follows.

- To improve helmet and visor test methods, evaluate new helmet concepts and devise a possible consumer information scheme, so as to facilitate worthwhile improvements in helmet and visor design to reduce fatal head injuries and mitigate environmental factors.

The **specific** project objectives are listed below.

- To hold a discussion workshop allowing frank and open exchange of views on how best to deliver better helmets capable of saving around 100 lives a year.
- To explore the potential for the activities set out within the invitation to tender and identified at the inception workshop, to be taken forward within the EC 6th Framework Programme.
- Produce a partial Regulatory Impact Assessment (RIA) on the options for introducing the COST 327 specifications in Regulations.
- Develop and verify test methods and performance criteria to measure and assess helmet performance as set out in the COST 327 report.
- Evaluate any alternative helmet and visor concepts that offer better protection, ergonomic performance or more efficient protection.
- Research and develop a ready to trial consumer information programme to rate and compare the performance of helmets and visors for head protection and ergonomic factors.

3 Strategic meetings, Inception Workshop and Conferences

3.1 Inception workshop

An Inception Workshop was held at GMH on 21 November 2003 in order to inform the European helmet community of the UK's work programme to advance helmet safety. The workshop allowed the objectives of the DfT programme (S0232VF) to be presented and discussed by delegates from organisations across Europe. Delegates attending the workshop included representatives from; Industry (16 organisations), User Groups (3 organisations), Motor Sport (2 organisations), Research, Testing and Certification (22 organisations).

During the workshop each of the project partners; Department for Transport (DfT), Transport Research Laboratory (TRL), University Louis Pasteur (ULP), EMPA and Health and Safety Laboratory (HSL) presented key project work areas which included advanced helmet technologies, test methods and helmet ergonomics. The future implications to helmet technology and test methods were further discussed and a consensus on the appropriate mechanisms for delivering safer helmets in the short, medium and long term was agreed.

The work shop successfully agreed short, medium and long term objectives for the programme which included the evaluation of advanced test tools and the specification of test methodologies for promoting advanced helmet designs. A report on the workshop which includes these objectives is provided in Appendix A (section iv). A summary of the short term objectives is provided below.

1. SHORT TERM (2 years)

Linear impact performance to include high speed and low speed

Test limits based on COST 327

More stringent limits for oblique impact testing

Development of instrumented head for Method A and correlation with Method B

Helmet retention – evaluation of mechanisms and preparation of point of sale advice

Vision – specification for light reactive visor materials

Durability of 'advanced' materials

2. MEDIUM TERM [5 years]

Real world accident simulation

Alternative tools (including advanced headforms)

Bimass (including test limits)

NOCSAE headform evaluation

FE simulation

Ventilation and noise research

3. LONG TERM [10years]

Smart materials

Ventilation and noise delivery

In addition to agreeing these objectives, a consortium for an EC 6th Framework programme proposal was also initiated. This could provide a vehicle for delivering the short and medium term objectives within Europe.

3.2 Break-point meeting

A Break-Point meeting was held on 8th March 2004 and it was agreed that the programme would continue as proposed. The DfT had wished for certain tasks to be brought forward into FY 2003/04 but it was clarified that the only candidate activity was the purchase of advanced helmets for the evaluation test work. And, as the ‘state of the art’ may advance further by the time of the testing, it was agreed that the purchase option would not be brought forward.

3.3 Meeting with Auto Cycle Union

A meeting was held with Auto Cycle Union (ACU) on 25th March 2004 to discuss the delivery of safer helmets. It was agreed that there was a political will for collaboration between the DfT and the ACU, although the technical compatibilities between road helmets and race helmets required further consideration.

3.4 ESV 2005 – Washington 6th to 9th June 2005

The advanced helmet technology developed, and its potential safety benefits, was presented at the Enhanced Safety in Vehicles (ESV) conference in Washington 2005. The technical paper raised awareness of the significant improvements in advanced helmet technologies which could be achieved but also promoted the UK DfT’s commitment to achieving road safety fatality targets through research programmes and a possible future consumer information scheme (CIS). The technical paper and the presentation are included in Appendix H.

4 European collaboration through Framework Programme 6

Within Europe helmet standards are used to set the minimum requirements for helmet performance in the member states. In order to raise these standards and facilitate significant improvements in helmet and visor design, an appropriate level of support from the helmet industry and European partners is necessary.

To initiate this process, a workshop, held at the beginning of this project was used to inform industry of the project's objectives and the current state of the art concerning helmet safety. The workshop was well supported; the need for further collaborative research was agreed. A concerted effort was therefore made towards obtaining European funding for a further research project under the Framework Programme 6 (FP6). FP6 is a European Commission initiative which supports research activities which strengthen the scientific and technological basis of industry to encourage international competitiveness but also to support EU policies.

TRL was therefore instructed by the DfT to complete a feasibility study to investigate the potential of delivering a proposal capable of achieving FP6 funding. It was considered that such a project could support S0232VF objectives whilst also allowing for the more rapid dissemination and agreement of future actions within Europe in order to support future European legislative change. This study was supported by strong liaison with potential consortium partners present at the workshop and suggested that a strong technical proposal could be delivered.

A call for Strategic Scientific Research Project (STREP) as part of FP6-2003-Transport-3 was identified by the DfT as suitable for the proposal proposed and TRL was subsequently instructed to further develop the proposal through to submission. The proposal focused on the development of new test methods which were appropriate, repeatable and reproducible and suitable for encouraging improved helmet design was conceived. The project built on the recommendations of COST 327 and allowed synergy with the ongoing S0232VF project. The title of the project was HELTEST.

The proposal was submitted to the EC during April 2004 and achieved a very high technical score of 20.5 out of 25 (excluding 'Relevance' score) which would typically warrant acceptance for funding. However, the project was deemed to be "not relevant" for this particular call and was not successful on this basis. It was suggested that the proposal be resubmitted as part of Research Domain 4.13 later that year, and this was conveyed to the DfT for consideration.

The proposal was later revised to take into account of progress within S0232VF, ready for resubmission to the EC with a new title, "HESTER" as part of the call 4.13 in 2005. However, despite a long term need to address European legislation and to target the large European market volume, a short term objective to develop a consumer information scheme within the UK alone, was given highest priority by the DfT. By promoting advanced, safer helmets, it was perceived that helmet manufacturers would rapidly respond to this scheme and consequently fatality reductions could be achieved sooner. Consequently, the DfT decided to support funding of a CIS in preference to the FP6 proposal.

5 Review of current test methods

The harmonisation of National standards to ECE Regulation 22 (with the 05 series of amendments) required considerable political negotiation so that a unified standard could be agreed. This exercise was necessary to encourage less restrictive trade within Europe and also to improve minimum levels of helmet safety across Europe as a whole. However, there is potential for helmet safety to be reduced where superseded National standards are considered to exceed the minimum levels agreed.

The British Standard, BS6658, is one standard which may have been compromised. Particular concerns relate to friction and projection strength assessment since the newly introduced Method B may not be aligned or as stringent as the BS6658 test method (Method A). Also, the discrete definition of the linear impact test sites may compromise performance across the helmet's extent of protection and allow helmets to be optimised to the standard. Since these concerns will have a detrimental effect on helmet safety, TRL has carried out further experimental work within this project to investigate these concerns. This work is further discussed in Sections 5.3, 5.5 and 5.6.

COST 327 has identified that a significant number of helmets are lost during the course of an accident or impact. This may indicate that the helmet retention and stability tests within regulation are inappropriate. Although the concerns are not specific to the Reg22.05 standard, TRL has investigated retention within this project to determine whether there are any technical reasons why the current methods used to assess helmet retention may be deficient. This is discussed in Section 5.2.

A final uncertainty regarding the reproducibility of free-motion headform impact test results has also been investigated in this project. Currently, free-motion headforms are used by Reg22.05 but it is thought that this method may be less repeatable than methods based on guided headforms, such as those used by Snell. Furthermore, guided headforms may be more stringent due to the inability of the headform to rotate during the impact. Any rotation can reduce the energy required to be absorbed by the helmet. The experimental work to investigate the repeatability of these methods is discussed in Section 5.4.

In summary, there are four areas that have been investigated. These are helmet retention, impact sites sensitivity, helmet friction/projection strength (Method A – B) and the stringency of guided and free-motion headforms. All relate to the test methods currently prescribed by Reg22.05 and the enhanced test methods proposed by COST 327, as discussed below.

It should be noted that it was not necessary to consider revisions to the chinguard test procedures. As a result of the COST 327 action, proposals were made for testing chinguards at 5.5m/s with a limit of 275g and 2,400 HIC and these were incorporated into Reg22.05. Further safety performance was not sought since this would require greater forward projection of the chinguard which was not desirable.

5.1 COST 327 Proposals

Based on the findings of the accident data and subsequent experimental research, COST 327 recommended a revised test specification based on new helmet test tools and advanced criteria. The purpose of the specification was to set new targets for helmet standards with an ultimate aim to improve helmet performance (See Figure 5.1).

The recommendations were based loosely around Reg22.05 test methods albeit with new test headforms and revised criteria. Consequently the four areas which have been further investigated by TRL would also apply to this specification.

<table>
<tr><th rowspan="2">Cost 327 Helmet Test Specification</th><th rowspan="2">Test Anvil</th><th colspan="2">Headform Type and Size</th><th colspan="6">Test Sites on Helmet[2]</th></tr>
<tr><th>Metal</th><th>Bimass[1]</th><th>B</th><th>X</th><th>R</th><th>P</th><th>S</th><th>Projections</th></tr>
<tr><td rowspan="4">Impact Velocity[3]
(m/s)</td><td>F (flat)</td><td>A E J M O
A E M O</td><td>
J
J</td><td>8.5
6.0</td><td>8.5
6.0</td><td>8.5
6.0</td><td>8.5
6.0</td><td>5.5[3]

5.5</td><td>-</td></tr>
<tr><td>K (kerbstone)</td><td>A E J M O
A E M O</td><td>
J
J</td><td>8.5
6.0</td><td>8.5
6.0</td><td>8.5
6.0</td><td>8.5
6.0</td><td>5.5[3]

5.5</td><td>-</td></tr>
<tr><td>A (abrasive)</td><td>-</td><td>J</td><td>8.5</td><td>8.5</td><td>8.5</td><td>8.5</td><td>8.5</td><td>-</td></tr>
<tr><td>B (bar)</td><td>-</td><td>J</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>8.5</td></tr>
<tr><td rowspan="4">Test Limits[4,5]</td><td colspan="3">HIC</td><td colspan="6">1000 at 6.0m/s and 2400 at 5.5m/s (S) and 8.5m/s metal headform only</td></tr>
<tr><td colspan="3">Peak Linear Acceleration</td><td colspan="6">180g at 6.0m/s and 5.5m/s (S)
180g at 6.0m/s and 275g at 8.5m/s and 5.5m/s(S) brain for Bimass, resultant for metal headform</td></tr>
<tr><td colspan="3">Peak Relative Linear Acceleration</td><td colspan="6">80g at 6.0m/s and 5.5m/s(S) Bimass headform only</td></tr>
<tr><td colspan="3">Peak Relative Rotational Acceleration</td><td colspan="6">35 000 rad/s^2, Bimass headform only</td></tr>
</table>

[1]based on Hybrid III Motorcycle Anthropometric Test Dummy headform
[2]as defined in UN ECE R22.05, paragraphs 7.3.4.2, 7.4.1.3 and 7.4.2.3 Helmet test sites: front - B
side - X
rear - R
crown - P
chin - S

[3]as defined in UN ECE R22.05.
[4] metal headform commensurate with AIS 2 and AIS 5/6
[5]Bimass commensurate with AIS2

Figure 5.1. **COST 327 Helmet Test Specifications**

5.2 Helmet retention

5.2.1 General

A comprehensive study of motorcycle accidents across Europe, reported by the COST 327 action committee, identified that, for 253 accident cases investigated in depth, 12.9% of helmets were lost during the course of the impact with 1.3% of helmets lost prior to the first impact. Unfortunately COST 327 does not detail specifically the reason for these helmet losses but a need to understand and improve helmet retention is recognised.

COST 327 neither specifies the mechanism of helmet loss or the consequences of ejection. To collect and analyse data suitably complete to derive this level of information would be both expensive and time consuming. In an attempt to rapidly identify possible contributory factors, TRL has undertaken a study as part of this project to investigate helmet fit and retention using real-world motorcycle helmet users. It was intended that the study would consider whether dynamic chinstrap strength and helmet stability tests, currently prescribed by motorcycle helmet standards, are appropriate and representative of these real-world conditions.

A survey was made which included an assessment of the wearer's ability to remove his/her helmet from a normal wearing state. This was considered to be a good indicator of the potential for helmet loss. Further observations relating to helmet wearing and fit were made. To ensure an unbiased result, it was intended that subjects should be randomly selected. However, this was more difficult to achieve than anticipated and consequently only a small survey was completed with just 10 subjects.

Four out of the ten subjects could remove their helmets (or potentially remove with further discomfort) from a normal wearing state. In all cases, the chinstrap was first passed over the chin and the helmet rolled forward off the head. This was considered to be the most likely mechanism for helmet loss, based on the subjects reviewed. Further risk of loss would be expected for open-face helmets.

On balance, the design of the helmet chinstrap and compatibility with the wearer's head and jaw shape were considered to be the most significant contributory factors for potential helmet loss. This is primarily because the fastened chinstrap could be passed over the chin regardless of how the chinstrap was worn i.e. tightness.

Although better consumer information may improve the fit demanded by helmet wearers, current test methods use rigid headforms of fixed geometry, and do not accurately represent the compliance of the human head in severe dynamic situations. Furthermore, the headform geometry may not reflect those of all humans and for cases where the head shape may contribute to helmet loss. A modification to the method may therefore be appropriate once these complexities are fully understood.

5.2.2 Accident data

5.2.2.1 COST 327 data

A comprehensive study of motorcycle accident across Europe was reported by the COST 327 action committee in 2001. The study brought together many data collection and analysis techniques, including on-the-scene accident reporting, computer simulation and experimental replication of accidents, in order to better understand injury and accident mechanisms for motorcyclists.

A significant finding of the study was that, for all 253 accident cases investigated (of which 52 were UK accidents), 12.9% of helmets were lost during the course of the impact. Although only 1.3% of helmets were lost prior to the first impact there is accepted to be a need to improve helmet retention.

The data collected revealed interesting statistics about the number of helmet losses as given in Table 5.1.

Table 5.1. Helmets ejected from motorcyclists heads during accidents

Loss of helmets:		
No	N = 199	85.8%
Yes, not further specified	N = 7	3.0%
Yes, before first impact	N = 3	1.3%
Yes, after first impact	N = 19	8.2%
Yes, after second impact	N = 4	1.7%
Total	232	100%

Source: COST database (100% = all motorcyclists)

The figures represent a considerable problem to the motorcyclist since, without a helmet fitted no head protection would be provided during an impact and the likelihood of a serious or fatal injury is therefore significantly raised. Indeed, UK accident data (Doyle et al, 2003) shows that the risk of serious and fatal (AIS4-6) injuries increases from 5.9% for retained helmets to 23.1% for ejected helmets.

In the UK alone, there were almost 26 thousand reported motorcyclist and pillion rider casualties in 2004 (the Stationary Office, 2004). It may be estimated from these casualty rates and UK helmet ejection rates (see Table 5.2) that almost 1600 (6%) helmets are lost during the impact sequence.

Data collected by COST 327 does not however discriminate between the precise causes of helmet loss, such as incorrectly worn or fastened helmets. However, there were no reports of obvious mechanical failures which suggest that such failures did not occur within the sample. Neither did the study link information about the impact site and severity, to the mechanism by which the helmet was lost, for example, due to high mass of helmet or impact loading in rearward direction. It is not, therefore, possible to attribute a frequency to any particular cause or failure mechanism.

COST 327 does however stipulate that all riders were adhering to the appropriate national law for helmet wearing at the time of the accident and, therefore, it may be assumed that the helmets were in working order (i.e. chinstrap fitted and fastener working). Although this does not necessarily verify that all the helmets were worn correctly, it does indicate that fundamental issues with helmet fit and design may influence helmet retention. To better understand these mechanisms and determine how to reduce the incidence of helmet loss, a further study was devised as follows.

5.2.2.2 UK data

Motorcycle accident data collected in the Strathclyde area of Scotland have been analysed (Doyle et al, 2003) as part of the S100L/VF project and similar trends to those observed in COST 327 have been reported.

In this study of 210 motorcycle accidents, helmets were not retained for 9% of 143 casualties where a helmet was known to be worn. When including some 59 cases where it was not possible to ascertain if the helmet was worn prior to the accident, the number of helmets ejected was 6% of the total.

Table 5.2. Helmets ejected from motorcyclists heads during accidents (UK data)

Loss of helmet:		
No	N = 143	66.5%
Unknown	N = 13	27.4%
Yes	N = 59	6%
Total	215	100%

Source: Strathclyde Southern General Hospital database (100% = all motorcyclists)

Interestingly, this study also considered the outcome to the rider, where helmets were lost, in terms of head injury. It was shown that, where the helmet was retained 5.9% sustained a serious or fatal head injury (AIS 4-6) whereas the value was 23.1% where the helmet was ejected. This highlights the importance of helmet retention to head injury outcome.

Although the mechanisms of ejection were not documented, rider age was analysed. It was found that 62% of the helmet losses occurred for riders in the 20-29 age groups. No helmets were ejected for riders above 50 years old. Although this may be somewhat attributable to exposure rates, the 30-39 year old category which has similar exposure rates to that of the 20-29 years age group (50 samples compared with 54) had only a 7.7% ejection rate. Although it was not possible to determine the exact cause of these losses, this data is indicative of possible head geometry or helmet misuse issues which could relate to age and experience.

5.2.3 Review of current retention assessment test methods

The importance of retention has been recognised by many motorcycle helmet standards around the world. These standards have addressed the issue by including chinstrap strength and helmet stability tests. The requirements of the current European (ECE Reg22.05), British (BS6658), American (DOT FMVS218) and Snell (Snell M-2000) are given in Table 5.3. Apart from the FMVS218 standard, the standards require similar dynamic strength test of the chinstrap system and helmet stability test. The stringency of the tests is not discussed here but it should be noted that only the Snell standard prescribes a rear and forward roll off test.

A study by the Head Protection Research Laboratory (Thom et al, 98), has looked at the test method used by Snell in anticipation of an improved FMVSS standard. The novel study focused on the validation of the test method using human subjects. The study highlighted a particular concern relating to open face helmets that did not provide significant resistance to forward roll-off, due to the absence of a chin bar. The study found good correlation between the human and standard tests but did not discuss the fit or chinstrap adjustment during these tests and it is not know whether the helmets differ from those currently on market.

A similar experimental investigation of helmet retention completed in COST 327 focused on the test method and the sensitivity of the method to chinstrap tightness. Completed using a novel test headform with a load cell fitted in the chin-section; the loads during a Reg22.05 regulation type test were measured statically before and dynamically during a standard regulation pull-off test. A conclusion that the chinstrap pre-tension influenced the potential rotation on the headform was made.

Although these studies investigate the validity of current test tools in terms of repeatability and reproducibility they did not address all the fundamental concerns about the mechanisms of helmet loss and how these may differ between a rigid test headform and the compliant human users. Neither did they address the potential misuse and abuse of helmets and their chinstraps which may contribute to the retention problem.

5.2.3.1 Instrumented retention headform

As part of this project, an instrumented retention headform was procured to allow future investigations into the effectiveness of current test methods with consideration of evidence obtained through the subject trials. The headform, manufactured by AD Engineering – Italy, was a revised version of the headform used within the COST 327 research.

COST 327 developed an instrumented test headform with a piezo-resistive load cell within the chin to measure chinstrap forces at 37º to the vertical axis of the headform. It was shown that the chin-strap static pre-load may influence the outcome of a roll-off test and should therefore be specified in a test procedure. The maximum force onto the chin during a dynamic retention test was also measured and was thought to be linked with risk of neck injury.

A tri-axial load cell has now been incorporated into the revised model to allow the measurement of the static and dynamic loads exerted on the chin by the chin-strap in all directions. This is important as the loads tangential to the load cell mounting face may be significant due to the variable loading direction due to chinstrap routing or helmet rotation.

The chin section provided was designed to maintain the ISO (size 57) headform geometry with the load cell fitted. This chin section is however interchangeable with other chin parts so that alternative geometry or compliance could be used to achieve a more realistic representation of the human head.

Figure 5.2 shows a diagrammatic view of the headform and components.

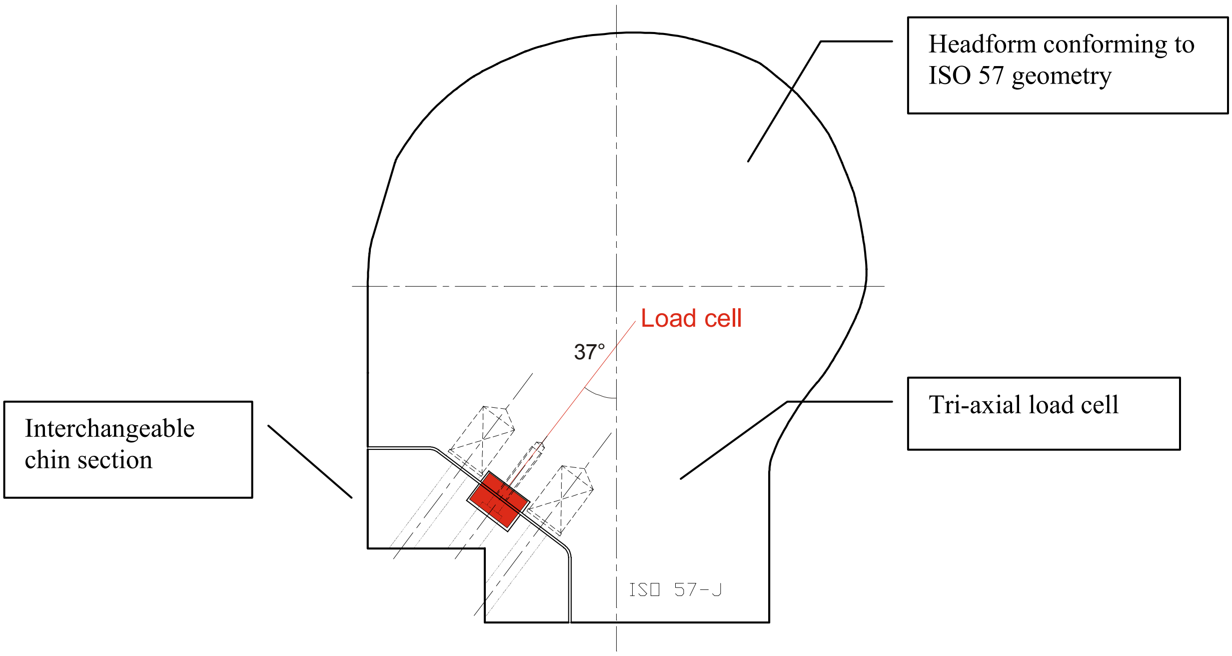

Figure 5.2 Instrumented headform devised for Reg22.05 retention test

Table 5.3. Summary of retention test methods

Standard	Year	Dynamic Strength test			Failure criteria		Positional stability		
		Preload	Test Mass	Drop height	Maximum dynamic extension	Maximum residual extension	Test type	Test mass & drop	Limit
BS6658	1985	7kg	10kg	750mm	1st test 32mm 2nd test 25mm	16mm 8mm	Forward roll-off	10.0kg, 750mm drop	Stay on headform
Snell M2005	2005	23kg	38kg	120mm	30mm	n/a	Forward & rear roll-off	4.0kg, 600mm drop	Stay on headform
ECE 22.05	2002	15kg	10kg	750mm 1	35mm	25mm	Forward roll-off	10kg, 500mm drop	No more than 30º rotation
FMVSS 218	2002	**Static test only** 22.7kg for 30s then 136.1kg for 120s				25mm	N/A		

5.2.4 Helmet retention study with subjects

It was evident that more information was required regarding real-world helmet use in order to better understand the likely mechanisms of helmet loss and to establish whether improved helmet design or improved end-user training could deliver enhanced safety. It was intended that this information would also provide the basis of improved test tools to ensure appropriate levels are achieved and maintained.

5.2.4.1 Development of Subject Trials Assessment Method

TRL reviewed recommendations of the UK Auto Cycle Union (ACU) and The British Motorcyclists Federation (BMF) regarding helmet fitment and wearing. These are published as both general end-user information and, in the case of the ACU, form part of the scrutineering requirements for competitive motorcycling events and track-days. The recommendations are essentially the same for both the ACU and BMF.

It was considered that these recommendations should form the basis of a subject trial for two reasons;

1) The recommendations were derived by riders and scrutineers with first-hand experience of the actual problems relating to helmet use

2) To consider whether these current recommendations are appropriate. A primary feature of both recommendations is that the helmet must be examined for security on the head by trying to remove the helmet from the user's head while the chinstrap is fastened. This is same mechanism examined by test in the current helmet standards.

A subject trial was thought most appropriate as it would allow information to be collected for real-world helmet use and would easily highlight any specific issues for those instances when a poor fit or retention was observed. A helmet stability assessment, similar to the ACU requirements was included in these trials but further detail relating to possible influential factors, such as helmet design, chinstrap design and adjustment were all necessary.

5.2.4.2 Assessment form

The features of the assessment form provided in Appendix B (ii) are detailed below.

Rider details

Basic details about the rider were recorded including a description of features such as hair length which were thought to be relevant to helmet retention. It was intended that a photograph would be taken of each subject without helmet to make a record of the overall build, but it was considered inappropriate due to the close links with personal information. However, basic geometry measurements were made of the longitudinal length, breadth (lateral length), circumference, and vertical height (top of head to bony tip of chin) of head as depicted by Figure 5.3, parts 12, 14, 15 and 17 respectively.

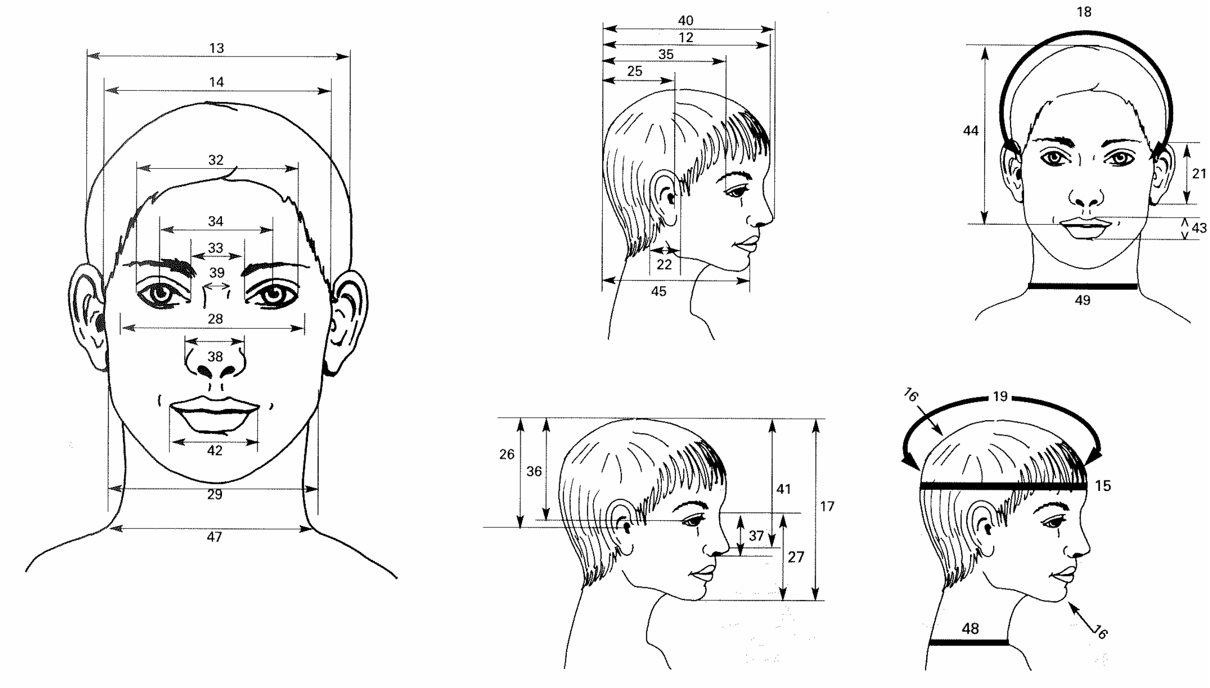

Figure 5.3. Head anthropometric measurements (Source – DTI Adult data handbook)

Helmet details

Key details about the helmet were recorded including make, model, size, certification and condition. Other information regarding chinstrap design was also recorded. An inspection of the correctness and fit of the chinstrap fastening, as worn, was also carried out.

Helmet pull off tests

The series of positional stability (pitch and yaw) tests were made followed by 'pull-off' tests where the subject was asked to try and remove their helmet once it had been fitted in the normal wearing manner. These assessments were completed to simulate possible mechanisms by which the helmet could be lost during an accident.

The helmet fit/stability tests included a front and rear pull off and a lateral rotation estimate. The wearer was asked to try to remove the helmet by pulling from the front and rear and the approximate angle of rotation noted. Similar to assess the lateral fit, the helmet was twisted from side to side.

A further fit test was completed where the rider was asked to try and remove the helmet from his/her normal wearing position by whatever means including movement of the chinstrap, but not by undoing it.

The assessment was relatively subjective and angles of rotation were estimated rather than measured. These were essentially indicative of a good, fair and poor helmet fit. This method was however suitable for detection and correlation between anomalies in design and overall fit helmet.

5.2.5 Subject selection

It was intended that a minimum number of 50 subjects should be included in such a study to establish some confidence in the data collected. It was also important to increase the number of subjects in order to detect any extreme cases which may highlight a particular problem relating to helmet retention.

Since it is unknown from the COST 327 research which mechanism of helmet loss is predominant, it was necessary to randomise the subject selection, thus ensuring that all possible potential combinations for helmet loss could be detected. Consequently all age and gender groups as well as physical attributes such as hair length, build etc were acceptable. Any such features which were considered to influence fit and retention were noted.

To ensure that subjects were suitably randomised, the survey was proposed to be completed at a large motorcycle show where potential subjects could be chosen randomly. Alternative methods of selecting subjects, though riding schools, delivery companies or road blocks, were dismissed as either too expensive to organise or as being likely to bias towards particular rider types e.g. young inexperienced riders.

5.2.6 Results

Data was collected at the 2005 BMF rally held in Peterborough. This is one of the largest annual motorcycle shows in the UK and has in the region of 10,000 visitors. However, only a small sample of 10 people were able or willing to participate in the study. There were several reasons for this poor response;

1) poor weather on the day
2) potential subjects not carrying their helmets due to 'helmet-parking'
3) many visitors arriving by non motorcycle transport
4) participants claimed to have insufficient time

The influence of poor weather and lack of available helmets could have been overcome by operating the trial from inside a helmet parking stall. This however would need to be pre-organised and with additional cost. It is likely that, even with a suitable base, incentives would have been required to entice participants to take part. Such incentives are necessary as visitors will be keen to observe the features of the show. It is suggested that measures to improve the success of future surveys may include (in no particular order);

1) Provision of suitable facilities to minimise inconvenience of bad weather.
2) Increased staff numbers and sites to maximise awareness and turnover.
3) Position sites close to main show features or/and close to entrance and/or exit.
4) Provide suitable incentives to entice subjects.
5) A reduction in time taken to complete the survey.
6) Increased publicity prior to event.
7) Alternative events or pre-organised survey.

Despite the setbacks and small sample size of ten subjects, a spread of subject types, helmets and results were obtained as detailed in Table 5.4, 5.5 and 5.6. The completed forms and photographs are given in Appendix B(ii).

It should be noted that, in order to minimise the time to complete the survey to make it more acceptable to the trial subjects, it was decided that core information would be recorded for all subjects but more detailed information would only be recorded where relevant e.g. additional photos of chinstrap if damaged.

Table 5.4. Subject details

Subject number	Gender	Hair description	Horizontal Circumference [cm]	Coronal Plane circumference [cm]	Longitudinal Length [cm]	Lateral Length [cm]
1	Male	Short	58	66	19.8	16.5
2	Female	Short/Medium	54.3	60	19.8	14.2
3	Male	Short	58	68	21	16
4	**Female**	**Medium**	**55**	**65**	**20.5**	**16**
5	Female	Medium	54	60	19.9	14.5
6	Male	Crew N0.5	56	62.5	20.4	15.6
7	**Male**	**Crew No.4**	**55.5**	**61**	**19.8**	**15.1**
8	**Male**	**Short**	**58**	**66**	**70.8**	**16.5**
9	Male	V. Short (front balding)	58.5	64.5	20.9	16.2
10	**Male**	**Medium**	**59**	**63**	**21.3**	**15.7**

Bold denotes helmet removed during stability assessment

Table 5.5. Helmet details

Subject number	Helmet Make	Helmet Model	Helmet Age [months]	Helmet Size	Helmet Standard	Overall Condition	Padding condition	Chinstrap design
1	Schuberth	Concept	0	54-55	Reg22	New	New	QR plug
2	Shark	S800	0	XS (~54)	Reg22/ACU Gold	New	New	QR plug
3	Caberg	Justistimo	24	L (58-60)	Reg22/ ACU Gold	Good	Good	QR Plug
4	**Caberg**	**Justistimo**	**24**	**M (57-58)**	**Reg22 / ACU**	**Good**	**Good**	**QR Plug**
5	Nolan	Integrali N81	36	XS (~54)	BS6658 TypeA / ACU	Average to Poor	Good	QR Plug
6	Nitro	N800 cU	12	n/a	Reg22.05 / ACU	Good	Good	Double Ring
7	**HJC**	**H8 Scramble**	**0**	**M (58)**	**Reg22.05 / ACU**	**New**	**New**	**Double Ring**
8	**Shoei**	**Synchro Tech II**	**24**	**XL (61-62)**	**Reg22.05 / ACU debadged**	**Good**	**Good**	**QR Plug**
9	Shoei	Synchro Tech II	30	L (58-60)	Reg22.05 / ACU debadged	Good	Good	QR Plug
10	**Shoei**	**XR-900**	**12**	**M (57-58)**	**Reg22.05 / ACU**	**Good**	**Good**	**QR plug**

Bold denotes helmet removed during stability assessment

Table 5.6. Results of stability tests

Subject number	Rear pull angle	Rear pull angle*	Front pull angle	Front pull angle*	Lateral rotation	Lateral rotation*	Anything goes removed?	Anything goes resistance	Chinstrap fastening fit	Comments
1	5º	Low	10º	Low	±5º	Low	No	n/a	Loose (1 finger gap)	Flip chinguard.
2	5º	Low	10º	Low	±5º	Low	No	Very good	Tight	
3	5º	Low	10º	Low	±5º	Low	No	n/a	Slightly loose (1 finger gap)	Slightly loose (1 finger gap)
4	**10º**	Medium	**12º**	Medium	**±5º**	Low	**Yes**	**Removed by chinstrap over chin**	**Very loose (4 finger gap)**	
5	15º	High	10º	Low	±5º	Low	No	Good	Loose (2 finger gap)	
6	10º	Medium	15º	Medium	±5º	Low	No	Good	Loose (2 finger gap)	
7	**10º**	Medium	**10º**	Low	**±7.5º**	**Medium**	**Yes**	**Removed by chinstrap over chin**	**Loose (2.5 finger gap)**	**Subject aged 10 years**
8	**15º**	High	**10º**	Low	**±10º**	**High**	**Yes (with further force - chinguard restricted)**	**May be removed with greater force by chinstrap over chin**	**Slightly loose (1 finger gap)**	Flip chinguard. **Home Office Approved Helmet**
9	10º	Medium	10º	Low	±5º	Low	No	Good	Incorrect fastening, - excessively loose (1 hand!)	Flip chinguard. Home Office Approved Helmet
10	**25º**	High	**15º**	Medium	**±5º**	Low	**Yes**	**Good**	**Slightly loose (1 finger)**	

Bold denotes helmet removed during stability assessment

* Generalised result assigned to observed angles of rotation as follows

	Rear pull	Front pull	Lateral rotation
Low	<=5º	<=10º	<=5º
Medium	10º	15º	7.5º
High	>=15º	>20º	>10º

5.2.7 Discussion

5.2.7.1 General

Although the number of subjects was limited to 10, there was good variety within the group with various helmet styles, hair styles, head sizes and both male and female riders. Furthermore, the results included 4 out of 10 helmet which could be removed by the wearer during the ‘anything goes’ assessment. These helmets were removed by a forward roll-off with the chinstrap passing over the chin. Analysis of the results was used to determine whether there were any particular patterns associated with this method of removal which was thought to be indicative of an increased potential risk of helmet loss.

5.2.7.2 Head/helmet sizing and appearance

The helmet sizes ranged from XS (54cm) to L (61-62cm), although not all manufacturers size markings were visible. This compared to the measured head sizes which ranged from 54cm to 59cm. Based on the maximum difference between the helmet size and the measured head circumference, the difference in size between the head and helmet ranged from +3cm (oversize helmet) to -4cm (undersize helmet).

In four cases where the helmet could be removed by the wearer, the maximum size differential was 2cm or more. This alone was not indicative of an increased risk of helmet loss since helmets which could not be removed had size differentials equal to or exceeding this value.

Based on this data, head size did not appear to influence the quality of fit or increase the likelihood of loss. Similarly, the subject’s hair appearance had no influence, although there may be potential for hair style to have a secondary effect on helmet size selection and therefore the quality of fit for some riders.

The helmet exterior and padding condition had no bearing on the ability of the helmet to be removed for the cases reviewed. This was a significant result as it was thought that deterioration of the padding material may have a detrimental effect on fit. However, the helmets were relatively new and no more than three years old whereas manufacturer’s recommended renewal after 5 years light use.

In one particular case, one helmet had sustained obvious but light impact damage to the helmet shell. Fortunately this helmet was retained on head during both the impact and during the stability trials of this survey.

5.2.7.3 Helmet design

In two instances, subjects were wearing identical helmet models. In both groups, one helmet could be removed and the other could not. This clearly illustrated that the retention capability of a helmet may be dominated by the fit on the wearer and the geometry and compliance of the wearer’s face and head. For both helmets, a typical chinstrap system was correctly fastened and the adjusted tightness did not influence the ability to remove the helmet. Due to the cost and logistics of providing a range of suitable helmets on the day, it was not possible to investigate the fit of alternative helmet designs with the same subjects on this occasion. Such a test may establish whether the removal was primarily specific to the wearer e.g. due to anatomy, or whether particular helmets could be improved to increase compatibility with a larger proportion of end-users.

Only one helmet conformed to BS6658 with the remainder conforming to Reg22.05. This helmet could not be removed by the wearer. Although differences exist between the test methods for Reg22.05 and BS6658, the chinstrap design and condition of the BS helmet were comparable to those observed on the Reg22.05 helmets. It was therefore considered that the standard of certification was unlikely to have been a significant factor to the helmet retention.

It was noted that for one subject, a hinged chin-bar helmet design created a smaller than usual opening (helmet is normally fitted and removed with chin bar open) thus providing a tight fit. The fit was sufficiently close to prevent helmet removal despite the chinstrap passing over the chin. Unfortunately, no open face helmets were included in the subject assessments, but this observation suggests that full face helmets may offer additional resistance to helmet loss once the chin strap is passed over the chin, which open face helmets would not.

5.2.7.4 Chinstrap design

Two types of chinstrap designs were observed; (1) Quick release plug lock and (2) double-d fastening rings. Only two of ten helmets had double-d fastener but all the subjects wore their helmets with a correctly fastened chinstrap. The adjustment of the strap tension varied considerably with one strap tightened to the extent that it would restrict the wearer's jaw movement yet another was sufficiently loose to allow a hand to pass between the jaw and the strap. In most cases a loose strap, sufficient to allow jaw movement and one or two fingers to pass between the chinstrap and the jaw was observed.

There was no direct link between chinstrap adjustment and those helmets which could be removed. In fact, for some wearer's a chinstrap adjusted with a single finger gap could still be passed over the subject's chin and the helmet subsequently removed. Although the looseness of the chinstrap is not critical in enabling the chinstrap to be passed over the wearer's chin, excessive looseness would likely make this easier to achieve and potentially raise the likelihood of helmet loss.

Chinstrap designs and their compatibility with the wearer's head and mandible shape is thought to be significant contributory factors in helmet retention since in all cases where the helmet could be removed, the chinstrap was passed over the bony end of the chin. There was an increased resistance to removal than would normally be required to fit or remove the helmet due to chinstrap catching the mouth and nose, but in most cases the chinstrap could be comfortably passed over the chin. It is believed that during a dynamic impact event, facial features such as the nose and flesh around the neck and face would offer only weak resistance to removal and the discomfort caused would be irrelevant.

It was not possible to determine the significance of head geometry and other secondary factors, such as helmet fit and fleshiness of the facial area due to the small sample size and the need to measure the anchorage points relative to facial features. This must be addressed in a more complete future survey. However, based on the evidence gathered here, it is believed that a combination of end-user factors allow chinstrap relocation over the chin and increase the risk of helmet loss. This would need to be addressed at point of sale rather than through certification process. A possible measure may be improved consumer information since simple checks, such as those recommended by the ACU and BMF, can assist in the selection of better and more suitably fitted helmets. Indeed, one subjects questioned within the survey was shocked by the apparent ease by which his helmet was removed and claimed to have another better fitting helmet that he would consequently be wearing instead.

No proposals for revisions to the Reg22.05 test methods were made following this preliminary study due to the limited amount of data collected. However, it is clear that a discrepancy exists between the flexibility of the human head and flesh, and that of the test headforms may justify more bio-fidelic headforms for future test methods. A headform which has a tri-axial load cell in the chin area and a detachable jaw section was procured within this project and may form a basis of any future investigations. Based on the evidence observed here, changes to test methods should be focused on reproducing a better likeness of the human head to ensure better compatibility and retention in real life.

5.2.8 Conclusions

1) A previous review of European accident data has shown that the risk of helmet ejection may be as high as 12.9% with 1.3% prior to first impact whereas in the UK, this may be lower and between 6% and 9%.
2) A trial of ten subjects has been completed to attempt to establish how factors such as retention system abuse or misuse may contribute to helmet loss. Four users could remove their helmets (or potentially remove with discomfort) from a normal wearing state. For all helmets removed the chinstrap was first passed over the chin and the helmet rolled forward off the head. This was considered to be the most likely mechanism for helmet loss, based on the subjects reviewed. This small sample size cannot provide definitive results but only an indication of potential contributory factors for helmet loss. The certainty of the trends observed is therefore limited and an enlarged subject trial is required to confirm these observations with greater confidence.
3) Trials involving random subjects, carried out in an uncontrolled environment, require significant organisation and incentives to ensure the participation of large subject numbers.
4) Differences between the designated size of the helmet and the wearer’s head circumference were noted. These ranged from a maximum oversize of 3cm to an undersize of 4cm. Only helmets with differences exceeding 2cm were removed by their wearers in this study. This was not considered to be a cause of helmet loss but a possible contributing factor.
5) No open face helmets were included in the study. Such helmets may offer significantly less resistance to a forward roll helmet removal due to the absence of the chin bar. This absence may increase the risk of helmet loss through this mechanism.
6) No helmets over 3 years old were inspected as part of the trial. Helmets above this age may have greater levels of chinstrap wear and it was therefore not possible to ascertain whether this contributes the levels of helmet loss.
7) Based on the subject trial compiled, the design of the helmet chinstrap and compatibility with the wearer’s head and jaw shape were considered to be the most significant contributory factors to helmet loss. It was not possible to quantify the significance of chinstrap design, head geometry and other factors which may contribute to helmet loss, such as helmet fit and fleshiness of the face. It must therefore be considered that a combination of such factors may add to the likelihood of helmet loss. Further data using this method for a greater number of subjects would allow the importance of these factors to be better quantified.
8) Better consumer information would improve the fit demanded by helmet wearers and this may reduce the likelihood of helmet loss. This assumes that the compatibility and fit between the helmet and wearer is a significant contributory factor to helmet loss, as observed during this subject trial.
9) Revisions to the Reg22.05 test methods have not been proposed but may be necessary given the inability of the rigid, fixed geometry, test headforms to accurately represent the compliance of the human head in severe dynamic situations. Also, the headforms can not represent other human head geometries which may be more susceptible to helmet loss. However, the methods are thought to be appropriate for ensuring adequate retention system strength and revisions to test methods may only be necessary if further data confirms that a combination of helmet fit and compatibility with the human head are significant contributory factors to helmet retention.

5.2.9 *Recommendations*

The subject assessment study determined possible links between the helmet retention system design, the wearer's head anatomy and ease of helmet removal. Most importantly, in cases where the chinstrap could be moved over the chin, the helmet could be removed. This was considered to be indicative of helmet ejection potential during an accident event. Clearer information regarding helmet fitment at point of sale could reduce the apparent lack of knowledge regarding helmet fit but this may still not tackle situations where a rider does not influence the helmet choice e.g. an occasional pillion rider or riding partners selecting identical helmets for aesthetic reasons (observed in study).

A further helmet fit assessment study with increased subject numbers should be completed so that all other potential loss mechanisms are identified and greater confidence can be placed on any observation made. The frequency of the loss mechanisms observed could be compared with accident statistics to verify the importance of these mechanisms and to define an appropriate strategy for preventing the helmet losses. A large motorcycle show is a suitable venue for such a study but there would be a need for suitable incentives to improve the likely numbers of participants.

An experimental study using a controlled group of subjects could evaluate links between helmet fit and the ease of removal (as an indication of ejection likelihood). Numerous helmet configurations (e.g. with repositioned chinstrap anchorages) could be investigated to establish whether helmet design could be optimised to prevent helmet loss. Input from manufacturers would be recommended here. Such data would assist in developing new test methods where appropriate.

Reproducing the ejection of helmets in accidents should be attempted in laboratory conditions to investigate the dynamics of these events. This would assist in defining the most appropriate test methodology. A more comprehensive review of accident data would first be required to ensure that helmet loss trends are not due to helmets being incorrectly used or worn. A new method may reflect the potential for slippage of chinstrap over the chin, articulation of jaw and compliance of flesh depending on their individual statistical significance.

5.3 Method A and Method B alignment

In order for UK Government to adopt EC Regulation 22 it was necessary for this Regulation to generally meet or exceed the performance requirements of BS6658. At the time of discussion, BS6658 included an assessment of surface friction and projection strength whereas Regulation 22.04 did not. It was, therefore, necessary for the revised Regulation 22.05 to include such a test. The BS6658 test methodology was included (with slight revisions) as Method A, and a new method, developed by the GRSP advisory group, was included as an alternative Method B.

Method A prescribes a helmeted headform impacting an oblique rigid anvil at a velocity of 8.5m/s thus requiring a fall height of almost 4m (see Figure 5.4). Method B prescribes a stationary helmeted headform which is preloaded against a trolley – the trolley is then translated relative to the helmet by a falling mass and pulley arrangement (see Figure 5.5). The differences between the two methods are numerous, but the objective was for both methods to ensure similar helmet performance in terms of both surface friction and strength of projections.

The methods were introduced on the basis that, although of different principles, the performance assessment would be similar. The aim of this work is to objectively evaluate the extent to which the two methods are aligned for current helmets, and whether both methods are appropriate for the assessment of advanced helmet technologies. It should be noted that Method A more closely simulates real world accident conditions, particularly with regard to surface friction assessment. This will be discussed in more detail later.

5.3.1 *Experimental study*

TRL has previously carried out a theoretical assessment of the stringency of the two test methods to establish whether the methods are aligned. This study concluded that Method B was most stringent for both surface friction and projection strength. However, the analysis made assumptions about the loading mechanisms and the mechanisms by which energy was transferred to the helmet. In reality, these matters are known to be non-linear and too complex to approximate since there may be many interdependent variables. Consequently, an experimental study was necessary to fully evaluate the methods and their suitability for alignment. Also of significant importance was to assess the suitability of the methods for evaluation of advanced helmet technologies for which some configuration parameters are thought to be inappropriate e.g. abrasion length.

Method A and Method B tests were completed using control helmets so that alignment of the methods could be fully explored. The helmets included both current and advanced technologies. For projection testing, the control helmet was fitted with replaceable projection elements, constructed using aluminium and nylon bolts. These were chosen to provide theoretical shear strengths above and below the Reg22.05 limit values.

Initial tests were completed using the Method A configuration to determine baseline levels of performance relative to the standard requirements. During Method A surface friction tests, the helmet is significantly damaged during each test and, therefore, only one test could be conducted on each site. For Method A projection strength tests, and all Method B tests, it was possible to use each site more than once.

5.3.2 Test configuration

5.3.2.1 Method A configuration

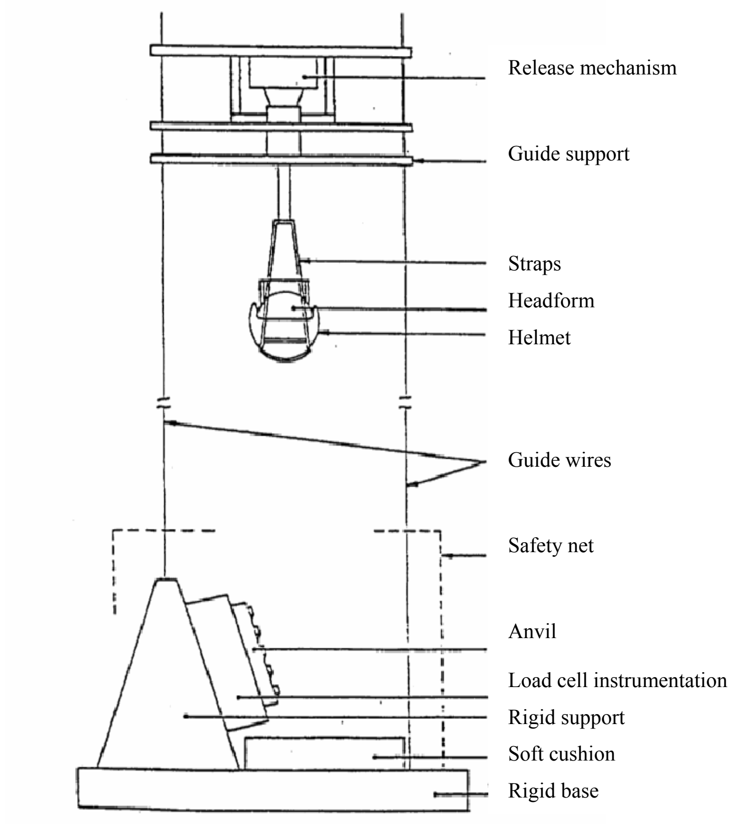

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Figure 5.4. Regulation 22.05 Method A

Standard Reg22.05 Method A tests were completed for both projection and surface resistance. The following parameters were controlled to define an appropriate baseline values for alignment with Method B;

- **Impact speed –** In accordance with Reg22.05 this was fixed at 8.5m/s. During surface friction tests an increased impact speed would increase normal forces and consequently tangential forces (for helmets with constant surface friction). Increased normal forces may influence the scale of mechanical surface interaction and potentially increase surface friction. For projection tests, an increased impact speed would have little effect on the force required to shear the projections.

- **Impact angle –** In accordance with Reg22.05 this was fixed at 15º. During surface friction tests an increased impact angle would increase normal forces and consequently tangential forces (for helmets with constant surface friction). Increased normal forces may influence the scale of mechanical surface interaction and potentially increase surface friction. For projection tests, an increased impact angle would have little effect on the force required to shear the projections.

- **Limit values –** Reg22.05 prescribes limit values for tangential force of 2500N (and 12.5Ns) for projection strength and 3500N (and 25Ns) and surface friction.

- **Test sites –** Within Reg22.05, the entire outer surface of the helmet shell may be tested. For this study, the left and right sides were chosen for surface friction testing, as this permits two equivalent sites on each helmet. For projection tests, the projection elements were positioned midway between the brow of the visor aperture and helmet crown.

5.3.2.2 Method B configuration

Standard Reg22.05 Method B conditions were applied for initial tests. Further tests were carried out with modified impact energies to investigate the response with respect to this variable and the potential for alignment with Method A.

Additional instrumentation was fitted to the falling mass and trolley to determine the full motion and transfer of energy during the test. The residual energy of the moving carriage was used as an indication of the ability of the helmet to meet the pass criteria.

- **Impact energy –** The total potential impact energy of the trolley is dependent on the fall height and mass of the falling elements. The mass of the trolley and the compliance of the tether material will also affect the energy transferred to the trolley. A calibration target speed of 4m/s is defined by Reg22.05 but this is determined without a test helmet fitted. The energy which is ultimately transferred to the helmet is actually dependent on the specific helmet performance – a high friction helmet will stop the trolley more quickly, thus reducing the total fall height and, therefore, the energy imparted.

- **Limit values –** The pass/fail assessment is based on position of the trolley relative to the headform after the test. An abrasive surface of 300mm length is defined for friction assessment and a 6mm high, 25mm wide bar anvil for projection strength assessment.

- **Test sites** – The helmet test sites are restricted by the current configuration of apparatus, due to the head attachment and armature. Although modifications to the apparatus may allow further sites to be investigated this may be difficult to achieve easily due to the need to ensure rigid fixture of the headform during the loading phase.

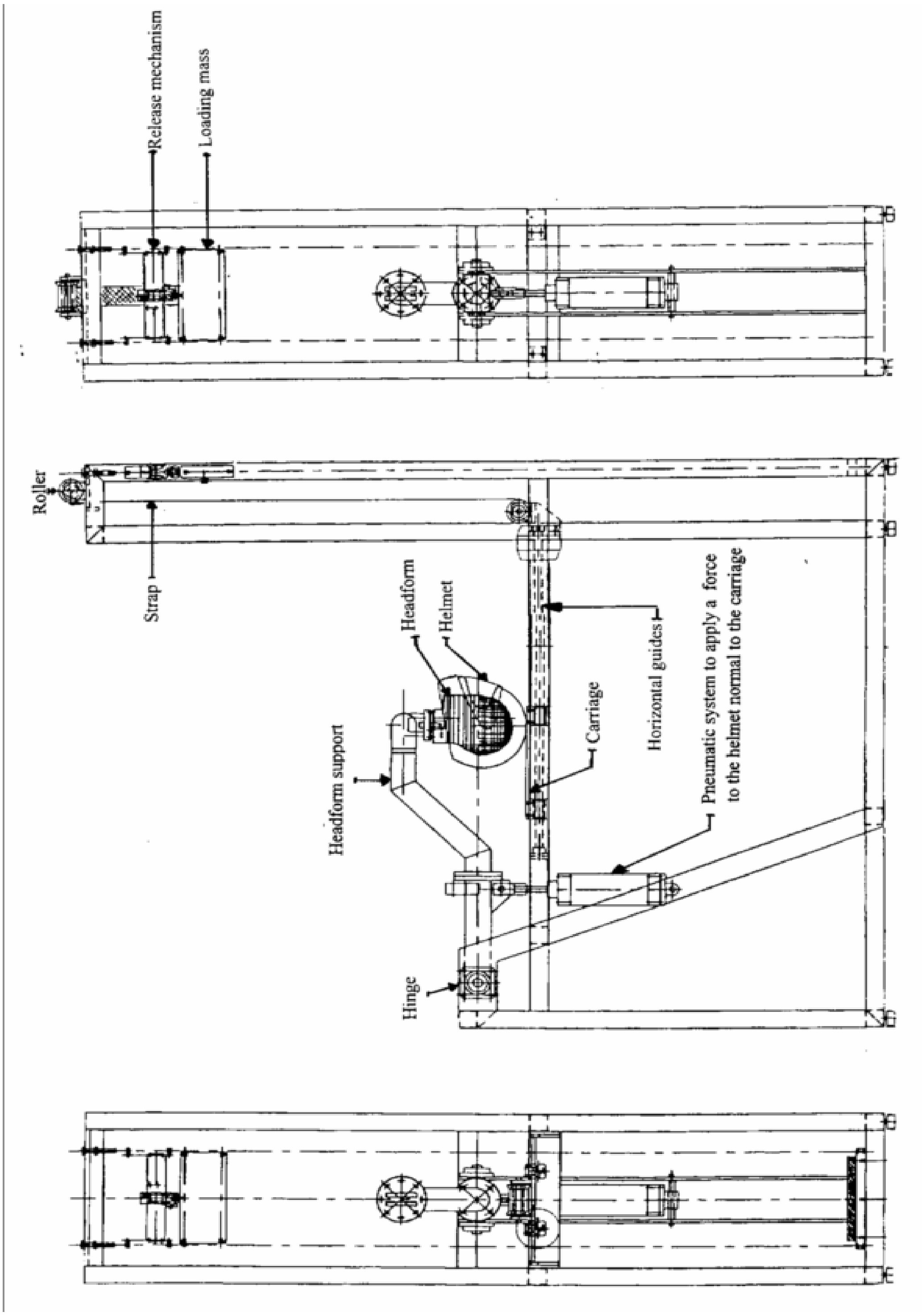


Figure 5.5. Regulation 22.05 Method B

5.3.2.3 *Test schedule*

Initial tests were completed using Method A. An important feature of Method A is that both the input parameters (impact velocity, impact angle, surface texture) and the limit values (tangential force, tangential impulse) may be revised whereas for Method B the input parameters may be revised but the limit values are effectively binary (i.e. trolley DOES or DOES NOT slide past the helmet) and cannot, therefore be revised. For Method A, therefore, it was possible to test the helmets in accordance with the standard and compare the results with the limit values.

For Method B, however, given the results were not graded but just 'pass' or 'fail' it was necessary to modify the input parameters in order to determine the conditions during which a helmet would just-pass or just-fail.

The test matrix for Method B was defined by incrementing the input parameters and retesting each helmet sample until 'just-passed' and 'just-failed' results had been achieved.

5.3.3 Results

5.3.3.1 *Projection testing*

Method A

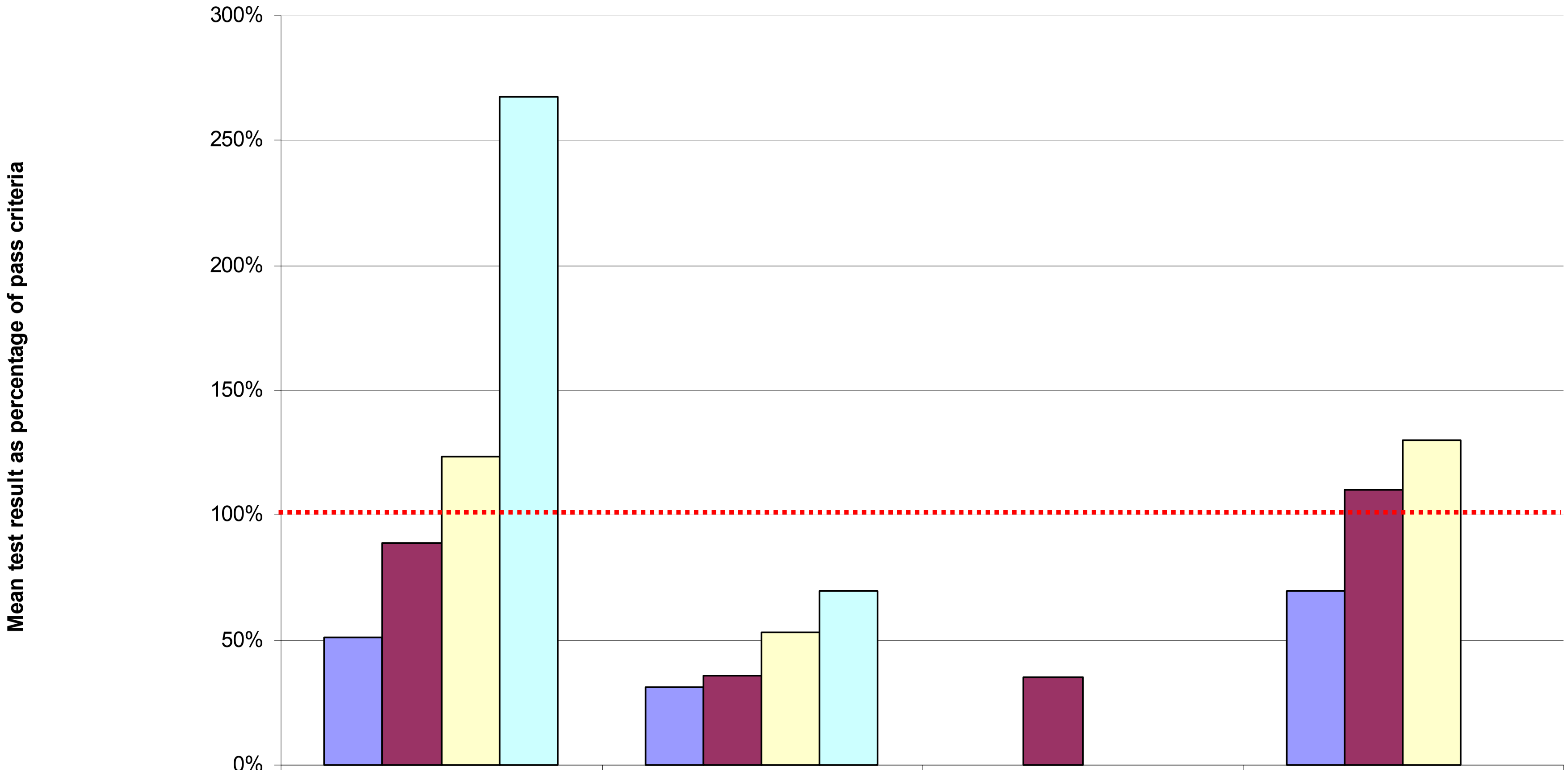
A summary of the results for Method A tests is provided in Table 5.7. Figure 5.6 presents the average value of each projection target as a percentage of the Reg22.05 limit values. The results for the 8mm nylon bolt were approximately 50% Reg22.05 limit of 2500N. The 10mm nylon bolt was close to, but slightly below, the Reg22.05 limit. The 5mm Aluminium bolt gave results both above and below the Reg22.05 limit but the repeatability was poor. The 8mm steel bolt gave results more than twice the Reg22.05 limit.

It was considered that the 10mm nylon bolt gave results closest to the Reg22.05 limit and, therefore, this projection was chosen for the Method B comparison testing. The tangential force results were approximately 10% below the limit values for Method A.

Table 5.7. Regulation 22 - Method A projection tests

Test ref	Projection target	Normal force [N]	Tangential force [N]	Tangential impulse [Ns]	Reg22 PASS/FAIL (2500N / 12.5Ns)
d28jx	8mm Nylon	3225	1415	4.31	PASS
e28jx	8mm Nylon	3482	1124	3.57	PASS
b28jx	10mm Nylon	3375	2215	4.09	PASS
c28jx	10mm Nylon	3493	2242	4.87	PASS
f28jx	5mm Aluminium screw	3510	4029	10.02	FAIL
g28jx	5mm Aluminium screw	2945	2180	5.06	PASS
h28jx	5mm Aluminium screw	3164	3964	3.01	FAIL
a28jx	5mm Aluminium screw	2020	2193	8.55	PASS
a27jx	5mm Aluminium screw	missed target			
i28jx	8mm 8.8 steel bolt	1900	7303	10.39	FAIL
j28jx	8mm 8.8 steel bolt	3510	6082	7.10	FAIL

*Shoei modified helmet with replaceable frangible elements, Bar anvil at 8.5m/s



	Load criteria	Impulse criteria	Method B (standard)	Method B (revised)
8mm Nylon	51%	32%		70%
10mm Nylon	89%	36%	35%	110%
5mm Aluminium screw	124%	53%		130%
8mm 8.8 steel bolt	268%	70%		

Figure 5.6. Results from Method A and Method B projection strength tests

Method B

The results for the first series of tests using the 10mm nylon bolt are given in Table 5.8. The first test was conducted in accordance with Reg22.05 Method B, using a 500mm drop and the 10mm nylon bolt met the requirements. The input energy was reduced for subsequent tests, with drops of 300mm, 100mm and 60mm and the requirements of the test were still met. A final test was conducted with 0mm drop (i.e. static application of 15kg falling mass) and the requirements were still met.

Table 5.8. Regulation 22 Method B (modified) projection tests

Projection	Test ref	Configuration*	Trolley stopped	Reg22.05 Pass/fail	Comments
Ø10mm nylon	c13jx	Reg22.05, 500mm drop	No	PASS	Projection not broken away
	d13jx	Reg22.05, 300mm drop	No	PASS	Projection not broken away
	e13jx	Reg22.05, 100mm drop	No	PASS	Projection not broken away
	f13jx	Reg22.05, 60mm drop	No	PASS	Projection not broken away
	g13jx	Reg22.05, 0mm (static)	No	PASS	Projection not broken away

*Reg22.05 indicates parameters to Reg22 Method B unless otherwise stated.

High speed video which was obtained from these tests was analysed and it revealed that there was significant rotation of the helmet on the headform. Figures 5.7 and 5.8 demonstrate a typical rotation observed during test f13jx. During this test the rotation was 34º (79º - 45º) and the most severe rotation was as high as 50º (test e13jx). A rotation of just 20º equates to approximately 80mm along the circumference of a 250mm diameter helmet. Rotation is significant as it allows the projection to pass over the projection without actually loading the element in shear. This effectively reduces the severity or effectiveness of the test.

To counteract the rotation of the headform straps were fastened around the helmet, and additionally around the headform, to prevent rotation of the helmet on the head and to stabilize the head on the load arm. Figure 5.9 illustrates this configuration. The results from the tests using this configuration are detailed in Table 5.9.

Table 5.9. Method B projection tests (restrained headform)

Projection	Test ref	Configuration*	Trolley stopped	Reg22 criteria	Comments
Ø10mm nylon	f03kx	Reg22.05, 500mm drop, helmet and headform restrained to prevent rotation.	No	PASS	Projection sheared away
	g03kx	Reg22.05, 250mm drop, helmet and headform restrained to prevent rotation..	Yes	FAIL	Marginal fail. Projection sheared away but locked helmet against trolley
	h03kx	Reg22.05, 150mm drop, helmet and headform restrained to prevent rotation.	Yes	FAIL	Projection not sheared away.
	i03kx	Reg22.05, 200mm drop, helmet and headform restrained to prevent rotation.	Yes	FAIL	Marginal fail. Projection sheared away but locked helmet against trolley

*Reg22.05 indicates parameters to Reg22 Method B unless otherwise stated.

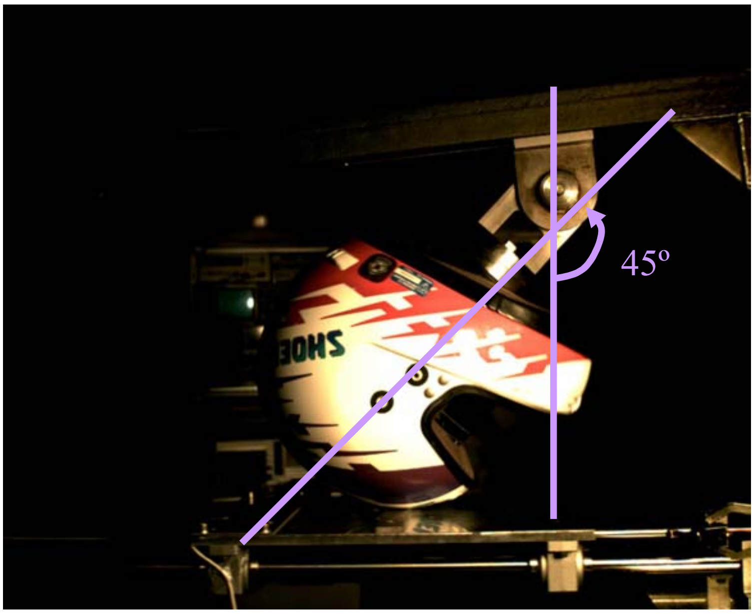


Figure 5.7. Pre impact conditions for Method B projection test f13jx

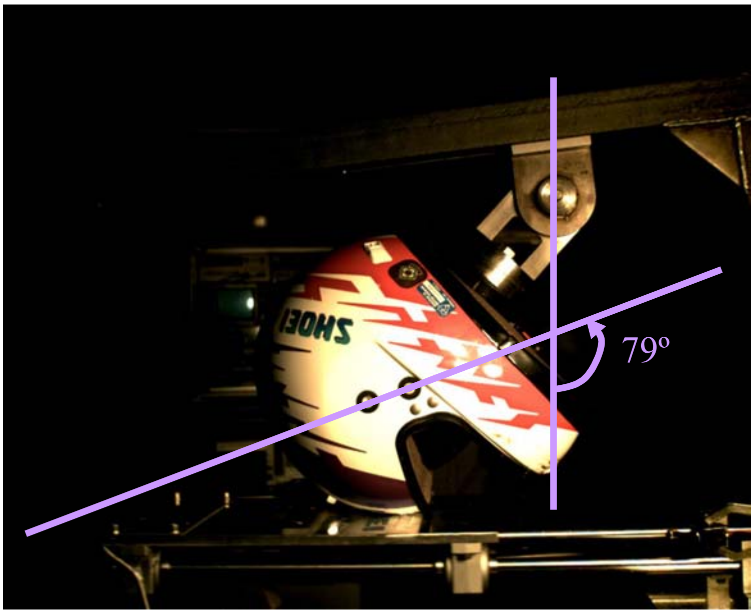


Figure 5.8. Post impact conditions for Method B projection test f13jx

Figure 5.9. Restrained helmet and headform configuration

The results in Table 5.9 illustrate that with the helmet and headform better secured, the loading mechanism on the helmet can be changed to one which is more appropriate for assessing the shear strength of projections. Indeed it was possible to shear the nylon projection at the standard 500mm drop which was consistent with Method A results. The threshold for the projection shear was estimated to be between 150mm and 200mm drop where a ‘marginal’ fail was observed. This is indicative of a pass level approximately 35% in terms of the current input energy. Indeed, closer inspection of Figure 5.11 shows that a similar stringency (based on the test result as percentage of pass criteria) is achieved between the Method A test and the revised (restrained headform) version of Method B.

When using stiffer projection elements e.g. 5mm aluminium nut, it was apparent that the helmet could also pass over the projection due to insufficient clamping load rather than by helmet rotation alone. Additional restraints were therefore used to prevent upward motion of the headform and load arm. As a consequence, normal forces on the helmet could exceed the 400N level set at the start of the test. It was however considered that this was justified in that the Method A tests produced normal forces in the region of 3 or 4kN. Figure 5.10 illustrates this configuration and Table 5.10 details the results of tests in this configuration including tests with a 10mm diameter nylon element.

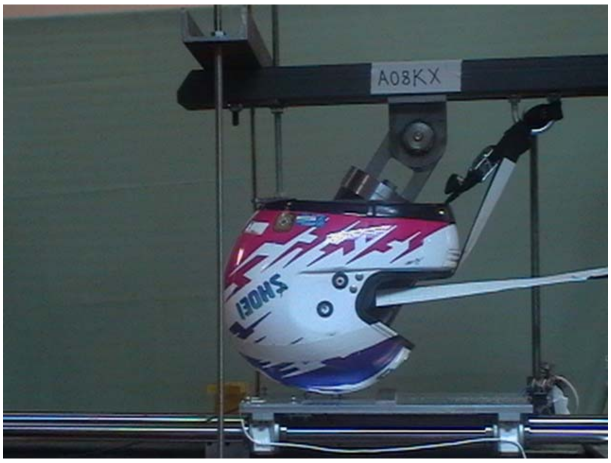


Figure 5.10. Fully restrained apparatus

The normal load was maintained at 400N as the test equipment was neither designed to exceed this or likely to perform correctly with high normal loads. At 3kN the bearing guides would be expected to distort and would prevent smooth sliding of the trolley.

Table 5.10. Method B projection tests (restrained headform)

Projection	Test ref	Configuration*	Trolley stopped	Reg22.05 criteria	Comments
Ø10mm nylon	j08kx	Reg22, 650mm drop, helmet and headform restrained to prevent rotation and translation.	No	PASS	Projection sheared away, residual speed = 3.9m/s
	k08kx	Reg22, 550mm drop, helmet and headform restrained to prevent rotation and translation.	No	PASS	Projection sheared away, residual speed = 3.7m/s
	l08kx	Reg22, 500mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away
Ø8mm nylon	a08kx	Reg22, 500mm drop, helmet and headform restrained to prevent rotation and translation.	No	PASS	Projection sheared away, residual speed = 1.6m/s
	b08kx	Reg22, 150mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away
	c08kx	Reg22, 200mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away
	d08kx	Reg22, 250mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away
	e08kx	Reg22, 300mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away
	f08kx	Reg22, 400mm drop, helmet and headform restrained to prevent rotation and translation.	No	PASS	Projection sheared away (residual speed = 1.6m/s)
	g08kx	Reg22, 350mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Marginal fail. Projection sheared but lodged in helmet stopping trolley
Ø5mm aluminium	h08kx	Reg22, 500mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Projection not sheared away,
	I 08kx	Reg22, 650mm drop, helmet and headform restrained to prevent rotation and translation.	Yes	FAIL	Maximum drop height. Projection not sheared away,

*Reg22 indicates parameters to Reg22 Method B unless otherwise stated.

The use of an additional support to prevent upward translation of the load arm and helmet resulted in a further change to the response of the apparatus when using a 10mm diameter nylon projection. Table 5.10 shows that, in this configuration, the drop height required to shear the projection was between 500mm (fail) and 550mm (pass), thus up to 10% more energy than prescribed by the current Method B test.

Given that an additional 10% more energy was required to fail the 10mm nylon bolt, and the performance of the bolt was 10% below the Method A limit, it may be concluded that the revised Method B (with helmet clamped) was approximately 20% more stringent than Method A.

The 5mm diameter aluminium projections did not fail (i.e. did not shear off) for all test conditions up to the maximum tested of 650mm using the clamped helmet arrangement. This demonstrates that the stringency of Method B was significantly improved by helmet clamping. Given that helmet clamping have been shown to significantly affect the Method B test results, it is important that such variables are agreed prior to further attempts to align the pass/fail criteria of Method A and Method B.

5.3.3.2 Surface friction tests

Method A

The results for Method A surface friction tests are given in Table 5.11. The results show that both current (reinforced glass fibre) and advanced (membrane) helmets met the requirements of Reg22.05 Method A. As would be expected, the membrane helmet gave significantly reduced tangential force values compared with the current helmets results. This is primarily due to the reduced coefficient of friction at the interface with the anvil surface. The normal impact forces were similar for both helmet types, typically 3 to 4kN.

Table 5.11. Method A friction tests

Helmet #	Test ref	Test site	Speed*	Configuration	Normal force [N]	Tangential force [N]	Tangential impulse [Ns]	Reg22
PHPS	a11jx	side	8.5m/s	As Regulation 22.05	4307	1118	4.0	PASS
	b11jx	side	8.5m/s	As Regulation 22.05	4375	1109	3.7	PASS
	c11jx	side	8.5m/s	As Regulation 22.05	4015	882	3.8	PASS
	d11jx	Side	8.5m/s	As Regulation 22.05	4122	911	3.7	PASS
Arai RV / Shoei Z1	a22kx	Side	8.5m/s	As Regulation 22.05	n/a	1724	12.4	PASS
	a23kx	Side	8.5m/s	As Regulation 22.05	4684	2212	12.1	PASS
	d11jy	Side	8.5m/s	As Regulation 22.05	2778	1469	13.1	PASS
	f11ky	Side	8.5m/s	As Regulation 22.05	3181	1806	11.7	PASS

Method B

The results for Method B surface friction tests are given in Table 5.12. The first test completed with the advanced (membrane) helmet (h13jx) *failed* to meet the Reg22.05 requirements. This was despite the drop height being reduced to just 10mm and approximately 5% of the energy required by the standard (based on 500mm drop). The trolley was stopped after 290mm travel and resulted in tearing of the membrane, which then gathered between the helmet and trolley. It was considered that this mechanism was unlike that observed during Method A testing where membrane did not gather and so did not represent the likely in-accident conditions. This result was also considered to be a marginal 'FAIL' and even a slightly higher energy input would likely pass the test. At 500mm the pass result would certainly have been achieved.

A similar test with a 10mm drop height was completed with a conventional helmet as test i13jx. This test also resulted in the trolley stopping but after only 150mm of displacement. Again, this was considered to be a marginal 'FAIL' result and the helmet would certainly pass the Reg22.05 requirement of 500mm drop height. As for the advanced helmet (membrane) test it was estimated that a small increase in energy would achieve a 'PASS' result yet the input energy was estimated to be less than 10% the specified input energy for this helmet (equivalent to 50mm based on 500mm drop).

The two tests described raised some concern about the validity of the test configuration. Firstly since there was significant rotation of the helmet on the headform but also because a 150-290mm contact distance was unlike that achieved in Method A where impact forces causes the helmet to move away. Consequently further tests were completed with the helmet clamped onto the test headform and using a reduced abrasive paper length of just 50mm. this distance was based on an estimation of the length of the contact patch observed during Method A tests.

By reducing the trolley stroke length to just 50mm, the stringency of the test was significantly reduced. The energy required to pull the trolley to the pass/fail point was effectively reduced to around 17% (50mm / 300mm) of the Reg22.05 Method B prescribed energy input, assuming constant resistance over the entire abrasive anvil.

When tested with the trolley stroke length of 50mm, the advanced (membrane) helmet required a drop height of 88mm to just-pass the test. This was approximately 18% of the input energy prescribed by Reg22.05 Method B and higher than may have been expected based on earlier tests. However, the higher result may be explained by helmet clamping which prevented rotation of the helmet and greater effort to move the membrane. However, Figure 5.11 shows that this test result represent a more similar level of stringency to those observed during Method A tests.

When using the same configuration tests (i.e. trolley abrasive paper length of 50mm) for the conventional helmet, a drop height of just 25mm was required to just-pass the test. This is an unexpected result as it implies that the current helmet has a lower surface friction than the advanced helmet and requires only 5% of the input energy (based on 500mm) to pass the test. This is also a differing trend to that observed during Method A. Furthermore the stringency of the test is significantly reduced compared to the standard test configuration. Although this can be in part be associated with the reduced length of abrasive paper used, this is also symbolic that the level of mechanical interaction between the paper and helmet is inadequate, which is probably due to the low normal forces.

A further reason for the inverted trend in stringency between the conventional and advanced helmets is that the advanced helmet generates tangential forces by two mechanisms (1) friction at point of contact via membrane to shell (2) translation of membrane. During Method A testing, and real-world accident conditions, the forces required to translate the membrane are very small in comparison to the normal and tangential forces acting on the helmet. However, as the normal and tangential forces reduce, the forces required to translate the membrane become proportionally larger. This is an important limitation of the Method B equipment for assessing future helmet technology.

These results highlight the importance of the normal force applied during Method B tests and the limitations of Method B for use with advanced membrane helmets. It is necessary to make considerations of these variables before proceeding with further efforts to align Methods A and B. When compared to the standard Method A configuration, Method B represents a 5 times less stringent method for abrasion resistance testing for conventional helmets and between 3 and 6 times more stringent for advanced (membrane) helmets.

A revised Method B configuration can achieve similar levels of stringency as Method A for advanced membrane helmets - approximately 20% of the pass/fail criteria. However, in this configuration conventional helmets can achieve a pass requirement at levels 10 times lower than those required by Method A. This discrepancy further highlights the inadequacies of Method B to correctly simulate impact conditions.

Generally Method B represents a lower level of stringency for both advanced and conventional helmet types. Method A is between 5 and 10 times more stringent for conventional helmets and 2 to 3 times more stringent for advanced (membrane) helmets, even when revised methods with improved helmet restraining techniques.

Table 5.12. Method B friction tests (restrained headform)

Helmet #	Test ref	Test site	Height of falling mass	Configuration	Trolley stopped	Reg22 criteria	Comments
PHPS	h13jx	side	10mm	As Regulation 22.05	Yes	FAIL	Helmet rotation, skin tear, trolley stopped @290mm
	m08kxa	front	0mm (static)	Helmet clamped, 50mm abrasive paper	Yes	FAIL	Helmet stopped trolley and held 15kg mass
	m08kx	front	100mm	Helmet clamped, 50mm abrasive paper,	No	PASS	
	n08kx	front	50mm	Helmet clamped, 50mm abrasive paper,	Yes	FAIL	
	o08kx	front	75mm	Helmet clamped, 50mm abrasive paper,	Yes	FAIL	
	p08kx	front	88mm	Helmet clamped, 50mm abrasive paper,	No	PASS	Skin tore
Arai RV	i13jx*	side	10mm	As Regulation 22.05	Yes	FAIL	Helmet rotation, trolley stopped after 150mm
	q08kx	front	100mm	Helmet clamped, 50mm abrasive paper,	No	PASS	
	r08kx	front	50mm	Helmet clamped, 50mm abrasive paper,	No	PASS	
	s08kx	front	25mm	Helmet clamped, 50mm abrasive paper	No	PASS	
	t08kx	front	0mm (static)	Helmet clamped, 50mm abrasive paper	Yes	FAIL	Helmet stopped trolley and held 15kg mass

* Shoei helmet similar construction to Arai RV used in this test.

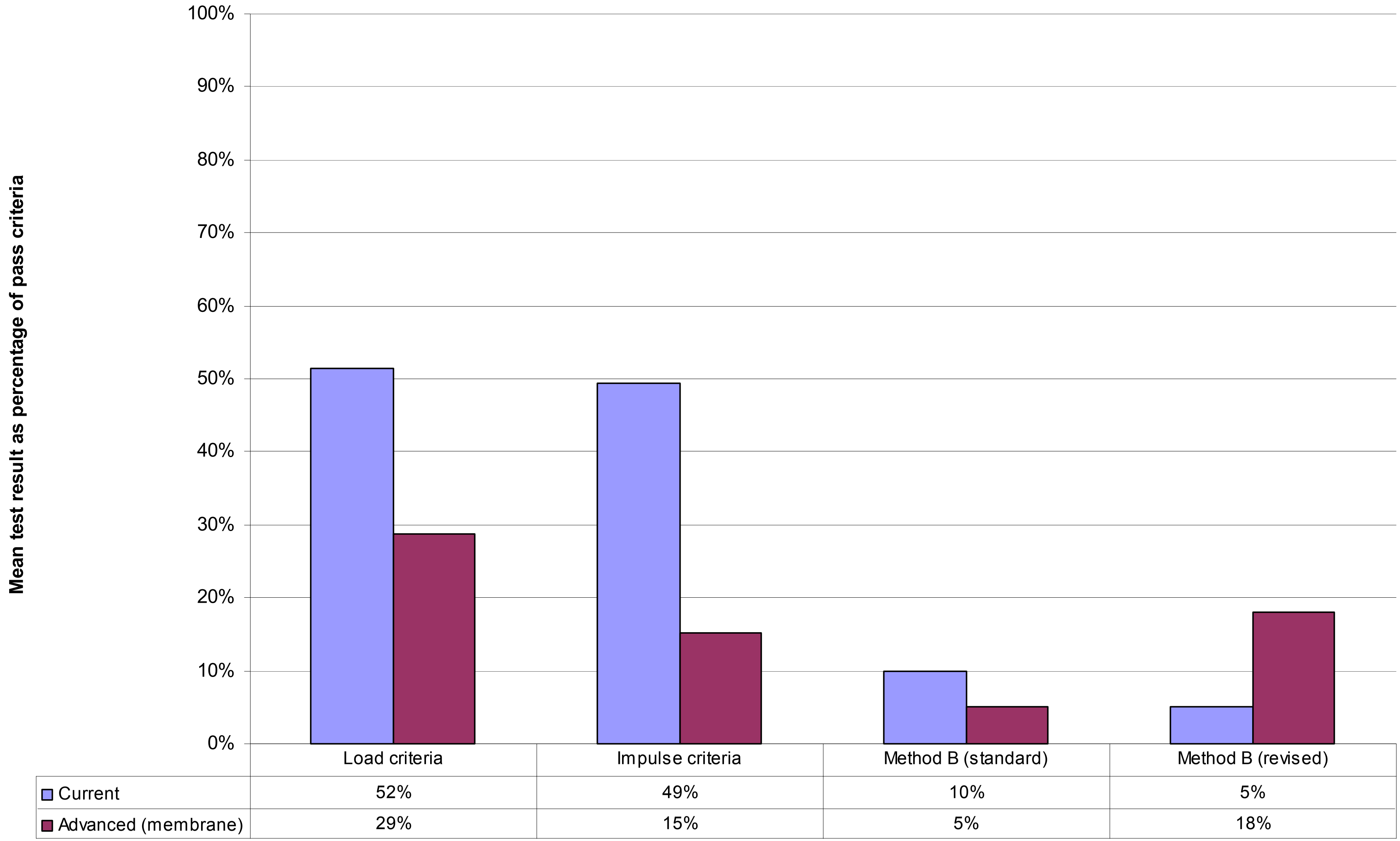


Figure 5.11. Method A friction tests

5.3.4 Discussion

During the course of an experimental study to investigate the stringency of Method A and B and the potential for alignment of this methods, particular issues have been raised about the configuration of Method B and the sensitivity of the test results to apparatus and its configuration. These concerns relate to –

- **Realism** – Method A drop tests are closely representative of the loadings which occur during real life head impacts. The tangential loads which are measured have been correlated with head injury unlike Method B where there is no correlated injury threshold.
- **Helmet stability** – During Method B testing, there was a need to restrain the helmet relative to the headform AND the headform relative to the load arm in order to prevent rotation of the helmet. Such clamps were successful in restricting helmet rotation. During Method A testing, it is far less important to restrain the helmet to headform motion as the kinetic energy of the helmet itself is enough to load and shear the projections without any significant contribution from the headform.
- **Normal forces -** During Method B are almost 10 times lower than those generated during Method A. This can significantly influence the mechanical interaction between the shell surface and the abrasive anvil.
- **Test equipment** – Method B apparatus may affect the helmet loading mechanism. For example, the guide rails may flex and recover thus allowing projections to skip over the test anvil rather than shearing. Also the performance of the apparatus may affect the repeatability and reproducibility of this test e.g. compliance of the tether fabric and friction of trolley guide. Also the track length for Method B tests was considered to be excessive and incompatible with advanced helmet solutions.
- **Impact sites –** For projection testing, Method A may not accurately permit sites to be impacted. Whereas Method B is more accurate, but restricts the sites which may be targeted due to the headform attachment and articulation.
- **A quantitative measure** of helmet performance cannot be achieved with Method B and, therefore, performance limits cannot be revised as Method A permits. However, additional instrumentation to measure trolley acceleration would allow a trolley motions to be calculated and could be used as alternative assessment criteria.

There are a number of configuration parameters that are not specified or controlled by Reg22.05 – Method B including the elasticity of the webbing between the falling mass and the trolley, the securing method between the helmet and headform and the headform to load arm. Also, the friction characteristics of the carriage rails when under load are not controlled. Consequently, there is clear potential for discrepancies in repeatability and reproducibility between laboratories, unless identical test equipment is used. It is essential to resolve such issues prior to aligning the two Reg22.05 methods.

Assuming Method B can be made more rigorous and repeatable using some of the techniques demonstrated, then it is feasible that the alignment with Method A could be achieved for current helmet technologies. A comparable assessment of current helmet technology could then be made and improved criteria established to improve safety. The use of additional instrumentation on the trolley of the Method B apparatus may allow a further quantitative measure of helmet performance (by calculating forces from trolley acceleration) and this could be used as an alternative performance assessment criteria.

However, this work has indicated that the methods may not align for advanced helmets such as those using membrane technologies. In fact when tested using Method B equipment, such helmets are potentially shown to be worse than current helmet technologies. This is very misleading and in strong disagreement with the latest research using instrumented headforms, fitted with nine-accelerometer arrays, which illustrates clear performance benefits of this type of technology. An alternative method which combines the benefits of both current Reg22.05 methods but is suitable for all helmet technologies may be a more appropriate solution.

It is proposed that Method A is the most representative of real life impact conditions and is appropriate for all helmet technologies. It is generally repeatable but test sites, particularly for projection testing, may not be accurately struck. It is difficult to ascertain from test data or post-test helmet-inspection the closeness to the impact site and therefore the validity of such test data. Improved guide and release system could improve accuracy and repeat tests with identical helmets and high speed video would assist in these judgements but may have an excessively high costs associated with them. Method A is therefore best suited for friction assessment but Method B would be the better method for projection testing as it may be configured accurately for even the smallest of projections.

To provide comparative testing, as would be required for a consumer information scheme, Method A is currently the only suitable method for assessment. Method A allows anvil force data to be collected and analysed to provide comparative test data on both friction resistance and projection strength performance.

5.3.5 Conclusions

1) Test work has been completed using both the both abrasion resistance and projection strength test methods described in Reg22.05. This experimental study has determined that Method A and Method B are currently not aligned and that experimentally, Method A is currently the most stringent method.
2) There are a number of fundamental equipment design issues for both Method A and B which must be resolved before the two methods can be aligned. For example, helmet rotation on the Method B test headform was observed to be as high as 50º and severely affects the outcome of the test,
3) A revised and improved Method B could be 20% more stringent than Method A for projection strength tests but would remain 5-10 times less stringent for abrasion testing. Unlike Method A, Method B cannot accurately evaluate the benefits of improved helmet designs as it does not simulate real accident dynamic loading configurations.
4) Method B prescribes a normal clamping load of 400N whereas during Method A tests the normal load may be 4kN. Advanced membrane helmets tested using Method A have results less than 30% of the limit values whereas for Method B these helmets failed. Reduced anvil force is believed to significantly affect the interaction between the helmet surface and the test anvil. This work demonstrated that Method B is not appropriate for assessing helmets with advanced surface technologies.
5) Method A threshold values may be reduced to improve safety. For current helmets the peak tangential force measurements were, typically, less than 50% of the Reg22.05 limit value. In order to revise Method B accordingly, the severity of the test must be reduced as the pass/fail assessment is non-quantitative. For similar reasons, only Method A currently allows helmet performance comparison as would be required for a consumer information scheme.
6) Method A currently allows a greater area of the helmet to be evaluated compared with Method B but requires helmets to be very accurately guided onto the anvil. An alternative method which combines the realism and quantitative assessment elements of Method A with the accuracy and control of Method B may be more appropriate for helmet assessment within both future legislation and a consumer information scheme.

5.4 Guided headform versus free-motion headform

To ensure robust standards, test methods must be both repeatable and reproducible. It is also recommended that any future consumer information scheme should use test methods which are deemed to be the most rigorous. Current test methods utilise either guided or free motion headforms.

Reg22.05 currently prescribes free-motion headforms and yet there is debate whether standards which use guided headforms may be more stringent due to improved repeatability and increased severity of tests with these headforms. It is considered that free-motion headforms may rotate during an impact and this rotation can reduce the energy required to be absorbed by the helmet and consequently lower the peak linear acceleration and HIC. This may be a function of helmet design.

To evaluate these methods, an experimental study has been completed to determine the repeatability of these methods using a modular elastomer programmer (MEP).

5.4.1 Experimental study

5.4.1.1 Test configuration

Linear guided headform

A guided headform, conforming to Snell M2005, was used in this study. This headform is currently used by Snell and is very similar to that prescribed by BS6658. The headform and guide have a total mass of 5.0kg.

This headform operates on two tensioned wires which restrain the motion of the headform to ensure a vertical motion before impact. The guide wires also restrict the motion of the headform during impact and consequently there is little potential for the headform to rotate or translate horizontally. The inability of the headform to rotate ensures that the centre of gravity remains aligned with the centre of the anvil and the helmet impact thus ensuring that the energy absorbed by the helmet is maximised.

Although this is somewhat a function of the guide-wire tension and the alignment of the centre of gravity with the impact site, these are well controlled to ensure that rotation is minimal. For example, the headform and guide are designed so that the headform constitutes a majority of the total mass and a ball joint ensures that the centre of gravity of the system remains immediately above the target anvil regardless of impact site on the headform.

Free motion headform

A free motion headform, conforming to ECE R22.05, was used in this study. The headform had a mass of 4.7kg. This headform is currently used by the Reg22.05 testing. Typically the headform is guided onto the test anvil but is released immediately at impact. This is often achieved using a guide which passes around the test anvil.

During impact tests, Reg22.05 requires that this headform is positioned such that the helmet impact site is aligned with the anvil centre with the target to the surface of the helmet shell, at the point of contact, horizontal. This is significant, particularly for kerb anvils, since the helmet geometry can be used to influence the position of the centre of gravity of the headform above the impact anvil. A misalignment between the headform centre of gravity and the impact site can cause rotation of the headform and a reduction in the linear impact severity. It is believed that some manufacturers may exploit the limitations of the method by designing helmets with severe profiles at the Reg22.05 rear site (discussed in the next section of this chapter). This will offset the headform centre of gravity relative to the impact site and, therefore, reduce the peak linear acceleration.

Although this is of obvious concern for helmet testing, this investigation of was focused on a comparison of the methods both of which could be affected. Consequently headform tests were completed onto an MEP, instead of a helmet. Sites of the headform which were judged to have the lowest resistance to rotation were used so the maximum variation of this test could be observed.

Modular Elastomer Programmer (MEP)

A cylindrical pad, known as a modular elastomer programmer (MEP) was used as a consistent impact surface. The MEP provides a uniform impact surface with highly consistent impact properties. The MEP gives repeatable test results for similar test configurations and can allow different test methods to be compared objectively.

The MEP consists of a polyurethane rubber material, approximately 150 mm in diameter and 25 mm thick with Shore A hardness of 60, and was fixed to a flat rigid supporting plate. All impacts were made into the centre of the MEP.

A target impact speed of 3.8m/s was chosen to produce peak acceleration values of approximately 275g which corresponds to the limit value of ECE R22-05.

5.4.2 Test results and discussion

Table 5.13 summarises the test results from the MEP impact tests using the two test methods (guided and free-motion headform). The following observations about the repeatability of the methods can be drawn from this data.

Generally speaking, the peak acceleration results for the guided headform were very slightly higher than those obtained for the free-motion headform. For all tests, the average guided headform result was 274.2g compared to 270.4g of the free-motion headform. This is despite the average speed being marginally higher for free-motion headform tests than the guided headform.

This difference can be best explained by the increased mass of the guided headform (5.000kg as opposed to 4.811kg for the free-motion head). An increased mass has greater impact energy for the same test speed and causes greater compression of the MEP. This, in turn, increases the force (and acceleration) exerted on the headform. However, it is also feasible that rotation of the free-motion headform may have contributed to this result. In this case, energy is lost as work done to rotate the headform thus reducing the peak linear acceleration. It is expected that rotation is more significant for the free-motion headform and this may, in part, explain the lower results for this headform.

Table 5.13. Summary of impact test results

		Tri-Axis (Free Motion) [1]		Uni-Axis (Guided) [2]	
		Rear45°		Rear45°	
		Speed(m/s)	Peak(g)	Speed(m/s)	Peak(g)
Rear	Test data	3.8	265	3.7	275
		3.8	278	3.7	272
		3.8	268	3.7	279
		3.8	266	3.8	272
		3.8	274	3.7	271
		3.8	277	3.7	277
		3.8	275	3.8	271
		3.8	273	3.8	277
		3.8	274	3.8	272
		3.8	269	3.7	270
	DEV.	0.02	4.58	0.03	3.13
	AVERAGE	3.79	271.90	3.73	273.60
	%	0.64	1.68	0.70	1.15
Side	Test data	3.8	260	3.7	276
		3.8	280	3.7	276
		3.8	267	3.7	277
		3.8	262	3.7	276
		3.8	261	3.7	275
		3.8	261	3.7	275
		3.8	273	3.7	271
		3.8	276	3.7	273
		3.8	275	3.7	276
		3.8	274	3.7	273
	DEV.	0.02	7.52	0.02	1.87
	AVERAGE	3.80	268.90	3.71	274.80
	%	0.40	2.80	0.53	0.68
Both sites	Test data	As above			
	DEV.	0.02	6.25	0.02	2.59
	AVERAGE	3.79	270.40	3.72	274.20
	%	0.52	2.31	0.67	0.94

For impacts onto both sites, the standard deviation was 2.4 times higher for the free-motion headform than for the guided (6.25g compared with 2.59g). Similarly, the variance was some 2.5 times higher than for the guided headform (2.31% compared with 0.94%). In terms of peak acceleration, this meant that results using the free-motion headform had a tolerance of ± 10g (260g to 280g) compared with the guided headform which had a tolerance of ± 4.5g (270g to 279g). Although these results suggest that the guided headform is the more repeatable of the two methods the deviation for the free-motion headform tests was reasonable. Furthermore, the measured deviation may, in part, be due to other uncontrolled variables. A greater data sample would be required to improve the statistical confidence in this data to ensure that there the measured difference were statistically significant.

On closer inspection of the impact tests on similar test sites, a similar trend was observed. The maximum deviation relative to the average peak acceleration observed for free-motion headform tests was 1.68% for rear impacts and 2.80% for side impacts. This compared to the guided headform results of 1.15% (rear) and 0.68% (side). It was also noted that the test on the side was the least repeatable for the free motion headform yet the most repeatable for the guided headform. The average deviation for the free-motion headform was more than four times higher (7.52g) than the guided headform (1.87g) on this test site.

Headform geometry and the moment of inertia are possible contributors to the poor repeatability of side impacts using the free-motion headform. The geometry at this site may be such that the impact force, which acts normal to the impact site, is sensitive to alignment with the centre of gravity. Similarly headform moment of inertia reflects the resistance of the headform to rotation, and may be lowest at the side of the free-motion headform. These contributory factors are less important for the guided headform.

Although test data suggests that the guided headform is more repeatable, the maximum standard deviation determined for the free-motion headform (2.8%) appears acceptable. Furthermore, the sample size of 20 tests limits the confidence that may be placed on these results and there may in fact be no significant differences in the repeatability between the tests. However, it is anticipated that, during real helmet testing, the orientation of the headform will be less well controlled in free-motion headform tests than was achieved in this study. Consequently there will be greater variation in the results due to greater differences in the alignment of the centre of gravity and the impact anvil. This would not occur with a guided headform as the centre of gravity is closely aligned with the geometric centre of the anvil.

On balance, it is therefore considered that the guided headform is the more repeatable of the two headforms. For this reason it is recommended that such a method be adopted for a future consumer information scheme so as to ensure the most repeatable test results, important for ensuring both consumer and industry confidence

5.4.3 Conclusions

1) Guided headform tests were generally found to be more severe that the free-motion headform tests in the configuration considered. Typically guided headform results were approximately 4g higher than the equivalent free-motion tests. Increased impact energy, due tot the greater guided headform mass and rotation of free-motion headforms will contribute to these differences.
2) The guided headform was found to be the most repeatable of the two test methods when impacting onto an MEP. The variance was 0.94% for all tests compared with 2.31% for the free motion headform.
3) In terms of peak acceleration, the accuracy of the guided method was ± 4.5g compared with ±10g for the free motion method.
4) During real helmet tests, it is likely that the repeatability of the free-motion headform would reduce further due to less control of the alignment between the centre of gravity of the headform and the impact site which would increase the tendency for undesirable rotational motion. The guided headform method ensures the headform centre of gravity aligns with the geometric centre of the anvil thus the repeatability should be more similar to the MEP results.
5) It is recommended that guided test headform be used as part of a consumer information scheme to ensure the most repeatable test results.

5.5 Centre of gravity alignment for free-motion headforms

Reg22.05 is a standard which specifies that a helmet must perform in a certain way in order to afford adequate head protection to the user. For example, the standard restricts the load which may be transmitted by helmet projections (using Method A). The helmet performance is assessed through a series of tests which are detailed by the standard. The standard does not define specific design requirements and consequently can ensure a minimum performance for a range of products with diverse and innovative design.

There is however a risk that performance based standards can be exploited by designs which achieve the minimum requirements, but by a means that reduces the overall protection offered to the user. Although this is against the spirit of the standard, this must be viewed as deficiency in the standard to have prevented such loopholes arising.

Partly driven by a demand for original helmet styles and advanced manufacturing techniques, modern helmets use sophisticated helmet geometries which may reduce the overall level of head protection. These helmets exploit, intentionally or otherwise, the current linear impact performance test specified within Reg22.05 since there are otherwise no design restrictions of the helmet geometry.

5.5.1 The significance of helmet geometry for Reg22.05 impact testing

Reg22.05 requires helmet testing using either oblique impacts (ECE R22-05 Method A) or impacts using a high speed trolley (ECE R22-05 Method B) to evaluate friction and projection strength. Only external projection features more than 2mm above the outer surface of the shell are tested during projection tests. However, projection features of the helmet shell itself are not assessed by this method.

Linear impact tests are used to assess linear impact performance at closely defined sites as follows:

B - Frontal
X - Lateral
R - Rear
P – Crown

The impact sites are defined relative to the test headform within a 10mm radius at the shell surface (R50mm for crown) and can be accurately reproduced. These sites may include projections or sculptured helmet shell geometry features. Figure 5.12 shows a conventional styled helmet with the typical location of the rear test site marked (see Figure 5.18 for illustration of other test sites). For all impact sites, the helmet must be positioned so that, at impact, the tangent to the surface of the helmet is horizontal. This is illustrated in Figure 5.13, again for a conventional helmet design.

Figure 5.12. Conventional helmet design
(approximate centre of gravity and rear impact site positions shown)

For these typical helmets the geometry is such that, for all points on the outer surface, the normal to the helmet surface is closely aligned with the centre of gravity of the helmet and headform. The impact force will therefore act closely through the centre of gravity. Torque and helmet rotation during an impact is therefore minimal. The amount of crush of the liner and shell materials and the force on the headform is therefore maximised. The impact can therefore be considered worse case and therefore indicative of the best protection that can be offered to the rider.

Figure 5.13. Conventional helmet in impact configuration
(centre of gravity aligned with impact site)

Generally speaking helmets with the lowest peak accelerations provide the best head protection. However, since the test site is defined relative to the headform geometry and can be determined accurately, it is possible to design helmets with features that improve performance specifically in the test areas. This does not however imply that safety is improved. In fact, such features could disguise the actual impact performance or encourage other dangerous head loading conditions which will be detrimental to the wearer's safety.

5.5.2 Possible deficiency of Reg22.05 linear impact test with respect of helmet geometry

A feature, which has become more common on modern helmets, is sculptured rear geometry. Figure 5.14 illustrates a helmet currently available with this feature. Here, the helmet shell geometry is sculptured around the area of the prescribed rear impact site and has significant implications to the impact test results, possibly to the detriment of end-user safety.

Figure 5.14. Helmet with sculptured shell design
(approximate centre of gravity and rear impact site positions shown)

Essentially, to satisfy the R22-05 test requirements (tangent to shell horizontal) at the rear impact site, it is necessary to rotate the helmet as shown in Figure 5.15. By rotating the helmet in this way, a significant offset is created between the impact site and the headform centre of gravity. During the impact, a significant torque is, therefore, generated about the centre of gravity. This torque causes the helmet and free-motion headform to rotate further during the impact. As the rotation is unrestricted, the helmet may tend to rotate around the anvil with a residual linear velocity, hence even less energy is dissipated by the impact.

This reduction in energy absorbed may be considered desirable by manufacturers as it may help to achieve the limit values prescribed by the standard. However, in reality the performance of the helmet may have been degraded and may not perform safely in real-world conditions where helmet and head motion is restricted by the rider's body and cervical spine.

Rotation induced by the centre of gravity misalignment can also generate high rotational headform accelerations which are known to have a significant contribution to head injuries with a 35% risk of serious or fatal (AIS 3-6) injuries at levels as low as 10,000rad/s².

If we consider the case depicted in Figure 5.15 where the offset, x, is 100mm, the rotational acceleration can be estimated as follows;

Peak rotational acceleration = peak torque (Fx) / moment of inertia (I)

(where peak torque = impact force multiplied by the load arm.)

Assuming that the second moment of inertia for the helmet and headform, I is 0.04kgm² and the peak force is 5kN (corresponding to approximately 100g for a 4.7kg headform), the peak rotational acceleration would be 12,500rad/s². At this level the rotational component of the impact would have a high risk of serious injury (exceeding 35% risk of AIS 3-6) compared with a relatively minor risk associated with the 100g linear component which is equivalent to an injury outcome of AIS 1 - 2 with a risk of fatal injury below 0.4%. This effect can be avoided by a more spherical helmet geometry which provides a closer alignment between the headform centre of gravity and the direction of the impact forces (see figure 5.12). The load arm, x and, therefore, the rotational acceleration component is consequently minimised.

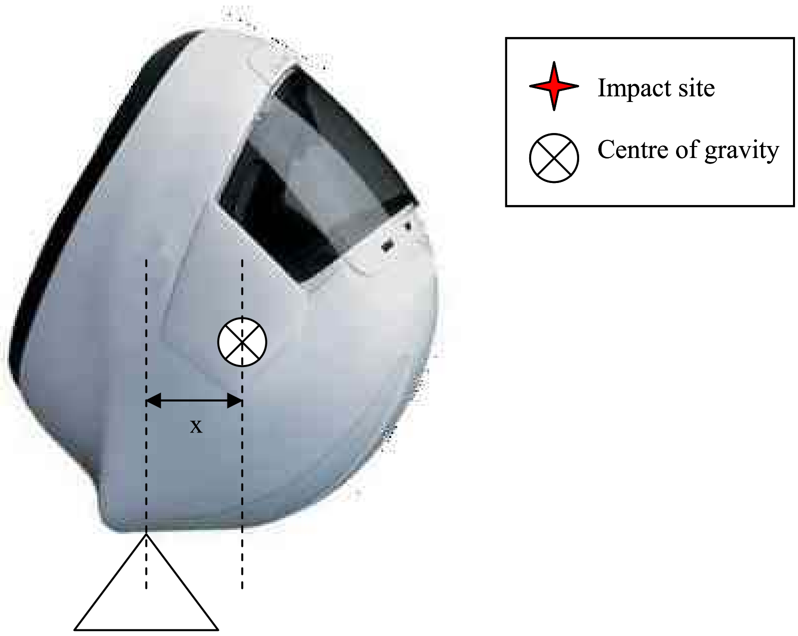


Figure 5.15. Helmet with sculptured shell design (centre of gravity and rear impact site not aligned)

It must therefore be considered that a deficiency exists in the test method as the effect of the centre of gravity misalignment and induced rotational acceleration are not assessed. This may be resolved by better definition of the impact site and conditions or by use of a design specification.

5.5.3 Discussion of possible solution

To maintain a performance specification approach, the test sites and orientation may be defined to ensure that the centre of gravity is directly above the geometrical centre of the test anvil. However this has the potential to create a deficient test since the geometry of some helmets is such that the helmet can skid off irregular shaped test anvils, such as the kerb, Figure 5.16 illustrates the conditions of an impact where the centre of gravity is aligned above the anvil and impact site. In this configuration, friction at the helmet-anvil interface is the only mechanism to react against the tangential forces to prevent slippage. It is therefore important to consider what angle would be expected, between the tangent to the helmet surface and the anvil to ensure slipping off the anvil is prevented.

In the configuration depicted by Figure 5.16, the friction between the helmet and anvil must be sufficient to overcome the forces acting normal to the helmet surface which encourage slippage. This angle is a function of the friction between the helmet and anvil.

At limit of slip, the tangential force,

$$\mathbf{T = N/\tan(Ø) = \mu N}$$

where N is the force normal to the helmet surface, μ is the helmet-surface coefficient of friction and Ø is the angle between the tangent to the helmet surface and the normal to the anvil.

Hence;

$$\boldsymbol{\mu = 1/\tan(Ø)}$$

at the point of at which the helmet begins to slip.

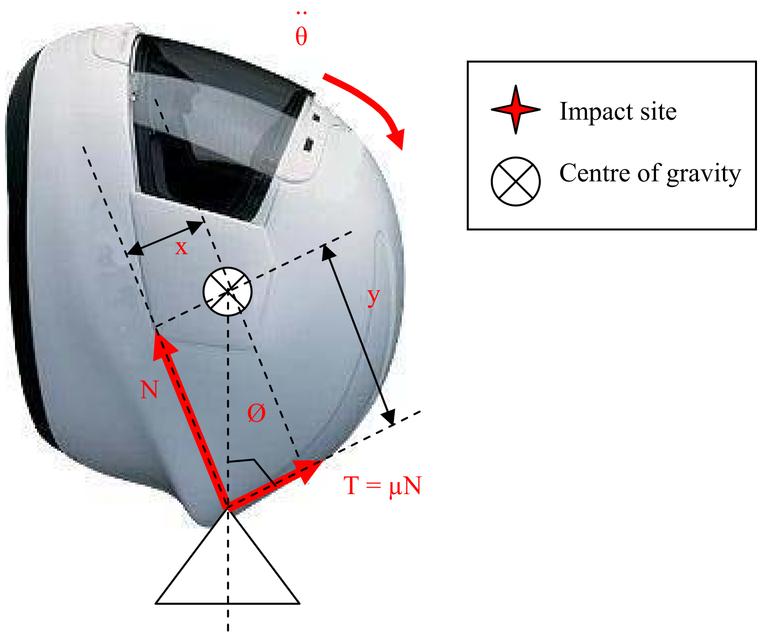


Figure 5.16. Helmet with sculptured shell design (centre of gravity and test site aligned)

The angle Ø is determined by the helmet geometry and there may be helmet designs for which slippage can not be avoided. This is of course dependent on the helmet friction. If we assume that helmet friction is constant and typically around μ=0.6 for a current helmet the maximum angle, Ø, is 60º. Helmet geometries an angle Ø, less than 60º would slip and can not be fairly assessed. Helmets with reduced surface-helmet friction would require the angle Ø to increase towards the maximum value of 90º where the anvil is perpendicular to the tangential of the helmet surface. Hence helmets with reduced friction may be more difficult to test fairly or would need to have less detailed helmet geometries.

The above calculations assume that the centre of gravity is directly above the impact site. An alternative test method would be to ensure that the impact site and helmet geometry are aligned so that the centre of the centre of gravity of the head and helmet is positioned within a narrow 30º cone (for typical μ=0.6 helmet), measured from a line perpendicular to the tangential of the helmet surface at the impact site. Such a configuration is depicted in Figure 5.17. In reality both methods of test configuration may be very difficult to achieve as the position of gravity and the surface friction are unknown. A design specification or a combined design and performance specification must, therefore, be considered as a possible resolution to this problem of sculptured helmet designs.

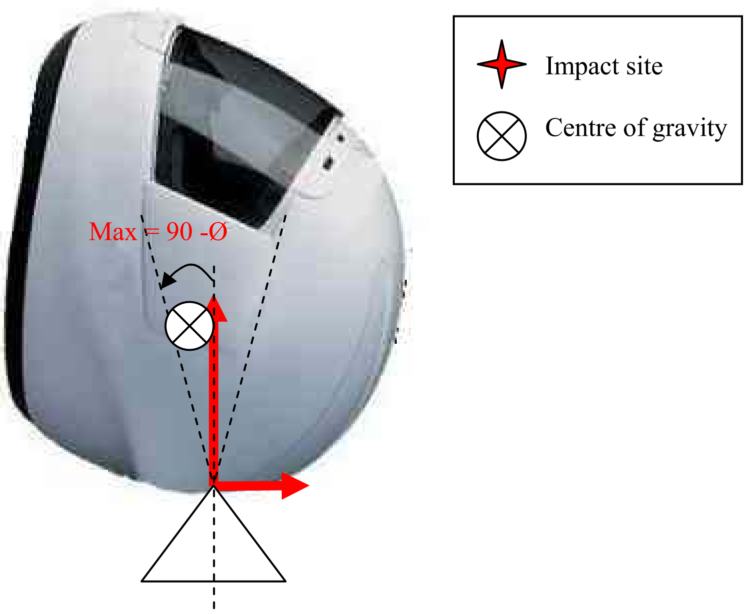


Figure 5.17. Alternative configuration with centre of gravity within cone above impact site

5.5.4 Conclusions

1. Reg22.05 is not design restrictive but defines test methods which measure the performance of helmets to ensure that they offer adequate head protection. The current test methods are deficient in that helmets can be optimised, using sculptured helmet geometries, to more easily pass the prescribed limit values but with a potentially detrimental effect on end-user safety.
2. Sculptured helmet geometry can create a misalignment between the headform centre of gravity and the impact test. This will generate reduced linear accelerations but high rotational accelerations. For relatively low linear acceleration of 100g, rotational accelerations may exceed 12,500rad/s². A 35% risk of serious or fatal (AIS 3-6) injuries can be expected at levels as low as 10,000rad/s².
3. Better definition of impact site and conditions can prevent optimisation of the helmet shell geometry. However, such specifications may be difficult to achieve with a free-motion headform as the centre of gravity would need to be closely controlled within a 30º cone perpendicular to the tangential of the shell surface at the impact site (for helmet with a relatively high friction coefficient of 0.6). The centre of gravity position is also dependant on the helmet's friction coefficient which is unknown. Design restrictions may therefore be necessary, perhaps as a supplement to performance testing, to prevent optimisation.

5.6 Extent of protection and points of impact

Figure 5.18 illustrates a typical motorcycle helmet which conforms to Reg22.05 and offers full face protection. Figure 5.19 highlights areas which have been marked on this helmet that are used by Reg22.05 to define the minimum extent of protection and the points of impact.

The area shown in green is defined as the extent of protection and indicates the minimum area over which the helmet should provide protective energy-absorbing material. This area is defined by a test line which is constructed with reference to the test headform geometry.

Despite this significant area of protection, Reg22.05 does not allow testing across the whole of the helmet's extent of protection. Instead, discrete points of impact are defined, as shown by the red areas shown on Figure 5.19. These sites are also defined by test lines constructed using the test headform.

Generally, the points of impact lie close to the extent of protection but are at well defined points with impacts allowable only within a 10mm range, except the crown area (point 'P') where a 50mm radius range is allowed.

Figure 5.18. Current motorcycle helmet conforming to Reg22.05

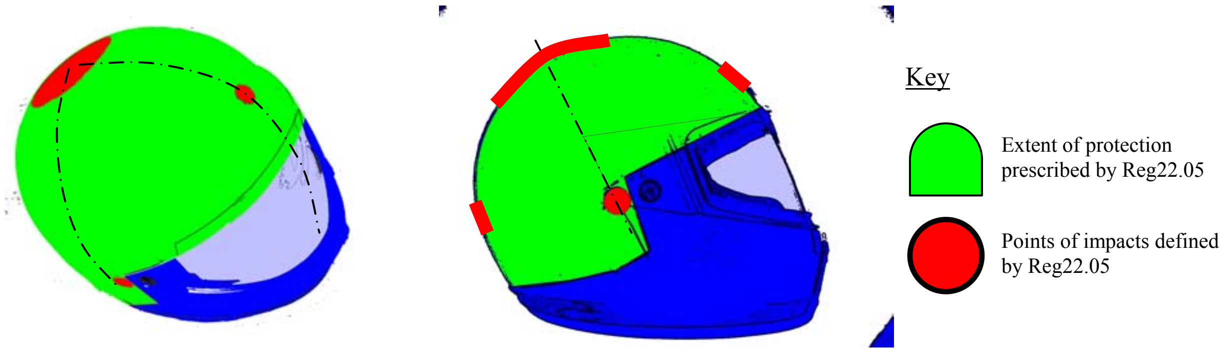


Figure 5.19. Current motorcycle helmet showing designated test areas[1]

The definition of such distinct impact points is unlike the preceding British motorcycle helmet standard; BS6658, and the Snell standard; M2000, which allowed some scope for the test house to evaluate sites which may be less well constructed and consequently compromise the overall protection offered to the wearer. Table 5.14 details the points of impact prescribed by these standards.

Following the less widespread use of BS6658 and the apparent inability of helmet manufacturers to meet both Reg22.05 and Snell standards with one helmet design, concern was raised that advancements in helmet technology and design was allowing helmet protection to be optimised at the discrete Reg22.05 sites. This optimisation, driven by marketing pressures to reduce costs and to include desirable features such as improved ventilation, was viewed to be detrimental to overall

[1] The extent of protection and points of impact for the chinguard have not been illustrated in this figure.

helmet safety since other areas of the helmet may potentially be compromised by this optimisation yet could not be evaluated or regulated by the Reg22.05 standard.

Section 5.5 describes how the definition of discrete impact test can be exploited by sculptured helmet geometries, which reduce the linear impact test severity yet may increase the potential for head injury. In an another extreme case, a helmet could exploit this definition by being designed as four energy absorbing patches at the Reg22.05 prescribed points of impacts and a minimal outer protective shell to meet the extent of protection requirements. Such a helmet would provide reduced and at worst no protection away from these prescribed impact sites. Furthermore, this helmet design would require extremely stiff energy absorbing liner materials to achieve the impact management requirements of Reg22.05 but these may induce potentially more serious head injuries such as a depressed skull fractures.

To investigate whether such helmet optimisations had taken place and were readily available on the UK market, an experimental assessment of current Reg22.05 helmets was undertaken with the test sites away from those defined by Reg22.05. Included in this study was an investigation of the protection offered to the chin during a chinguard impact. Currently Reg22.05 requires that the chin strap should be fastened during the chinguard test (site ‘S’) but this may not properly account for the compliance of the human neck since the test headform is rigid. It is thought that the energy-absorbing material provided within the chinguard may be inadequate if the chinstrap and neck compliance was sufficient to allow the chin to contact the inside of the chinguard during the impact event.

Table 5.14. Helmets selected for impact site study

Sites (in Reg22 test order)	**Reg22.05**	**BS6658-85**	**Snell M2000**
Front	B, in the frontal area, situated in the vertical longitudinal plane of symmetry of the helmet and at an angle of 20° measured from Z above the AA' plane.	Within 25mm of the central longitudinal axis of the helmet.	Above test line but outside 120mm of other test site
Side	X, in either the left or right lateral area, situated in the central transverse vertical plane and 12.7 mm below the AA' plane.	Above AA’ line but not more than 25mm rearwards of the transverse plane through the central vertical axis.	Above test line but outside 120mm of other test site
Crown	P, in the area with a radius of 50 mm and a centre at the intersection of the central vertical axis and the outer surface of the helmet shell.	Other site above AA’ line.	Above test line but outside 120mm of other test site
Rear	R, in the rear area, situated in the vertical longitudinal plane of symmetry of the helmet and at an angle of 20° measured from Z above the AA' plane.	On or above AA’ line and within 25mm of the central longitudinal axis of the helmet.	Above test line but outside 120mm of other test site
Chinguard	S, in the lower face cover area, situated within an area bounded by a sector of 20° divided symmetrically by the vertical longitudinal plane of symmetry of the helmet.		
Test sites and prescribed impacts	Test order, B, X, P and R. One impact per site @7.5m/s within 10mm radius of the defined point. Smallest helmets onto kerb and flat anvils (hot or cold). Largest helmets onto flat (hot) and kerb (cold)	Test order, rear or side, crown, front. Two impacts per site @7.5m/s then 5.3m/s (Flat) or @7.0m/s then 5.0m/s (Hemi) [Type A helmet]	Two impacts per site @150J followed by 110J Temperature conditioning includes hot, cold and wet on all test sites.

5.6.1 Experimental study

An experimental study has been devised to evaluate the protection offered by current Reg22.05 helmets away from the designated impact sites. Using the impact management tests prescribed by Reg22.05, any reduced performance will be indicative of helmet optimisation and a higher injury risk.

5.6.1.1 Helmet selection

To select suitable helmets for this study, initial liaison was made with motorcycle helmet test laboratories to establish whether there were any particular current helmets, approved to Reg22.05, which were considered to be heavily optimised to the extent of reducing impact protection away from the Reg22.05 designated sites.

Some supporting concerns were voiced regarding the protection offered by current helmets conforming to Reg22.05, these concerns were somewhat focused on helmets, typically sourced from China, where the legitimacy of their approval was in question and conformity of production concerns existed. In one event, an Italian motorcycle helmet manufacturer's representative organisation had already completed an experimental assessment of a batch of Reg22.05 helmets. The results of this study suggested that indeed some helmets may have COP and quality approval issues but there was nothing to suggest there was detrimental helmet optimisation to Reg22.05.

Although the report by the Associazione dei Costruttori Europei di Caschi (ACEC) for the Associazione Nazionale Ciclo Moto Accessori (ANCMA) presents considerable evidence for concern and demands further investigation, the helmets in this study were excluded from the TRL study which was focused on the inadequacies of the Reg22.05 test methods rather than discrepancies within the conformity of production and validity of approval matters.

Unfortunately, no suitable helmets were identified through the industry consultation and instead TRL selected helmets by inspection of helmets available for sale at motorcycle helmet retail outlets. The helmet inspections were difficult since a full inspection was not possible without causing significant damage to the helmets, but 4 suitable helmets were selected for the study as detailed in Table 5.15.

The helmets were selected to ensure that a range of construction materials (i.e. glass reinforced plastic and thermoplastic shell materials) and retail prices were included. Helmet price was also used in the selection process as it was thought to indicate the overall helmet quality and possible helmet optimisation. Cheaper helmets were considered to be of lower quality and therefore less likely to retain performance across the whole helmet whereas more expensive helmets were more likely to have been optimised for reasons such as improved ventilation. Where possible, features that were indicative of optimisation to Reg22.05 were included as detailed in Table 5.15.

It should be noted that helmets conforming to Snell M2000 and BS6658 standards were excluded from the study.

Table 5.15. Helmets selected for impact site study

	Features	Photo / reason for selection
'Helmet A'	**Approvals:** Reg22 - E13/ 050124 **Mass:** 1.529kg **Materials:** ABS shell, EPS liner **Chinstrap fastener:** Quick release **Size:** 58cm (M)	Additional foam pad in crown area indicating possible optimisation to Reg22.05
'Helmet B'	**Approvals:** Reg22 - E11/ 050017, ACU Gold **Mass:** 1.590kg **Materials:** Fibreglass shell, EPS liner **Chinstrap fastener:** Double 'D' **Size:** 58cm (M)	Liner has ridged details particularly in crown area indicating possible optimisation to Reg22.05
'Helmet C'	**Approvals:** Reg22 – E2/ 0503013 **Mass:** 1.590kg **Materials:** Thermoplastic shell, Multi-element EPS liner **Chinstrap fastener:** Quick release **Size:** 57-58cm (M)	Large ventilation port immediately behind Reg22.05 front impact site. Possible weakness in shell. Deep slotted liner (for ventilation) may reduce energy absorption away from Reg22.05 impact sites.
'Helmet D'	**Approvals:** Reg22 - E13/ 050060 **Mass:** 1.590kg **Materials:** Polycarbonate and ABS shell, EPS liner **Chinstrap fastener:** Quick release **Size:** 57cm (M)	No obvious features but very low retail price possibly signalling low-budget construction methods and materials.

5.6.1.2 Test site definition

Five tests were completed using two test helmets. The tests were completed using Reg22.05 configuration and specification but with modified impact sites. The tests and the sites are detailed in Table 5.16.

Table 5.16. : Experimental test configurations

Test	Anvil	Nominal impact site	Target impact speed	Test configuration
1	kerb	Front	7.5	Reg22.05
2	flat	Side right – High	7.5	Reg22.05
3	kerb	Side Left – Low	7.5	Reg22.05
4	flat	Rear	7.5	Reg22.05
5	flat	Chinguard	5.5	Reg22.05

The extent of protection was limited to that defined by Reg22.05, but using Snell M2000 site selection criteria i.e. anywhere within the extent of protection and sites separated by at least 120mm. BS6658 was not used as it is more restrictive than M2000 and defines three sites (at least) as narrow bands within 25mm of a specific helmet plane.

Impacts were made at the selected sites using standard Reg22.05 prescribed conditions and test equipment. However, the most aggressive test configuration was chosen to ensure the worst case results to highlight possible helmet deficiencies but also to minimise test costs. The chosen test sites are detailed below;

- Front – was nominally positioned mid way between the centre of the points 'B' and 'P' defined by Reg22.05 and typically 65mm or more above point 'B'. A kerb anvil was used here as it this was considered to be most aggressive anvil and likely to penetrate through ventilation features.

- Side right - was selected as high as possible on the side of the helmet but no less than 120mm from the Reg22.05 front and rear targets. This point was at least 35mm below the range encircling site 'P'. A flat anvil was used here.

- Rear – nominally positioned mid way between the centre of the points 'X' and 'P' sites defined by Reg22.05 and at least 65mm above point 'R'. A flat anvil was used at this site to investigate the opposing configuration to that of the kerb front.

- Side left – an arbitrary point for each helmet but placed on the AA plane within the Reg22.05 extent of protection. Limited energy absorbing padding material was observed in this area. A minimum separation of 120mm between previous impact sites was maintained and the kerb anvil, likely to generate highest loading, was aligned to be parallel with the A-A plane

- Chinguard - testing was completed as defined in Reg22.05 but with chinstrap unfastened to investigate the lack and suitability of padding in this area. Testing with the chinstrap unfastened is very significant as during R22.05 testing with the chinstrap tightly fastened, energy can be absorbed via a load path through the shell and chinstrap to the headform. Such a load path does not exist in real-world conditions due to the compliance of the soft-tissues within the neck.

5.6.1.3 Test Equipment

Impact tests were carried out to the Reg22.05 standard configuration except with a modified impact site as detailed in 6.6.1.2. The variable test site did not compromise the configuration and the test equipment was unmodified.

The equipment is configured such that that the test headform can move freely at the point of impact. The headform used was a free motion headform of size 'J' as all the helmets tested were size 570mm (Medium). The headform used had a mass of 4.8kg which was towards the upper limit of the mass tolerance for this standard. This was expected to reflect a worse case condition for the tests.

A chinguard test was made at 5.5m/s with the helmet longitudinal plane aligned with the vertical. The helmet was tipped forward such that the central vertical axis of the headform was at 65º to the vertical. All other shell impacts were made onto the kerb or flat anvils at 7.5m/s.

5.6.1.4 Test results

A summary of the test results is given in Table 5.17 with graphical results in Appendix B(iii).

The linear displacement has been calculated using double integration of the acceleration data. This calculation assumes that the resultant acceleration remains in one constant direction during the impact, and that this is perpendicular to the anvil surface. In reality, the headform is able to rotate and the direction of the headform resultant acceleration may consequently change. For linear impacts the rotation is likely to be small since the impact forces remain generally aligned with the headform centre of gravity. However, this calculation is less rigorous for chinguard impacts where the helmet and head rotate more readily. For this reason, the acceleration-displacement results reported for chinguard impacts should be treated with additional caution.

Table 5.17. Impact test results

	TRL test number	Anvil	Impact site	Target / Actual impact velocity [m/s]	Peak resultant acceleration [g]	HIC [36]
’Helmet A’	A04kx	Kerb	Front	7.50 / 7.55	201	1985
	d04kx	Flat	Side Right High	7.50 / 7.52	228	**2658**
	b04kx	Kerb	Side Left Low	7.50 / 7.50	135	816
	c04kx	Flat	Rear	7.50 / 7.53	244	**2905**
	a23cy	Flat	Chinguard	5.50 / 5.53	**907**	5720
‘Helmet B’	i04kx	Kerb	Front	7.50 / 7.55	189	1737
	l04kx	Flat	Side Right High	7.50 / 7.54	204	1953
	j04kx	Kerb	Side Left Low	7.50 / 7.52	208	1655
	k04kx	Flat	Rear	7.50 / 7.56	245	**2701**
	b23cy	Flat	Chinguard	5.50 / 5.53	196	1003
‘Helmet C’	e04kx	Kerb	Front	7.50 / 7.53	213	2015
	h04kx	Flat	Side Right High	7.50 / 7.52	225	2318
	f04kx	Kerb	Side Left Low	7.50 / 7.50	164	1055
	g04kx	Flat	Rear	7.50 / 7.56	213	**2542**
	c23cy	Flat	Chinguard	5.50 / 5.54	**632**	5565
’Helmet D’	m04kx	Kerb	Front	7.50 / 7.56	186	1746
	p04kx	Flat	Side Right High	7.50 / 7.48	227	**2453**
	n04kx	Kerb	Side Left Low	7.50 / 7.51	153	848
	o04kx	Flat	Rear	7.50 / 7.51	209	2375
	d23cy	Flat	Chinguard	5.50 / 5.54	**302**	1458

Note - Bold indicates that the Reg22.05 limit has been exceeded

5.6.2 Discussion of results

5.6.2.1 Linear impacts

Helmet optimisation may be driven by a manufacturer's desire to reduce weight, decrease material costs or improve comfort or helmet styling, yet may have a detrimental affect on the overall helmet safety afforded to the rider. In an extreme example, the required level of performance could be achieved at the specified impact sites and little or no protection elsewhere on the helmet.

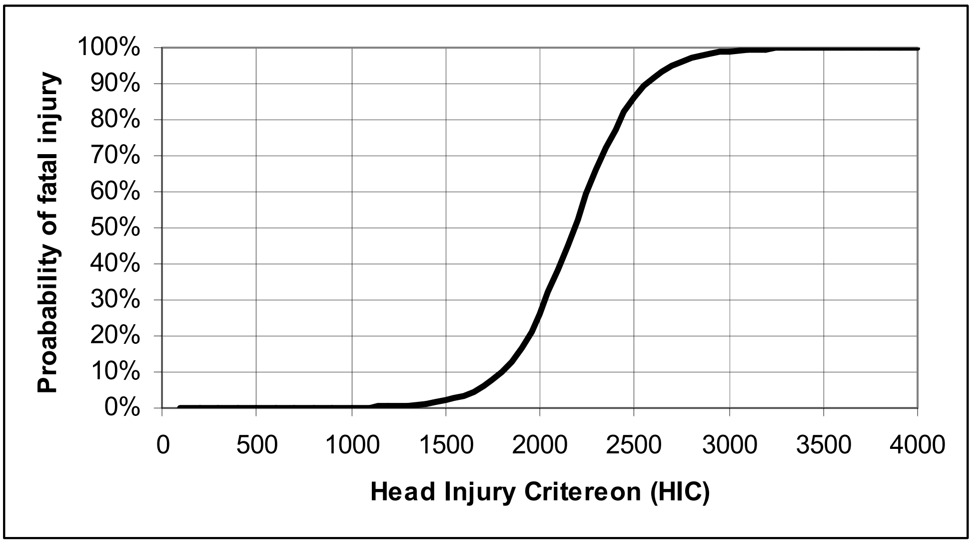
Helmets which may have been optimised to Reg22.05 would be expected to offer reduced protection away from the Reg22.05 designated sites and consequently may not meet peak linear acceleration and HIC criteria stipulated by the Regulation for the standard test configurations. For linear impacts at 7.5m/s (excludes chinguard), Reg22.05 requires that the resultant linear acceleration measured at the centre of gravity of the headform must not exceed 275g and that the calculated Head Injury Criteria (HIC) must not exceed 2400.

Analysis of the test results show that the helmets tested away from the Reg22.05 sites met this peak linear acceleration requirement of 275g with the highest result of 245g more than 10% below this limit value. However, in 5 of the 16 linear impact tests the HIC value was exceeded by as much as 20%. In fact, each of the helmets tested failed this criterion on at least one of the four sites tested.

It must be accepted that the testing methods used here differed slightly from that of Reg22.05 and may consequently generate unusual loading conditions in the helmet e.g. due to the combination and order of impacts. However, the methods used were generally consistent with widely accepted standards, such as Snell M2000, which allow repeat tests on a single helmet providing that the test sites are separated by 120mm. Any uncertainties relating to the unusual impact combinations for these tests may therefore be disregarded and the test results can be considered valid and representative of the helmet performance during a single impact alone. The poor results observed in this study must therefore be attributed to some level of helmet optimisation to Reg22.05 and justifies concern about the performance of Reg22.05 away from the regulation sites.

Since additional tests were not made on the Regulation test sites to confirm that the helmets met the Reg22.05 requirements, it was not possible to conclude precisely the reason for these apparent failures which may include poor conformity of production, optimised sites or designed close to maximum capacity on Reg22.05 sites. It must however be assumed that the helmets are legitimate Reg22.05 approved helmets and that the performance has been compromised at the Reg22.05 sites. This may have been prevented using standards such as BS6658 or Snell M2000.

To understand the significance of these results the HIC values have been used to consider injury risk by application to the Expanded Prasad/Mertz injury tolerance curves. These curves were developed by NHTSA based on the AIS 4+ Prasad/Mertz curve, and allow an estimate of head injury risk as a function of HIC. The Expanded Prasad/Mertz FATAL injury curve is illustrated in Figure 5.20.



Probability of fatal injury = $[1 + \exp((12.24 + 200/HIC)-0.00565 \times HIC)]^{-1}$

Figure 5.20. Expanded Prasad/Mertz curve for FATAL injury

For the worst-case test result (in terms of HIC), the helmet 'A' produced a HIC_{36} of 2905 when tested onto the rear on a flat anvil (test reference - c04kx). This is almost 21% higher than the 2400 limit set by Reg22.05, approximating to a 98% chance of fatal injury compared to 78% at HIC 2400. It can not be assumed that the helmets tested would pass the regulation value of 2400, but helmets which perform below this level would have an even lower risk of fatal injury. Indeed, the average HIC result recorded for impacts that passed the Reg22.05 requirement was 1659 and this equates to a very low 4% risk of fatal injury.

It should however be remembered that the peak accelerations measured for all the linear impact tests were all below the 275g limit of Reg22.05 and that this is generally accepted to be a level appropriate for ensuring safe helmet performance (Snell M2000 prescribes a 300g limit). Indeed, a recent Snell workshop on the criteria for head injury and helmet standards (www.smf.org, Milwaukee, 2005) reached a general agreement between industry experts that HIC, which was derived from cadaver head impacts onto rigid automotive structures, is generally considered to be inappropriate for application to motorcycle crash helmet testing.

On balance it may generally be concluded that the helmets are still performing to a relatively safe levels but the methods used by Reg22.05 to define impact sites may be restrictive and the overall performance of these helmets may be compromised as a result. Impact sites over a greater area of the helmet's extent of protection may improve overall safety in this case.

5.6.2.2 Chinguard impacts

All of the helmets tested were all approved to Reg22.05 for chinguard protection and would therefore meet the prescribed 275g and HIC 2400 during a standard regulation chinguard impact in order to have obtained approval. However, the chinguard impact tests completed within this study are more severe since the chinstrap is unfastened. In this case the headform is able to move forward during the impact and more likely to load the chinbar padding directly. Failure to meet the standard requirements was therefore anticipated.

The chinguard test results given in Table 5.17 highlight the additional severity of this impact with only one helmet passing the Reg22.05 requirement when the chinstrap is unfastened. All other helmets failed both the linear acceleration and HIC thresholds set by the standard.

Although the high peak acceleration and HIC levels are somewhat as expected and representative of levels likely to cause severe injury, this should not be considered as an indication of poor helmets design. Instead it indicates a possible inadequacy of the current standard to consider head motions which are plausible in real life due to the human compliance but not in a standard headform test configuration. These motions are likely to be more injurious than those currently addressed by the standard.

A positive result from this testing was that test helmet 'B' met the Reg22.05 standard requirements despite the chinstrap being unfastened. Post impact inspection did not reveal precisely why this helmet performed more effectively that other helmets but it is postulated that the stiff rubberised chinguard padding insert (up to 22mm thick in central axis) was optimised for absorption of the residual impact energy. Similar inserts were found on the other helmets (e.g. helmet 'A' had a 23mm expanded polystyrene insert) and it must also be accepted that other geometrical, fit and perhaps rotation of the headform contributed to the improved performance of helmet 'B'.

Helmet 'B' results demonstrates that there is potential to pass even a 'worst case' chinguard impact test and more stringent test standards could be introduced which could improve helmet safety within the constraints of current helmet production techniques and costs.

A further encouraging result of this study was that all helmets remained on the headform during and after the impact. Almost 13% of helmets are reported to be lost during accidents (COST 327) and a chin-bar impact would generate loads causing the helmet to rotate forward on the headform. These results highlight that it may not be the chinstrap effectiveness alone which ensure helmet retention.

In conclusion, the tests show that there may be deficiencies in the current Reg22.05 chinguard tests due to the poor bio-fidelity of the test headform and unfeasible adjustment of the chinstrap tension. A worst-case test, with the chinstrap undone may be suitable in encouraging better protection, especially for the face. Further research would first be necessary to investigate the head loading which occurs during chinguard impacts and whether the current test is sufficient to ensure that this injury mechanism encourages safer helmet design.

5.6.3 Conclusions

1) An experimental study has evaluated the linear impact performance of a range of Reg22.05 helmets at impact sites away from those prescribed by the Reg22.05 regulation. All helmets met the peak acceleration requirements but failed to meet HIC limits for at least one of the four test sites. HIC levels were around 21% higher than the accepted pass level. Increasing the test area over which helmet can be impacted would prevent helmet optimisation and ensure higher levels of head protection across the helmet's extent of protection.
2) Reg22.05 chinguard tests permit the chinstrap to be securely fastened despite the human head being unable to tolerate energy absorption via this load-path, due to the compliance of soft neck tissue. Chinguard impact tests conducted with the chinstrap unfastened resulted in three of the four helmets failing the R22.05 requirements. This indicates that the protection offered by current Reg22.05 helmets may be inadequate for real-world conditions.
3) One helmet met requirements of Reg22.05 chinguard test with the chinstrap unfastened and this indicates that improved designs are achievable. A revised test method to represent real-world conditions may be appropriate to improve helmet performance in this area. Surprisingly, all helmets were retained during the chinguard impact tests, despite the chin strap being unfastened.

6 Bimass headform

6.1 General

A novel headform, consisting two mass elements connected by a spring element, has been developed by University Louis Pascal (ULP). The 'Bimass' headform is based on a Hybrid III headform but modified to include a central component which represents the brain mass. The two masses (skull and brain) are linked by a plastic spring element designed to give the headform a natural frequency of 150Hz. This frequency is representative of that at which the brain and skull masses are believed to decouple in a living human head.

Importantly, the Bimass headform was evaluated as part of the COST 327 action and was recommended as an improved test tool. This was primarily due to the more realistic injury predictions that could be made using the headform's unique performance indicators such as the relative rotational acceleration of brain and skull. Furthermore, the Bimass headform provided a closer correlation between predicted injuries and actual injuries during the COST 327 study.

During the Inception Workshop a general consensus was shown that the industry would tolerate advanced test tools such as Bimass where improving helmet technologies with clear safety benefits demanded such tools. However, prior to introduction to standard tests, such tools must be fully validated to ensure they are both reproducible and repeatable.

Within this project, it was proposed that the issue of reproducibility and repeatability of the new Bimass test tool be researched more fully. However, it was felt to be of the highest priority to first demonstrate what benefits the Bimass headform would offer over existing test methods with regard to assessment of helmet design and optimisation. For this reason, reproducibility and repeatability evaluations were substituted with a computer simulation study, as detailed below, to illustrate how helmet optimisation could be influenced by the Bimass headform test tool.

A full report is provided in Appendix C.

6.2 Helmet optimisation

To better understand the application of this headform to future test methods and its relevance to advanced helmet technologies, this project has completed a helmet optimisation process using a computer model of the Bimass headform. A similar optimisation procedure was previously completed by ULP using a Hybrid III headform to illustrate how Bimass could contribute to helmet improvements and whether these projected safety benefits were detectable using more conventional methods.

The headform computer model was fitted with a helmet FE model for this work. This enabled accurate repeatability and allowed a total of 16 different helmet options to be evaluated. Concerning the calculated injury parameters, three outputs were considered, as follows:

1. The maximum force computed at the interface between the skull (wrapped by the scalp) and the helmet. *This mechanical parameter seems to be well correlated with skull fracture.*

2. The maximum angular acceleration undergone by the brain relative to the skull. *This mechanical parameter is correlated with the subdural and subarachnoidal Haematoma.*

3. The linear acceleration of the brain. *This is correlated with neurological injuries.*

6.3 Results and conclusions

It was found that for tests at 7.5m/s onto the R22-05 flat anvil, the best optimisation was a softer shell and softer liner. However, when tested at 10m/s, the best optimisation was a stiffer shell with either a stiffer foam with reduced elastic limit or softer foam with increased elastic limit.

The best optimisation at 7.5m/s was found to ‘bottom out’ when tested at 10m/s effectively giving excessive forces to the headform. However, the best optimisation at 10m/s was found to provide effective performance at 7.5m/s only slightly worse than the best optimisation for this speed.

Given that COST 327 proposed a need to increase energy management of helmets, this work demonstrated that high-energy helmets can be designed which offer more protection at higher impact severities without excessive compromise at lower severities. The COST 327 recommendation for both high speed and low speed tests has been adopted by the proposed Test Protocols for the new Consumer Information Scheme.

The results were also analysed with regard to rotational acceleration. It can be seen in Appendix C - Figure 9 that impacts to the front and side of the helmet. This may be due to impacts to the rear of the helmet producing a larger offset of forces relative to the centre of gravity of the headform as discussed in section 6.5.

7 Helmet visors

7.1 General

Low angle sun and sun glare have been identified as significant problems for riders of motorcycles, leading to discomfort, distraction and loss of clear vision. This may be a contributory causation factor during a number of accidents each year. It is anticipated that the industry may respond to this need by developing novel light-reactive visor systems for motorcycle helmets. Although advanced photo-reactive and electro-chromic visors may meet current standard requirements, they have significant potential to be hazardous if the function does not meet appropriate performance objectives. For example, an electro-chromic visor may not remain transparent if the power source fails. The development of these advanced visor technologies may, therefore, require a revision to current standards

Such situations must be considered in anticipation of the widespread introduction of such visor technologies so that standards may assure an appropriate level of visor safety whilst embracing the potential benefits of the technology.

7.2 Visor technology and draft performance requirements

A review of current technology has revealed that visors with either photo-reactive or electro-chromic properties are either currently available or very close to market. This is significant in that although such devices may address the problem of glare, there are other performance constraints which may be counter productive. For example, the relatively slow response time of a photo-reactive visor, in some cases exceeding of tens of seconds, may obstruct visibility when travelling into a dark tunnel from a very bright environment.

It is important that standards are written which take into account the variable performance of such devices and ensure that the performance is both appropriate and safe for motorcycle use. A draft standard giving performance requirements for these new motorcycle visor technologies has been developed as reported in Appendix D. The draft standard is based on existing requirements drawn from British and European eye protection standards, modified where necessary for this application.

The draft regulation prescribes requirements for the following parameters;

- General – field of vision, impact strength, resistance to fogging, abrasion and corrosion, optical properties resistance to UV, diffusion of light.
- Residual protection - to BS 4110 shall remain in the wearer's field of view.
- Resistance to water - shall be unaffected during and after wetting.
- Angular dependence - darkening shall be initiated by incident radiation from any angle within the field of vision of the helmet / visor.
- Transmittance - two filter categories corresponding to the lightest and darkest states.
- Reaction time - less than 5 seconds to approach 5% of final value in response to a change in incident illumination , both darkening and lightening.
- Spectral transmittance - relative visual attenuation quotient Q for red, yellow, green and blue signal lights shall not be less than 0.8 for all states. For wavelengths between 500 nm and 650 nm, the spectral transmittance of filters shall not be less than $0.2\tau v$.
- Active filters - in power-off condition, luminous transmittance not less than 80%.
- Manual control – it shall be possible to manually over-ride the shade setting system to provide a luminous transmittance of greater than 80%, within 2 seconds.
- Passive filters – it shall be possible to remove the filtering visor from the wearer's field of view, and for the filtering visor to remain in this position, within 2 seconds.

It is intended that the draft regulation could be proposed to, and considered by, an appropriate group of experts in order make final recommendations for a revised ECE R22-05.

The proposed draft regulations are provided in Appendix D.

7.3 Ambient light levels – verification of values from literature

Understanding ambient light levels is a significant step towards defining appropriate performance requirement for reactive visor technologies. A review of the needs of drivers and riders (PPAD 9/33/39 Quality and field of vision – Cook et al, ICE Ergonomics Ltd) has defined ambient light levels for a variety of typical riding conditions. These values were reproduced using a scale-model road environment. To verify the ICE ambient light levels and, in addition, possible extreme conditions that a motorcycle rider may be exposed to, a survey has been completed. Light levels have been measured in a wide range of environments ranging from extremely bright sunlight to dark unlit roads.

The results of this survey are provided in Appendix E.

The range of ambient light levels was from 100,000 LUX (very bright direct sunlight) to 0.18 LUX (road lit only by dipped beam), this being a factor of 500,000 from the highest to lowest. A summary of the data for both ICE and TRL is provided in Table 7.1.

The data from the TRL measurements correlated approximately with the ICE reported values. For direct glare from the sun the maximum TRL value was 100,000 LUX (daylight) and ICE reported 90,600LUX (low sun). For night time conditions, TRL measured 3.7LUX for street lamps greater than 7m compared with 7.48 reported by ICE.

It may be concluded that the values presented in the ICE report may be used for establishing test methodologies for assessment of visor light transmission levels.

Table 7.1. Comparison of ICE and TRL data for ambient light levels

Lighting Condition	Maximum LUX	
	ICE data	TRL data
Bright daylight	4,661	9,000 (blue sky - summer)
Cloudy daylight	1,143	5,600 (cloudy – summer)
Low sun	90,600	12,000 (glare from setting sun) 100,000 (glare from daytime day sun)
Dawn/Dusk	7.48	200 (Lighting up time)
Night – street lights	6.47	3.7 (street lamps >7m)
Night -headlamps	0.64	0.4 (main beam)

8 Advanced helmets

With the DfT funded programme S100L/VF, TRL developed a prototype helmet which was assessed to be capable of preventing up to 100 fatalities per year, in the UK, if all riders wore helmets with this level of protection. Although this helmet has not yet been taken forward to the motorcycle market, a similar technology has been adopted by the Federation Internationale de l'Automobile (FIA) for helmets for competitive motor sport. The FIA has encouraged advanced helmets using state of the art technology by publishing a high performance standard FIA8860. Helmets to this standard are currently mandated for use in Formula One with the potential to transfer the technology to a much broader application of helmet designs.

Other advanced technologies, close to market, include the Phillips Helmet Protection System (PHPS) which includes a sliding membrane technology. This helmet focuses on reduced friction in order to minimise rotational accelerations to the riders' skull and brain, whilst maintaining linear impact protection similar to current designs. COST 327 reports that 60% of motorcyclist head injuries result from rotational motion.

Both the FIA 8860 and PHPS helmets were included during a preliminary assessment of the test protocols for the proposed for the consumer information scheme. Further information on each helmet is Appendix F of this report.

9 Consumer Information Scheme (CIS)

Note: the full test and assessment protocols are provided in Appendix H (i and ii).

9.1 Introduction

Each year more than 500 motorcycle riders or pillion passengers are killed on British roads, 7,000 are seriously injured and a further 20,000 suffer slight injuries. Approximately 80% of the motorcyclists killed and 70% of those with serious injuries sustain head impacts. In more than half of these cases, the head injury was the most serious of those injuries sustained.

The "Tomorrow's Roads - Safer for Everyone" Road Safety Strategy document has set out the Government's targets for improving road safety, for delivery in 2010. Fatality reduction is a key delivery element with an aim to save 100 motorcycle user's lives per in Great Britain alone.

TRL has developed a new advanced protective helmet and demonstrated that a level of protection could be achieved beyond that currently required by BS 6658A and UN ECE Regulation 22-05 standards. This has been achieved with a lightweight carbon composite shell fitted with a high-efficiency expanded polystyrene energy absorbing liner and a low friction sacrificial shell coating.

Significant reductions in injuries and fatalities could be achieved but only when the use of such helmets by motorcycle users is widespread. To achieve the Government road safety targets, improved test methods are required to illustrate the potential benefits of safer helmets and facilitate customer awareness to ensure sufficient market penetration.

During the RIA (Dry et al, 2004), a consumer information scheme (CIS) was identified as the most practicable method of delivering safer motorcycle helmets to the market place. As a national initiative, a CIS may be introduced without agreement from EC thus enabling much more rapid implementation.

A CIS for improved motorcycle helmets requires robust test methodologies and assessment criteria which reflect both the state of the art technology and the end user exposure and tolerance to injury. This report discusses the basis of a consumer information scheme and the importance of accident statistics and injury thresholds in defining the test methodologies and assessment protocols.

The CIS protocols do not include any assessment of retention system. COST 327 did not report any mechanical failures of the retention system and the study into retention performance during this project supported this finding and concluded that helmet retention is very dependant on actual head geometry thus should be assessed by each and every end user before the helmet is chosen. The CIS protocols require all helmets to achieve the retention requirements of ECE Regulation 22-05 and will be supplemented with very clear instructions for the end user to ensure the helmet fits correctly and securely.

The CIS programme presented here is based on current knowledge and research completed both within this project and from previous European and UK research efforts. The proposal is based on helmet performance and fatality reductions outlined by project S100L/VF, and considers accident and injury mechanisms described in COST 327. The proposal also reflects current best practice in terms of helmet design and test methodologies.

Within this project it was not possible to consider all scientific opinion and evidence which may influence the integrity of the consumer information scheme protocols. The authors have therefore presented a reasoned rationale for each technical inclusion where possible. The CIS protocols are based on considered scientific evidence and best practice, but TRL could not anticipate all contrasting and determined views which may be held by external organisations. Consequently, the proposed CIS is ready for implementation as a trial scheme thus enabling feedback from interested stakeholders. The credibility of the protocols will be strengthened by this influence and would further the success of a full test programme and publication of the results.

The full test and assessment protocols are provided in Appendix G.

9.2 Accident Analysis

9.2.1 General

An important objective of a consumer information scheme is to ensure that any response to the information is appropriate and will lead to improved safety. The analysis of accident statistics can help to define the exposure and risk of injury and thus defining the areas where improvements will be most effective.

To ensure an appropriate baseline, accident data was included up to the year 2000 (see Table 9.1). This period corresponds with the Government's baseline period and the analysis period of the COST 327 research action. The data has been used to determine the number of casualties who may benefit from improved helmets, the distribution and severity of these casualties' injuries and the overall risk of fatality.

Table 9.1. Motorcycle casualties (1999-2002; RAGB 2003)

		Year			
		1999	**2000**	**2001**	**1999-2001 (Mean)**
Riders	Killed	525	573	554	551
	KSI (Killed or Seriously Injured)	6,443	6,885	6,883	6,737
	All severities	24,516	26,513	27,135	26,055
Pillion Passengers	Killed	22	32	29	28
	KSI (Killed or Seriously Injured)	465	489	422	459
	All severities	1,676	1,699	1,675	1,683
Total	**Fatal**	547	605	583	578
	Serious	6,361	6,769	6,722	6,617
	Slight	19,284	20,838	21,505	20,542

9.2.2 Casualties and injury distribution

Previous accident data analysis has shown that 81.3% fatal, 67.9% serious, and 37.7% slight injured riders sustained head impacts (COST 327 final report, page 43) which corresponds to 470 fatal, 4,493 serious and 7,744 slight.

Based on data presented by TRL (Chinn et al, 1993), the head was the most severely injured body region in 80% of fatal and 70% of serious cases where a head impact was sustained, which corresponded to 376 fatal and 3,145 serious cases per year. It was estimated that the proportion of slight injuries where the head was the most severely injured body region was 60% corresponding to 4,647 cases per year.

A detailed analysis of 158 motorcycle accident cases from the COST database has allowed a detailed AIS distribution to be constructed for these cases. Table 9.2 illustrates this distribution, accounting only for impacts where the head was the most severely injured body region. The data in Table 9.2 is used to construct Module 2 of the CIS assessment protocol (please refer to Appendix G(ii) – Module 2). Table 9.3 illustrates the resulting injury distribution when applied to the rider exposure values in Table 9.1. The data in Table 9.3 is of particular interest as it can be used to illustrate the risk of fatality as a function of casualty severity.

Further analysis of the 158 cases has shown that, for a proportion of these accident cases, the impact severity will exceed the capability of any helmet e.g. due to penetration through visor or massive linear impact severity. An improved helmet can provide additional protection during many, but not all, accident configurations. The proportion of cases during which an improved helmet will provided additional protection is provided in Table 9.4.

By combining the results in Table 9.3 with the values in Table 9.4, Table 9.5 concludes the number of casualties who may potentially benefit from an improved helmet design but who may equally receive reduced safety if the helmet worn has reduced safety performance. These totals form the accident exposure component of a consumer information scheme assessment protocol as presented in Appendix G(ii) - CIS Module 3. These values represent the number of casualties who may be influenced by helmet performance.

Table 9.2. AIS injury distribution for fatal, serious and slight motorcycle casualties

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	All
Fatal*	33.3%	33.3%	22.2%	11.1%	0%	0%	100%
Serious*	0%	13.0%	13.0%	17.4%	56.5%	0%	100%
Slight†	0%	0%	0%	0%	12%	88%	100%

* based on analysis of 158 cases from COST 327

† based on COST 327 final report

Table 9.3. AIS injury distribution for casualties with head most severely injured body region

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	All
Fatal	125	125	84	42	0	0	376
Serious	0	409	409	547	1,777	0	3,142
Slight	0	0	0	0	611	4,478	4,647
Total	**127**	**534**	**492**	**589**	**2,335**	**4,089**	**8,165**
Risk of fatal injury	***100%***	***23.5%***	***17.0%***	***7.1%***	***0%***	***0%***	***4.6%***

Table 9.4. Proportion of cases† for which an advanced helmet may provide additional protection.

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1
Fatal	16.7%	66.7%	100%	100%	N/A	N/A
Serious	N/A	100%	100%	75%	92%	N/A
Slight	N/A	N/A	N/A	N/A	92%	40%

† *cases with head injury and head most severely injured region*

Table 9.5. Number of casualties where the head was the most severely injured body region and an advanced helmet may have provided additional protection

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	*Total*
Fatal	21	83	84	42			*233*
Serious		409	409	410	1,777		*2,959*
Slight					558	4,089	*2,353*
Total	*21*	*492*	*493*	*452*	*2,193*	*4,089*	*5,544*

9.2.3 Injury thresholds and risk of fatality

Whilst striving to improve protection during severe accidents, great care must be taken not to worsen the situation during the less severe accidents. The risk of injury during less severe accidents may be low but due to the large exposure, even a small risk could result in a disproportionately large number of riders being seriously or fatality injured.

In addition to the accident exposure data (Table 9.5), the threshold for injury and the risk of fatality is vital in ensuring that helmet performance is optimised appropriately to ensure best overall safety, i.e. a safe helmet must provide good protection during both high severity and low severity impacts.

The replication of motorcycle accidents using instrumented headforms has been used to correlate accident severity with head injury (COST 327). Figure 9.1 illustrates the relationship between the peak linear acceleration and the injury outcome using an abbreviated injury scale (AIS) scale. The dataset deliberately precludes two cases which resulted in fatal head injuries at very high acceleration levels.

The proposed CIS risk function has a similar shape curve to that presented by COST 327 (Figure 7.5 of the COST final report) with an important difference that for the new regression, AIS 3 corresponds with 200g compared with 300g for COST 327. This difference is due to the sensitivity of the COST 327 regression to the two fatal data points, for which the acceleration values were significantly greater than for the other data points with the same AIS values of 4 and 5. However, given that the revised CIS risk curve presents a lower tolerance to injury, it supports the approach proposed by COST 327 that helmets must be designed to absorb the energy of higher speed impacts and reduce head acceleration levels during low speed impacts.

The Newman injury risk function, derived from an investigation of brain injury using post-mortem human surrogates, (Newman, 1986) has also been presented in Figure 9.1 for comparison. The function indicates increasing injury severity at 50g intervals with AIS 6 corresponding to more than 300g. The proposed CIS risk function closely replicates the Newman curve for AIS values of 1, 2 3 and 4. However, for AIS values of 5 and 6, the revised data and CIS risk function suggests that the tolerance to injury is somewhat higher than the Newman injury curve (375g and 500g for AIS 5 and AIS 6 respectively, compared with 250g and 300g for Newman).

The authors consider that relating helmet performance to injury risk is essential for establishing the performance of helmets with regard to injury prevention. It was accepted that, given the limited data that exists to verify this relationship, the curve should be considered the best estimate that is possible at present and that more data is needed to establish the relationship with a stronger statistical basis. It is, therefore, recommended that this, together with other modules in the CIS should be discussed and agreed with other key experts within the helmet community. This approach would help to ensure a robust scheme is developed for implementation.

Based on the relationship shown in Figure 9.1, it is possible to define a head injury threshold relationship to define the acceleration level at which a given AIS injury outcome is likely. This “CIS risk function” is shown on Figure 9.1. The injury risk function may be associated with casualty severity, as detailed in Table 9.3, to produce a head injury risk curve in terms of linear acceleration. This curve, Figure 9.2, forms Module 2 of the CIS assessment protocols.

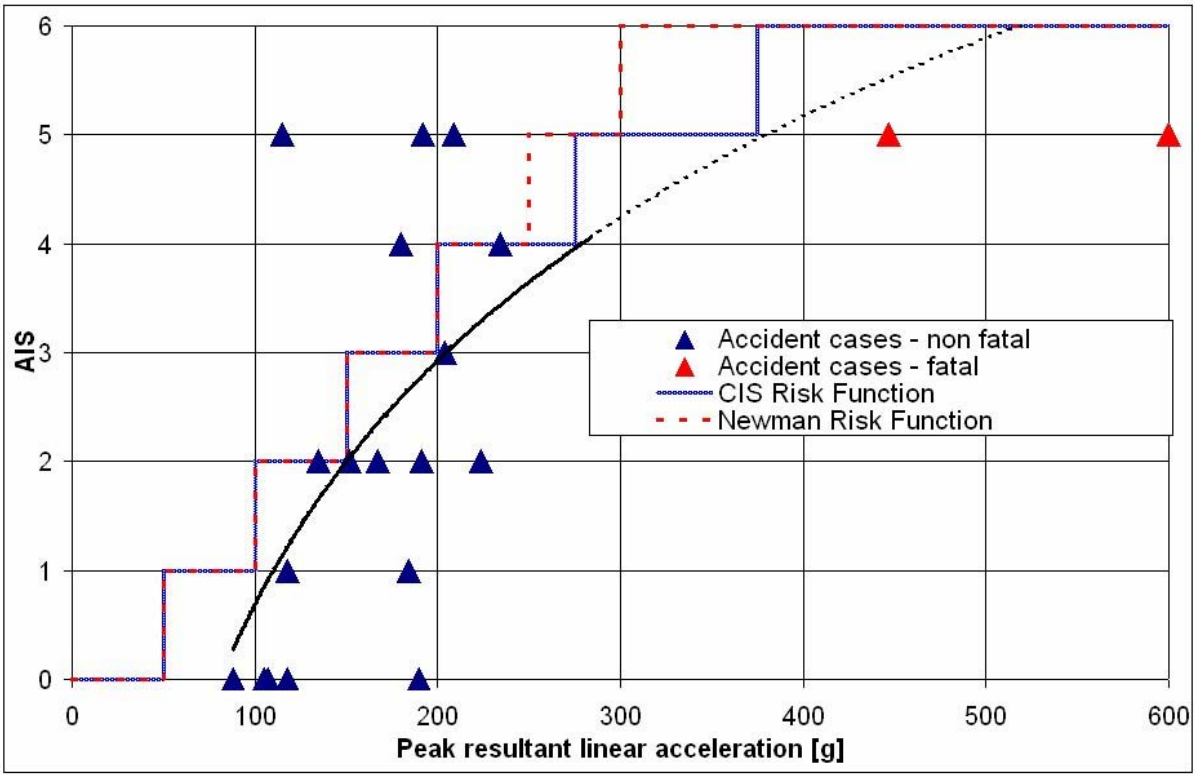


Figure 9.1. Injury outcome (in terms of AIS) as a function of peak linear acceleration for COST 327 motorcycle accident replications excluding fatal head impacts.

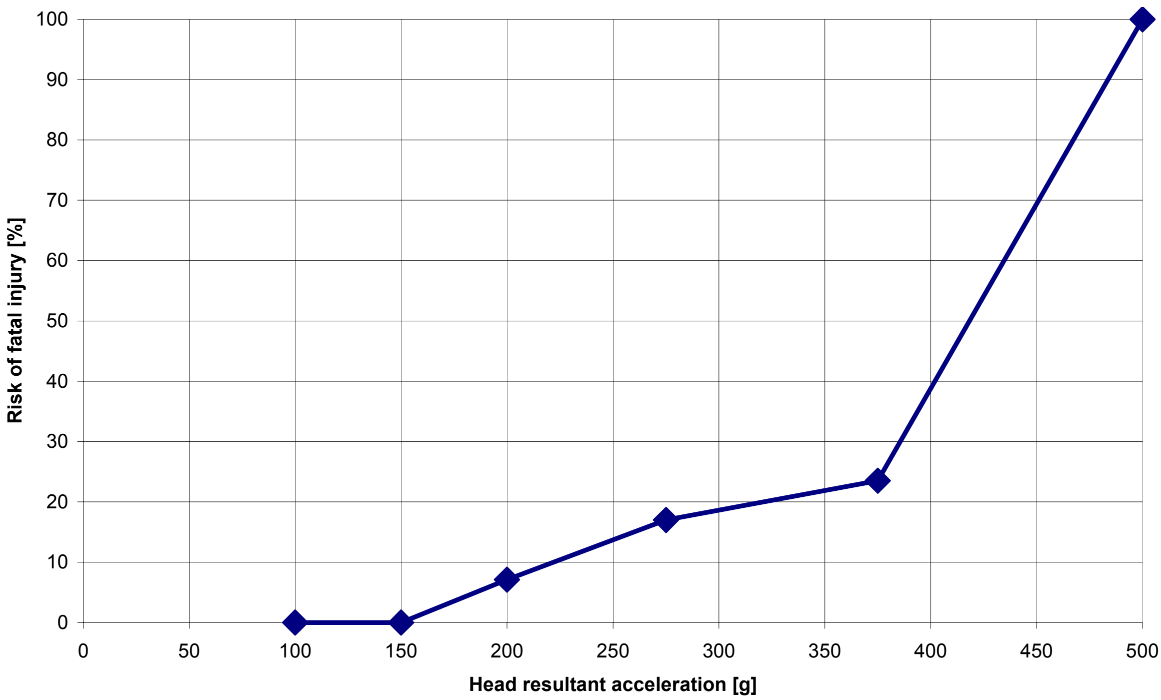


Figure 9.2. Injury risk as a function of peak linear acceleration

9.2.4 *Impact conditions*

To ensure that the protection offered by helmets to riders is appropriate, it is necessary to ensure the impact conditions are representative of those experienced in real life. For this reason accident data provided by COST 327 was analysed to establish the frequency and direction of helmet impacts.

COST 327 reports the distribution of impacts by location on the helmet as follows.

Front	23.6%
Side	53.2%
Crown	2.2%
Rear	21%

COST 327 also reports the distribution of impacts by surface type as follows

Flat surface	38.4%
Kerb surface	1.6%
Oblique impact	60%

The distribution of head impact velocities is reported as follows.

Cumulative 50% AIS 1 injuries	25km/h
Cumulative 80% AIS 1 injuries	45km/h
Cumulative 50% AIS 2-4 injuries	50km/h
Cumulative 80% AIS 2-4 injuries	80km/h
Cumulative 50% AIS 5/6 injuries	56km/h
Cumulative 80% AIS 5/6 injuries	80km/h

9.3 Test protocols

Note: the full Test Protocols are provided in Appendix G(i).

9.3.1 *General*

The Test Protocols aim to define accurate, repeatable and reproducible methodologies for measuring helmet performance. The following parameters have been defined and a justification for each is provided.

9.3.2 *Helmet Sizes*

Ideally all available helmet sizes should be tested as it has been shown that the safety performance of a helmet can vary considerably depending upon the actual shell and liner combination. A manufacturer may provide helmets in up to 10 sizes as follows; XXXS, XXS, XS, S, M, L, XL, XXL and XXXL. It would be cost prohibitive for the CIS to test each and every size and, therefore, it is proposed that the selected sizes should represent the volume sales. It is the authors' opinion that the sales for the whole helmet market will be centred on size M (medium) helmets. Consequently depending on funding available, the sizes tested shall vary as follows;

If CIS funding will permit 5 sizes of helmet, then XS, S, M, L, XL should be prescribed.

If CIS funding will permit 3 sizes of helmet, then S, M, L should be prescribed.

It would NOT be appropriate to test the worst case shell/liner combinations, as is used for homologation testing, as this would not represent the helmet sizes for volume sales and, therefore, the results would be of reduced value to the consumer.

9.3.3 Headform geometry

The geometry of the headform shall conform to BS6489 (EN960 and ISO DIS 9220) extending down at least to the line H-H. This geometry is likely to be most acceptable to helmet test laboratories and manufacturers operating within Europe, as this geometry is well established within the current European regulation, Reg22.05. It is essential that each helmet is tested with a size of test headform that closely fits the helmet. The available sizes are as follows. Size A(50cm), E(54cm), J(57cm), M(60cm) and O(62cm).

9.3.4 Headform mass

The variable headform mass values prescribed by ECE R22-05 have been adopted. TRL believes that the variable mass data, whereby larger headforms have greater mass than smaller headforms most closely represents real-world conditions. Furthermore, it is the author's view that the "international helmet community" is converging on variable mass headforms with mass values in accordance with ECE Reg22.05.

The target headform masses are as follows;

Designated Size	Mass
A	3.1kg
E	4.1kg
J	4.7kg
M	5.6kg
O	6.1kg

It is proposed that the tolerance on mass should be more stringent than for ECE R22-05, and ± 0.05kg is proposed. This will reduce, to a practicable minimum, the variation in impact energy for a given impact velocity. In addition, this will minimise the variation in measured impact response of the helmets.

When using a twin-wire guided test apparatus, a headform support assembly is required to guide the headform during a vertical drop. The total mass of the headform and support assembly shall be included in the proposed 'headform' mass.

9.3.5 Test configuration

There are essentially two test configurations currently used by leading International Standards:

1. Guided Headform (as used by Snell and BS)
2. Free Motion Headform (as used by ECE R22.05)

It is proposed that the guided method shall be used in order to ensure accurate, repeatable and reproducible results. It is the view of the authors that the guided method will provide more accurate, repeatable and reproducible results than the free motion method. This view is supported by the MEP tests (see section 6.4.2) which gave a variance of 2.31% for the free motion headform compared with 0.94% for guided headform.

With a guided method, the wire guides simulate the response of the neck, controlling pitch, roll and yaw motion of the helmeted head during initial milliseconds of an impact until the peak acceleration has occurred. With the free motion headform, the head can slide and rotate around the anvil thus reducing the measured peak acceleration. Section 5.5 discusses how helmet features can, potentially, be designed to exploit the response of free-motion headforms, to the detriment of safety.

It should be noted that all test equipment is subject to wear and tear. The limiting factor for damage to helmet test equipment is, typically, the peak acceleration during an impact, rather than velocity itself. Very high peak acceleration may cause excessive loading to the accelerometer and drop arm assembly. Testing at 9.5m/s will tend to give higher peak accelerations and, consequently, hence more wear and tear and risk of damage. However, during the pilot CIS test programme no breakages were observed despite testing current helmets conforming to Regulation 22-05.

9.3.6 Instrumentation

The instrumentation shall conform to an appropriate international standard applicable to the measurement of dynamic impact events. For this reason, SAEJ211 (SAE, 2003) is recommended to ensure accurate, repeatable and reproducible test results.

9.3.7 Velocity for linear impact tests

Two impact velocities are proposed as follows;

1. Low severity 6m/s
2. High severity 9.5m/s.

It is important that the helmet is assessed during both low and high severity impacts. COST 327 proposed 6m/s and 8.5m/s. However, more recent work by TRL has demonstrated that helmets can be designed to protect at speeds up to 9.5m/s. Furthermore S100L demonstrated that a significant proportion of serious and fatal injuries occur at speeds above 8.5m/s and that a 'high energy' helmet should be very effective during those accidents where the energy management capacity of current helmets is exceeded. It should be noted that during 2004, the Fédération Internationale de l'Automobile (FIA) published a standard referred to as FIA8860 (cf. www.fia.com), which included impact tests at 9.5m/s. Helmets to this standard became compulsory for Formula One racing during 2004.

9.3.8 Velocity for oblique impact tests

The oblique impact tests shall be conducted at 8.5m/s in accordance with ECE R22-05 Method A.

Section 5.3 of this report concludes that Method A is able to accurately evaluate the benefits of improved helmet designs whereas Method B is not, as Method B does not simulate in-accident dynamic loading configurations. Furthermore, Method B provides only a pass or fail result, whereas Method A provides a numerical measurement which may be used for the analysis.

The surface friction results from these tests shall be considered representative of impacts at lower and higher severities.

9.3.9 Impact surface

Three impact surfaces are prescribed as follows.

1. Flat anvil to ECE R22-05 (linear impacts only)

2. Kerbstone anvil to ECE R22-05 (linear impacts only)

3. Abrasive surface to ECE R22-05 (oblique impacts only)

These impact surfaces correspond to the real-world data reported by COST 327.

9.3.10 Assessment of projections

It is proposed that projections shall be assessed with regard only to Motor Sport applications.

COST 327 reported the importance of non-rigid projections on the exterior of motorcycle helmets. However, the accident data studies did not specifically correlate injury with projection strength. Furthermore, the projection strength test prescribed by ECE R22-05 aims to ensure that helmets do not have rigid projections on the shell surface.

The inclusion for Motor Sport applications is to address the specific interaction between the helmets and rumble strips on a race circuit.

9.3.11 Temperature

All tests will be conducted at ambient temperature. ECE R22-05 prescribes tests with hot (+50^{o}C) and cold (-20^{o}C) conditioning which ensures that the materials used for helmet construction are not sensitive to temperature extremes. Thus it is assumed that the response of a helmet during an accident with hot or cold conditions will be closely similar to the response during ambient conditions. It should be noted that COST 327 did not investigate the effect of ambient temperature on helmet performance.

9.4 Assessment protocols

Note: the full assessment protocols are provided in Appendix G(ii).

9.4.1 General

The new test procedures and assessment protocol will permit objective evaluation and comparison of the protection provided by a wide selection of motorcycle helmet models. The results may be published to provide consumers and end-users with an independent and objective assessment of the safety performance. Furthermore, it is intended that the new procedures will encourage significant improvements to the protection afforded by future helmet designs.

An enhanced safety helmet must provide good protection during both high severity and low severity impacts. The risk of injury increases rapidly with impact severity, but the exposure reduces significantly, and the vast majority of head impacts cause slight or moderate rather than serious or fatal injuries. Thus, whilst striving to improve protection during severe accidents, great care must be taken not to worsen the situation during the less severe accidents. Although the risk of injury during less severe accidents may be low, due to the large exposure, even a small risk could result in many numbers of riders being seriously or fatally injured.

For the purpose of this assessment, the injury risk function is based on COST 327 data but takes account of other relevant published data. The exposure data is based on RAGB 2001 which corresponds closely to the time of the COST 327 action.

It should be noted that chin guard impact tests are not included in these protocols. As a result of the COST 327 action, proposals were made for testing chinguards at 5.5m/s with 275g limit and this was incorporated into the latest revision of Reg22.05. Thus, all new helmets conforming to ECE Reg22.05 will incorporate effective chinguard protection. The chinguard of the S100L/VF project advanced helmet was designed to meet Reg22.05, but further safety performance was not sought since this would require greater forward projection of the chinguard which was not desirable and was beyond the design restriction of using existing helmet geometry. The CIS, therefore, requires that all helmets conform to Reg22.05 as minimum entry conditions.

These protocols enable the performance of a helmet to be determined with respect to a broad range of accident conditions and severities, and the Final Assessment corresponds to the number of lives that may be saved, or indeed lost, each year, on UK roads, if all riders and pillion passengers wore such helmets.

9.4.2 Equivalent test speed

Table 9.6 defines the equivalent test speed for each AIS accident severity level. These speeds are based on the values included in the Cost Benefit Analysis conducted for DfT project S100L/VF. In order to determine the response of a helmet at each test speed there are two possible methods;

(1) Test each helmet at each speed onto each anvil type

(2) Test each helmet at 1 or 2 speeds and integrate the results to derive the response at intermediate speeds.

It was accepted that there may be slight differences between results from method 1 and 2 for equivalent speeds. However, during accidents the energy dissipated by the helmet is dependant on the loads imparted by the impacted surface which may be moving or deformable, as opposed to rigid and stationary. It was, therefore, concluded that method 2 would be no less appropriate than method 1. Most importantly, method 2 would be the most cost effective.

Thus, for each anvil type, the helmet is tested at two speeds; 6m/s and 9.5m/s, and the response of the helmet at the intermediate speeds is calculated by integration of the results. A flow chart which demonstrates the methodology for the integration is provided in Figure 2 of the CIS Assessment Protocols (see Appendix G(ii)).

Table 9.6. Accident severity by equivalent test speed

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed[1] [m/s]	3.2	5.0	6.6	7.9	8.8	9.5
Kerb anvil equivalent test speed[1] [m/s]	3.7	5.4	6.8	8.3	9.0	9.5
Oblique anvil equivalent test speed[2][m/s]	2.7	4.0	5.2	7.0	8.1	9.5

[1] data used for assessment of linear impact

[2] data used for assessment of oblique impacts

Specific test requirements are described below:

- Flat and Kerb Anvils

For each flat and kerb accident severity presented in Table 9.6, the peak acceleration of the helmet will be calculated by integration of the 6m/s or 9.5m/s test data. The full procedure is detailed in Appendix G(ii) (Figure 2).

Thus, for each helmet, an array of linear acceleration results will be calculated for each site (front, side, crown, rear), each anvil (flat and kerb), and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6). These results will be used to determine the risk of head injury for each accident severity and anvil type as described in 10.4.3.

- Oblique Anvil

For each oblique accident severity presented in Table 9.6, the reference acceleration of the helmet will be calculated by integration of the 6m/s or 9.5m/s test data. The procedure is detailed in Appendix

G(ii) (Figure 2). The results from the surface friction tests shall be processed to determine the effective coefficient of friction, for each test, as follows:

(i) The peak normal force shall be determined F_normal_max

(ii) The coefficient of friction (i.e. the tangential force divided by the normal force) shall be calculated for all values where the normal force exceeds 0.7* F_normal_max.

(iii) The average value of the coefficient of friction shall be calculated for the cumulative period during which the normal force exceeds 0.7* F_normal_max.

The two results will be referred to as COF1 and COF2.

The average of these two results $COF_{average}$ = (COF1+COF2)/2

The peak resultant linear acceleration for each accident severity, during oblique impacts, shall be calculated as follows:

Peak acceleration = reference_acceleration x $\sqrt{}$(+$COF_{average}$^2)

Thus, for each helmet, an array of oblique acceleration results will be calculated for each site (front, side, crown, rear), the flat anvil only, and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

These results will be used to determine the risk of head injury for each accident severity and anvil type as described in 10.4.3.

9.4.3 Head injury risk

The acceleration data from 10.4.2 will be combined with the head injury risk data (as presented in Figure 9.2) to determine an injury risk for each accident severity. Thus for each helmet, an array of head injury risk values for both linear and oblique anvils can be produced.

For linear tests, this will include each site (front, side, crown, rear), each anvil (flat and kerb), and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

For oblique tests, this will include each site (front, side, crown, rear), flat anvil only, and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

9.4.4 Accident exposure

The Cost Benefit Analysis for the S100L/VF final report presented the number of UK accident cases per year where the rider or pillion passenger suffered a head impact, where the head injury was the most severe of all injuries sustained, and an improved helmet may be beneficial.

A summary of this data is provided in Table 9.7. The data was based on an accident study conducted around the time of COST 327 and corresponds with the analysis used to derive the CIS protocols. It may be appropriate to revise these values at some time in the future to reflect changes in accident exposure and injury rates.

Table 9.7. Accident exposure

Accident Severity	1	2	3	4	5	6
Number riders and pillion passengers	4089	2193	452	493	492	21

This exposure data shall be combined with the Head Injury Risk data to determine the number of injured riders and pillion passengers for each accident severity and anvil type.

Thus, for linear tests, the injury values will include each site (front, side, crown, rear), each anvil (flat and kerb), and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

And, for oblique tests, the injury values will include each site (front, side, crown, rear), flat anvil only, and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

9.4.5 Distribution of impacts by location on helmet

Table 9.8 presents the distribution of impacts by location on helmet as reported by the COST 327 accident study (compared with Table 3.5 in the COST 327 report). It was found that only 2.2% of impacts were located on the crown of the helmet, the vast majority being to the front, side and rear.

The data from section 10.4.4 shall be weighted in accordance with these values for each accident severity and anvil type.

Thus, for linear tests, the injury values will include a combined value for each anvil (flat and kerb), and each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

And, for oblique tests, the injury values will include a combined value for each accident severity (AS1, AS2, AS3, AS4, AS5, AS6).

Table 9.8. Distribution of impacts by location on helmet

Impact Site	**Distribution [%]**
Front	23.6
Side	53.2
Crown	2.2
Rear	21
Total	100

9.4.6 Distribution of impacts by surface type

The COST 327 report concluded that oblique impacts represented some 60% of all helmet impacts. Table 3.6 of the COST 327 presents data showing that 10 of 250 helmet impacts were onto edge shaped objects, the remaining objects being round or flat. Given that 60% of all impacts were oblique and the remaining 40% were linear, it may be concluded that 1.6% (10/250 x 40%) of impacts were onto edge shaped surfaces and the remaining 38.4% were onto flat or round shaped surfaces. A summary of these values is presented in Table 9.9. The data from 10.4.5, linear tests and oblique tests, shall be weighted in accordance with these values, thus providing an injury value for each accident severity.

Table 9.9. Distribution of impacts by surface type

Impact Surface	**Distribution [%]**
Flat anvil	38.4
Kerb anvil	1.6
Oblique impact	60.0
Total	100

9.4.7 Final assessment

The final assessment shall be the sum of the six accident injury values severity scores. This value will represent the number of riders that would be fatally injured each year (in the UK) if every helmet worn was of the type tested. A lower value will, therefore, represent a safer helmet and a high value, a less safe helmet. During the pilot study, presented below, the safest helmet produced a final assessment value of 105 and the least safe helmet a value of 204, thus a difference of 99 lives per year between the best and worse.

9.4.8 Performance rating

The final assessment represents the number of riders who would be fatality injured, each, year, on UK roads, if all helmets worn were of this type. A lower value, therefore, represents a safer helmet. The overall performance rating will simplify the final assessment into, say, 5 stars, whereby a safer helmet attracts more stars. The actual Performance Rating system will be devised during the subsequent CIS programme. An example for the performance rating scheme is provided in Table 9.10 below.

Table 9.10. Example of performance rating scheme

Final Assessment Value	Performance Rating
<125	5 star
125-150	4 star
150-175	3 star
175-225	2 star
>225	1 star

9.5 CIS pilot study

9.5.1 General

A CIS pilot study was conducted using the proposed Test and Assessment protocols as presented in Appendix G (i and ii). The aim of the pilot study was to provide data with which to validate the CIS Test Protocols and to ensure that the Assessment Protocols enabled the safety performance of helmets to be accurately evaluated with regard to real world accident conditions. Several helmet types were used, including advanced helmet technologies, to establish whether the protocols were sensitive to subtle helmet differences and whether helmets with perceived safety benefits were assessed appropriately.

9.5.2 Helmets

Six helmet models were included as follows:

1. ECE R22-05 (Shoei Z-One) - size small
2. ECE R22-05 (Shoei Z-One) - size medium
3. ECE R22-05 (Shoei Z-One) - size large
4. TRL advanced helmet (S100L/VF) – size medium (cf Appendix F (i) for further information)
5. FIA 8860 advanced helmet (Arai GP5RC) – size medium (cf Appendix F(ii) for further information)
6. PHPS helmet- size medium (cf Appendix F(iii) for further information)

9.5.3 Linear impact results

The linear impact results are presented in Figure 9.3 (9.5m/s) and Figure 9.4 (6.0m/s). It can be seen that TRL and FIA helmets provide best performance during the 9.5m/s tests. And, during the tests at 6.0m/s all the helmets provide similar performance. This would suggest that the TRL and FIA helmets should provide the best overall assessment. However, closer inspection of the 6m/s results shows that the FIA results are slightly higher than the other helmets, particularly the frontal impact which exceeds 200g, and there is consequently a rise in the risk of fatal injury for such impacts. Since there are significantly more riders exposed to these low speed impacts, this raised injury risk has a significant effect on reducing the overall CIS performance rating, as shown in section 10.5.5. The results demonstrate that a helmet should be designed to provide good protection during both high and low speed impacts, as recommended by COST 327. The CIS assessment shows that such a helmet will provide the best overall injury reduction.

9.5.4 Oblique impact results

The peak normal and tangential anvil force results are provided in Figure 9.5. From these the average coefficient of friction was calculated with reference to 10.4.2. The frictional results are provided in Figure 9.6. The R22-05 helmet, with a GRP shell, has an average friction of 0.52 compared with 0.38 for the FIA helmet with a carbon shell. The PHPS membrane helmet has a coefficient of friction of 0.22 and the TRL sacrificial-layer helmet has a friction of 0.14.

These results demonstrate that helmets may be designed with low friction coatings. Given that 60% of the overall assessment is dependant, in part, on the frictional performance, this should strongly encourage manufacturers to develop low friction shell coatings and systems.

9.5.5 Graphical results

The full sets of graphical results for each helmet type are provided in Appendix G(iii).

The results have been presented in a consolidated layout which could be adopted to aid dissemination of CIS test data to the manufacturers.

9.5.6 Overall assessment

The final assessments for the six helmets are provided in Table 9.10.

The best overall performance was achieved by the TRL sacrificial-layer helmet which was able to save 99 lives per year relative to the R22-05 size Medium.

9.5.7 Discussion and conclusions

Being of the type typically used in the UK, the Reg22.05 helmet in size M (Medium) was considered to provide a reference performance with which to compare safer or less safe helmets. A result of 204 fatalities per year (within the sub-group of those riders and pillion passengers that suffered a head injury whereby an improved helmet may help) was calculated for the reference size M helmet. The best performing helmet was found to be the TRL advanced helmet fitted with a low friction sacrificial-layer, which gave 105 fatalities per year, a saving of 99 compared with the reference helmet.

Interestingly, the FIA 8860 helmet gave 194 fatalities per year, a saving of only 10 lives, compared with the reference helmet. Although this helmet provides excellent protection during high energy impacts, the protection during low energy impacts is slightly reduced due to the optimisation for the most severe impacts. As the exposure to lower speed head impacts is much greater than high speed impacts, these high end benefits were somewhat mitigated by the slight loss in low end performance. Additionally, the FIA 8860 helmet was homologated with a 5kg headform, thus when tested with a

4.7kg headform, the resulting acceleration levels were proportionally higher. It is very likely that an FIA 8860 helmet could be optimised to provide very effective protection during both high speed and low speed accidents, thus achieving a very strong CIS rating.

The PHPS helmet gave 155 fatalities per year, a saving of 49 lives compared with the reference helmet. This result demonstrated the potential benefit of low friction helmet coatings as the linear performance was judged to be comparable to that of the reference helmet. It is understood that the PHPS system is close to production and will add only a small cost to the retail price of helmets with a modest weight penalty of less than 200g.

The protocols have demonstrated that helmet performance can be compared objectively and the enhanced safety benefits of advanced helmets can be measured.

Table 9.10. Final assessment during CIS pilot study

Helmet	Size	Final assessment (fatal injuries per year)
ECE R22-05 (Shoei Z-One)	Small	161
ECE R22-05 (Shoei Z-One)	Medium	204 (reference)
ECE R22-05 (Shoei Z-One)	Large	172
PHPS	Medium	155
TRL advanced helmet (S100L/VF)	Medium	123 (standard carbon shell) 105 (sacrificial coating)
FIA 8860 advanced helmet (Arai GP5 RC)	Medium	194

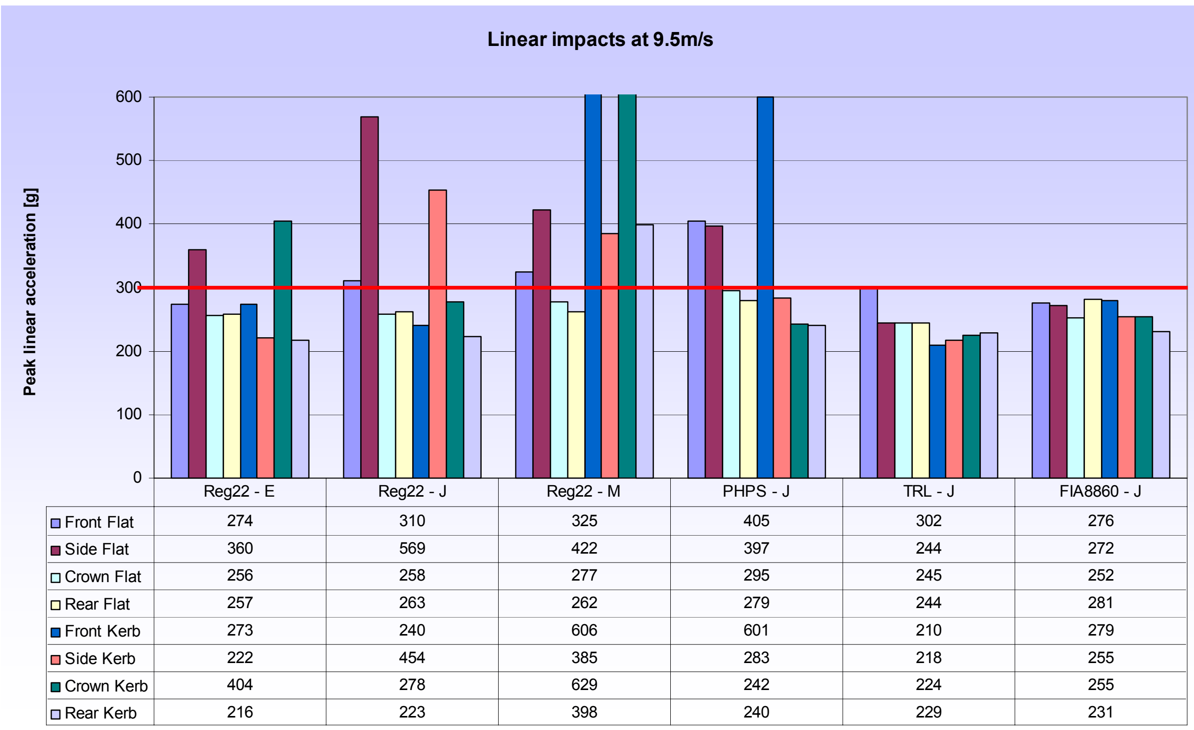
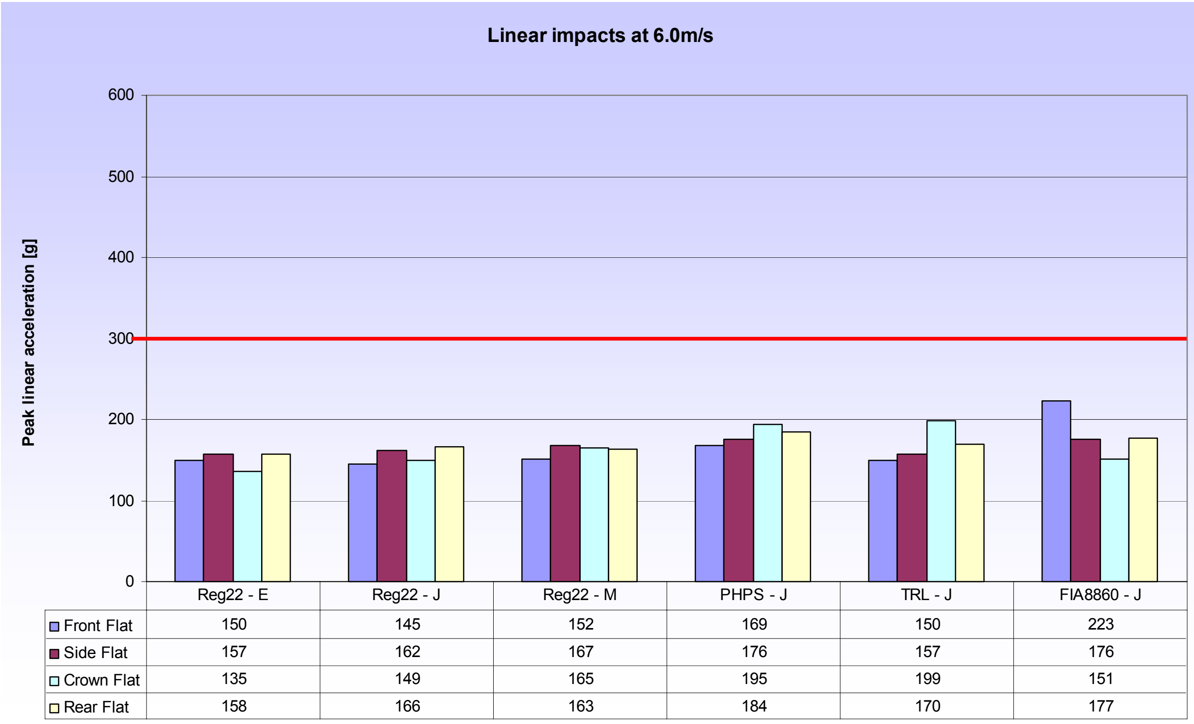
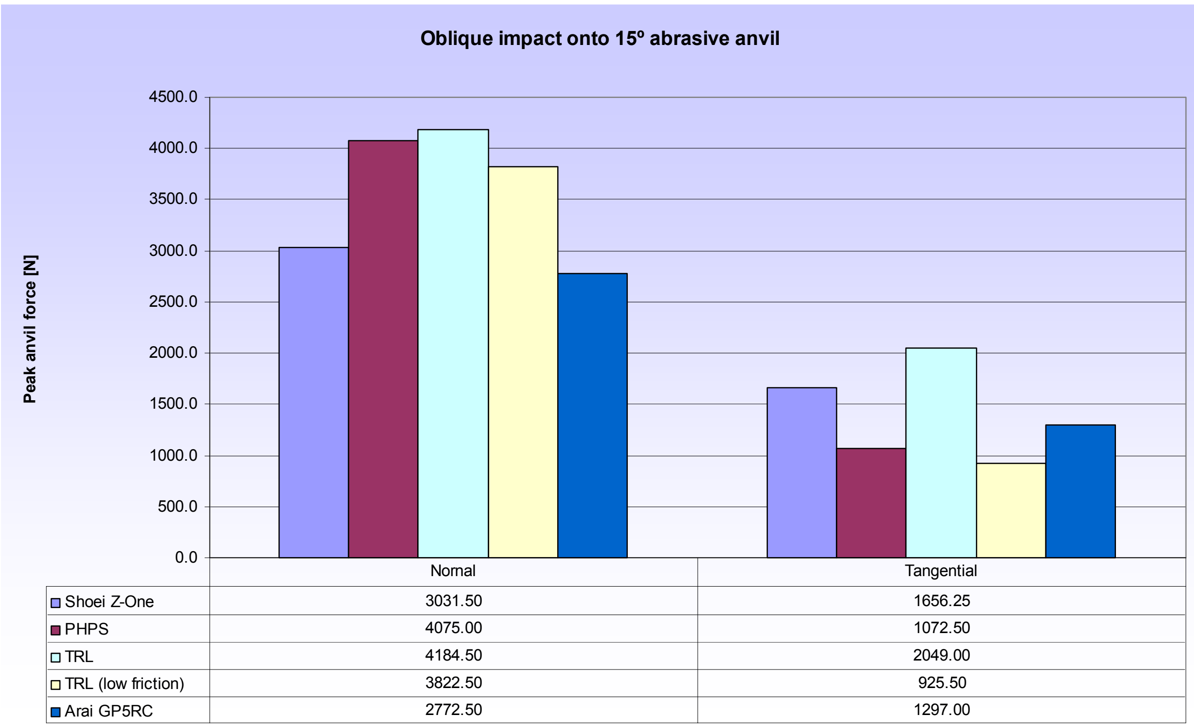


Figure 9.3. Results from linear impact tests at 9.5m/s by helmet type



	Reg22 - E	Reg22 - J	Reg22 - M	PHPS - J	TRL - J	FIA8860 - J
Front Flat	150	145	152	169	150	223
Side Flat	157	162	167	176	157	176
Crown Flat	135	149	165	195	199	151
Rear Flat	158	166	163	184	170	177

Figure 9.4. Results from linear impact tests at 6m/s by helmet type



	Nomal	Tangential
Shoei Z-One	3031.50	1656.25
PHPS	4075.00	1072.50
TRL	4184.50	2049.00
TRL (low friction)	3822.50	925.50
Arai GP5RC	2772.50	1297.00

Figure 9.5. Normal and tangential force results from oblique impact tests

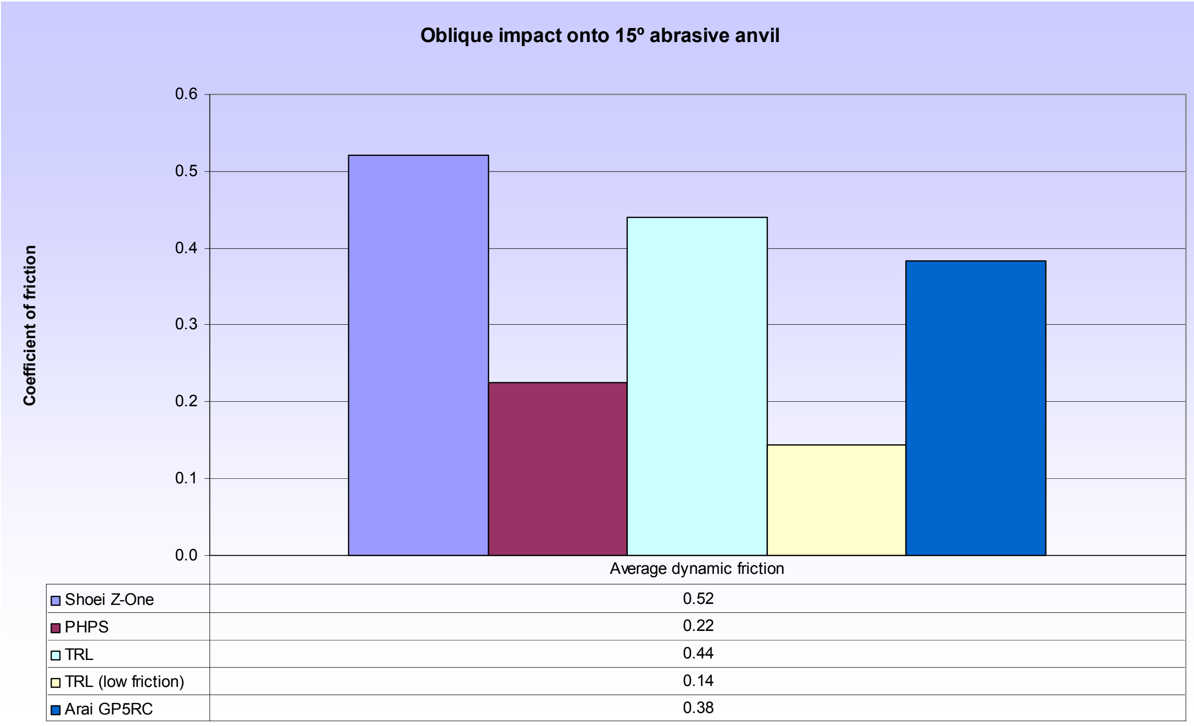


Figure 9.6. Frictional results from oblique impact tests

10 Discussion

This project has focused on two main areas of research. The first, relating to test methods has required investigations into possible deficiencies of the Reg22.05 standard but also the appropriateness of current and future test tools for future advanced helmet technologies. The second has focused on how demonstrated improvements in helmet safety may be encouraged to the market place in order to meet fatality reduction targets. Both legislative and consumer information scheme mechanisms have been considered and developed as part of this project with an RIA completed to assess the merits of both approaches. The project achievements are discussed further below.

10.1 Improved test methods

TRL has investigated current helmet test methods and including those within the COST 327 enhanced test specification. This action was necessary to establish the suitability of the methods for future helmet technologies. Furthermore, deficiencies in the methods are believed to exist which may be detrimental to current helmet performance. Establishing robust test methods which are appropriate, reproducible and repeatable is essential to promote enhanced safety helmets through either improved legislation or consumer awareness methods. This investigation was centred around possible deficiencies of Reg22.05 which relate to:

- Helmet ejection
- Method A-B misalignment
- Guided versus free-motion
- Impact sites

Test methods relating to advanced technologies were considered as follows:

- Advanced "Bimass" headforms
- Advanced visor technology

10.1.1 Helmet ejection

A review of helmet ejection data and test methods together with a subject trial was completed to ascertain the likely loss mechanisms which contribute to ejection rates which are reported to exceed 12% in Europe (between 6% and 9% in UK). The subject trial identified that compatibility between the wearer's head and jaw shape and the design of the helmet chinstrap could contribute to helmet loss. Looseness of the chinstrap was not a critical factor, but correct helmet fit was important and better consumer information may improve the fit demanded by wearers, thereby reducing the likelihood of helmet loss. From this study, helmet loss was generally attributed to end-user issues rather than those relating to helmet test methods and regulation. Indeed, current methods are believed to be ensuring adequate chinstrap strength. However, rigid headforms do not accurately represent the compliance of the human head in severe dynamic situations and potential improvements in helmet retention may be achieved by modifications to the test method. These observations were however based on a small subject trial and further data would verify the validity of these findings. Based on this helmet retention study, improved consumer awareness may best tackle the high incidence of helmet ejection.

10.1.2 Method A-B misalignment

An experimental assessment of the equivalence of Method A and Method B for the evaluation of helmet friction resistance and projection strength has been completed. From this work, it was shown that Reg22.05 Method A and Method B are not currently aligned with Method A being most stringent. Fundamental issues exist with both methods which must be resolved before the methods can be aligned. Helmet instability is one such issue with Method B where rotation of the headform was observed to be as high as 50º, severely affecting the outcome of the test. Method B also prescribes a normal clamping load of 400N which is only 10% of that for Method A tests (4,000N) that closely represents real-life head impact dynamics. Furthermore, helmets with an advanced, low friction, outer membrane that slides relative to the shell to reduce rotational motion gave values typically less than 30% of the permitted maximum for Method A, yet failed Method B. Method B is therefore unsuitable for evaluating certain types of advanced helmets. Improvements to both methods are necessary to improve the precision and stringency of the tests and raise helmet safety levels. It is estimated that an improved Method B would be 20% more stringent than Method A for projection strength tests, but would remain 5-10 times less stringent for abrasion testing. To provide comparative friction resistance and projection strength testing, as would be required for a consumer information scheme, Method A is currently the only suitable method as anvil force data can be collected and analysed. It has been shown that Method A threshold values may be reduced to improve safety as current helmets are, typically, less than 50% of the Reg22.05 limit value.

10.1.3 Guided versus free-motion headform

A comparison of guided headform and free-motion headform test methods was made to determine the methods' repeatability. When using unhelmeted headform drop tests onto a controlled Modular Elastomer Programmer (MEP) anvil, both methods were generally shown to have good repeatability with an average variance of 2.31% (±10g) for the free-motion headform and 0.91% (±4.5g) for the guided headform. The guided headform method was shown to be marginally more stringent (+1.4% higher linear acceleration) despite the free-motion headform having greater mass. This was attributed to rotational acceleration induced into the free-motion headform due to a misalignment between the centre of gravity and the geometric centre of the anvil. For real helmet tests this may further deteriorate the free-motion headform repeatability as helmet features, such as sculptured helmet shells may increase these rotational effects. To some extent, the tensioned wires of a guided headform will simulate the response of the neck and control the pitch/roll/yaw rotational motions, thereby assuring repeatability closer to that demonstrated for MEP tests.

The sensitivity of the free-motion headform to the misalignment between the centre of gravity and anvil has been highlighted as a deficiency of the Reg22.05 standard. Reg22.05 is not design restrictive but defines test methods which measure the performance of helmets. These methods can be exploited by manufacturers to optimise helmets, using features such as sculptured helmet geometries, to more easily pass the prescribed limit values but with a potentially detrimental effect on end-user safety. Indeed, it has been shown that for relatively low linear acceleration of 100g, rotational accelerations may exceed 12,500rad/s². A 35% risk of serious or fatal (AIS 3-6) injuries can be expected at levels as low as 10,000rad/s².

10.1.4 Impact sites

Impact tests have been completed using Reg22.05 helmets to determine whether or not helmet optimisation, to the detriment of overall safety, has been made at the discrete impact test sites prescribed by the standard. This work was focused on possible weaknesses in the helmet's linear impact protection away from the specified impact sites, rather than the effect of rotation motion attributed to sculptured helmet designs. For the small sample of helmets tested some optimisation was apparent with HIC levels around 21% higher than the Reg22.05 accepted pass level. However, all helmets met the peak acceleration requirements and the overall performance was considered reasonable. It is recommended that an increase in the test area over which helmet can be impact tested would prevent helmet optimisation and ensure higher levels of protection right across the helmet's extent of protection. This would, to some extent, apply to sculptured helmet designs.

Revisions to the impact site specifications may be difficult to achieve with a free-motion headform as the centre of gravity would need to be closely controlled within a 30º cone perpendicular to the tangent of the shell surface at the impact site (for a helmet with a relatively high friction coefficient of 0.6). The centre of gravity position is also dependant on the helmet's friction coefficient which is unknown. Design restrictions may therefore be necessary, perhaps as a supplement to performance testing, to prevent optimisation. These findings support the proposal to use guided headform tests within the consumer information test protocols.

Following further Reg22.05 impact tests onto the chinguard area, it was considered that permitting the chinstrap to be fully fastened against a rigid headform may be inappropriate for such a test. It was judged that the human head would not allow energy absorption through the chinstrap load-path due to the compliance of the soft tissues within the neck. Chinguard tests completed with the chinstrap unfastened, to simulate real-world conditions, resulted in three of four helmets failing the Reg22.05 limit of 275g. One helmet did meet this requirement thereby indicating that improved helmet designs might already exist. Although a revision to the current Reg22.05 test method may improve bio-fidelity and thus, the level of safety demanded by the Regulation, the Regulation already incorporates the recommendations of COST 327. However, exceeding this requirement may further increase the extent of chinguard projection. The consequences of this have not been evaluated from either a safety or consumer acceptance perspective. The CIS should therefore require that all helmets conform to Reg22.05 as minimum entry conditions.

10.1.5 Bimass headform

A novel headform, developed by University Louis Pascal (ULP), was evaluated as part of the COST 327 action and, due to the more realistic injury predictions that could be made using the headform's unique performance indicators, was recommended as an improved test tool. During the Inception Workshop a general consensus was shown that the industry would tolerate advanced test tools such as Bimass where enhanced helmet technologies with clear safety benefits demanded such tools. An optimisation study using a computer simulation of Bimass and finite element models of 16 unique helmets was completed and demonstrated good agreement with the design principles proven in TRL's advanced helmet. This helmet was designed to cope with both high speed and low speed impacts as recommended by COST 327. Bimass is therefore suitable for the evaluation of these enhanced safety helmets but it does not provide alternative methods of helmet optimisation. Furthermore, the enhanced helmet performance demanded by COST 327 can be evaluated using conventional test headform tools. Given the additional complexity and cost associated with the headform and the obligatory data acquisition equipment, it is inappropriate to recommend Bimass as a test tool for immediate use in regulation or CIS test protocols.

10.1.6 Advanced visor technology

Advanced photo-reactive and electro-chromic visors may meet current standard requirements but have significant potential to be hazardous if the function is inappropriate for real-world riding conditions. For example, the relatively slow response time of a photo-reactive visor may restrict visibility when travelling into a dark tunnel from a very bright environment. In anticipation of the widespread introduction of advanced visor technologies a standard has been developed based on existing requirements drawn from British and European eye protection standards (Appendix C). Specific requirements for motorcycle application have been considered in order that this draft regulation can form a recommendation to a revision of Reg22.05. To support any future revision, baseline ambient light levels reported in literature have been verified by experimental study (Appendix D).

10.2 Mechanisms for delivering safer helmets

An initial partial RIA completed at the start of this project identified two main mechanisms for introducing improved safety helmets in order to meet Government fatality reduction targets. The first was to increase the minimum level of safety demanded by helmets through compulsory legislation. The second was a consumer awareness programme to provide manufacturers with a marketing incentive to improve helmet performance and to provide end users with safety performance information to enable them to make an informed choice.

Both mechanisms indicated a similar and positive cost benefit ratio within a 5 year period. However, the Regulatory route is predicted to achieve full market penetration over this period with all new helmets meeting the desired performance. This compares with the 10% penetration which is estimated for a consumer information programme. The consumer programme was however considered to support more rapid implementation together with lower initial investment and could lead to improved standards in the future.

Support from the helmet community was considered to be vital to the successful implementation of either a consumer information scheme or revisions to helmet legislation. For this reason, an Inception Workshop was held to consult the industry over the UK's programme to advance helmet safety. The future implications to helmet technology and test methods were discussed and a consensus on the appropriate mechanisms for delivering safer helmets in the short, medium and long term were agreed which included revisions to Reg22.05.

In support of the agreed objectives a consortium was established to bid for EC Framework Programme 6 (FP6) funding. The proposal would allow more rapid dissemination of research and agreement of future actions within Europe which would be needed to support Regulation change. Despite the proposal's high technical appraisal, it was rejected on the basis that the selected call was not relevant. Rather than waiting to resubmit to an appropriate call, it was agreed that the delivery of the Consumer Information Scheme could offer a more effective route to casualty reductions in the immediate term. UK government funding from the Department for Transport was therefore prioritised to the CIS, as recommended by the initial partial RIA.

Test and assessment protocols have been developed for the Consumer Information Scheme (CIS). Helmets will be tested at velocities up to 9.5m/s, a value at which current helmets are known to exceed the maximum permitted acceleration and HIC (275g, 2400 HIC). The scheme has been evaluated with three current and three advanced prototype helmets. The results have demonstrated that up to 100 lives per year may be saved with advanced helmet designs that achieve high ratings in the CIS.

Within this project it was not possible to consider all scientific opinion and evidence which may influence the integrity of the consumer information scheme protocols. The authors have therefore presented a reasoned rationale for each technical inclusion where possible. The CIS protocols are based on considered scientific evidence and best practice, but TRL could not anticipate all contrasting and determined views which may be held by external organisations. Consequently, the proposed CIS is ready for implementation as a trial scheme thus enabling feedback from interested stakeholders. The credibility of the protocols will be strengthened by this influence and would further the success of a full test programme and publication of the results

A revised partial RIA was conducted which presented more recent road accident statistics but which concurred with the findings of the initial partial RIA.

11 Conclusions

1. A partial RIA concluded that Regulatory change could achieve up to 100% usage of enhanced safety helmets over a period of 5 years, with the potential to improve the injury outcome for up to 20% of motorcyclists who currently suffer serious or fatal injuries. It was estimated that as a minimum a Consumer Information Scheme could encourage approximately 10% usage of enhanced safety helmets over 5 years, delivering a pro-rata safety improvement. The benefit to cost ratio of both options was similar (4:1 Regulation and 3.5:1 CIS). The CIS was considered the most effective option for the rapid delivery of enhanced safety motorcycle helmets to the market place, thereby providing consumer choice. Furthermore, the CIS would lead manufacturers in a positive direction and may ease the transition to Regulatory change.

2. The CIS could be delivered as a National or European initiative, both offering a faster timescale to improved helmets than the regulatory route. The successful delivery of a CIS would quickly establish COST 327 performance as "best practice" thus supporting the subsequent delivery of improved Regulations in the future in order to maximise fatality reduction.

3. A number of deficiencies exist in the current ECE Reg22.05 were identified as follows:

- The definition of specific impact sites should be extended to include additional test sites within the defined test area, to be chosen by the test house.
- The alignment of helmet during impact tests should be modified to ensure headform CoG is vertically above the geometric centre of the anvil. Sculptured shell geometries can create a misalignment between the headform CoG and the test site thereby generating high rotational head accelerations.
- The chin strap should not be fastened securely during chinguard test in order to prevent a load path through the chinstrap to the neck the headform.
- Investigation into helmet retention using ten subjects showed that if the chinstrap could be pulled over the chin when fastened correctly, the helmet could be ejected during a simulated roll off test; facial geometry determined the outcome. It was concluded that a headform with a better likeness to the human head could be developed for the retention test but, importantly, the end users should be encouraged to assess helmet stability before purchasing a helmet.
- The surface friction and projection tests prescribed by Method A and Method B were found not to be aligned. In order to improve safety, the <u>limit values</u> for Method A could be reduced by 50% based on the best performing current helmets.

4. An assessment of the Bimass headform using a finite element simulation showed that an advanced helmet could be designed to satisfy the COST 327 proposals at the high and low speed tests, with only a little reduction in the optimised performance at the normal test speed.

5. Ambient light levels reported by ICE have been validated by a series of light measurements. Incident light could vary from 100,000 Lux in bright sunlight, to 200 Lux at dawn dusk and less than 1 Lux during night time riding. TRL has developed a range of criteria that should be incorporated into the visor Standard to ensure satisfactory performance. In particular the reaction time should be no greater than 5 s for the transmittance to reach 95% of the final value, for both darkening and lightening, and not less than 80% light transmittance in the event of power failure.

6. Test and Assessment Protocols for a Consumer Information Scheme have been developed on the following basis:

- The guided headform was found to be more repeatable than the free-motion headform when testing with an MEP. The variance was 0.94% for the guided headform compared with 2.31% for the free motion headform.

- The COST 327 proposals for high speed (9.5m/s) and low speed (6m/s) tests have been included in the proposed Test Protocols.
- The Consumer Information Scheme has been piloted with 3 current and the 3 advanced prototype helmets.
- The Consumer Information Scheme pilot study demonstrated that up to 100 lives per year may be saved with advanced helmet designs.

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Useful web sites:

http://www.cordis.lu/cost-transport/home.html

http://www.cordis.lu/cost-transport/home.html

http://www.statistics.gov.uk/STATBASE/ssdataset.asp?vlnk=3669.Dti

www.smf.org - Workshop on the criteria for head injury and helmet standards – Snell

www.fia.com

Appendix A. Workshop reports

(i) Programme

(ii) Organisations attending

(iii) Presentations

(iv) Workshop Report

Appendix A. Workshop reports

(i) Programme

(ii) Organisations Attending

(iii) Presentations

(iv) Workshop Report

Department for Transport

TRL

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS
Final Programme

Date:	**Friday November 21st, 2003**
Location:	**London, UK.**
Venue	**Room LG1 – on arrival please go to the Reception Desk, Department for Transport, Great Minster House, 76 Marsham Street, London SW1P 4DR**
Time	**09.30 – 16.30**

This active workshop will bring together delegates from representative groups with interests in motorcycle safety helmets. The delegates represent helmet users, manufacturers, motorsport organisations, researchers and regulatory bodies. The state of the art will be outlined by the speakers and active discussions will follow. The event will be led jointly by the Department for Transport (DfT) and the Transport Research Laboratory (TRL).

0900- 09:30	*Registration and coffee*
09:30	**Welcome and introduction.** Malcolm Fendick (DfT)
09:40	**Background.** Bryan Chinn (TRL)
10.00	**Improved protection by advanced helmet performance and technologies.** Andrew Mellor (TRL)
10.30	**Improved test procedures.**
	• **Bi-mass headform.** Remy Willinger (ULP, Strasbourg)
10.50	• **Helmet retention and physiology.** Paul Bruehwiler, (EMPA)
11.15	*Coffee break*
11.30	• **Ventilation, noise and vision.** Nick Vaughan (HSL)
11.50	• **Impact testing, criteria and limits.** Vincent St Clair (TRL)
12.15	**Delivery mechanisms –DfT projects, collaborative projects, regulations and consumer information scheme**. Steve Gillingham (DfT)
13:00	*Lunch and question box*
14.00	**Way forward and discussions.**
15:30	*Coffee break*
16:00	**Summary and conclusions.**
16.30	**End of Workshop**

Appendix A. Workshop reports

(i) Programme

(ii) Organisations attending

(iii) Presentations

(iv) Workshop Report

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS
November 2003

Organisations Attending

Industry
ANCMA/ACEC
Arai Helmet (Europe) BV
CFT Ltd
Dynamic Research Inc.
FAOS
Grand Prix Racewear
Industrial Design Consultancy Ltd
JSP Limited
Lloyd Lifestyle
Madison Powersports
MAT-MASM S.L.
Motorcycle Industry Association (MCIA)
Omega S.R.L.
Phillips Helmets Ltd.
Phoenix Distribution (NW) Ltd
RMIF

User Groups
AA Motoring Trust
British Motorcyclists Federation (BMF)
MAG UK

Motorsport
Auto Cycle Union (ACU)
FIM

Research, Testing and Certification
AD Engineering S.R.L.
BSI Product Services
Cellbond Composites Ltd
Cranfield Impact Centre
Laboratory for Protection and Physiology, EMPA
Eindhoven University of Technology
French National Research and Safety Institute
HPE
HSL
IDIADA Automotive Technology, S.A.
IMF, University Louis Pasteur, Strasbourg
Inspec International
Institut fur Rechtmedizin, Munich University
MIRA Ltd.
MERL Ltd
NEWTON S.R.L.
Qinetiq
SG Studio
TNO Automotive, Netherlands
TÜV Kraftfahrt GmbH
University of Valenciennes
UTAC

Road Safety
Institute of Advanced Motorists
LARSOA
PACTS
RoSPA

Appendix A. Workshop reports

(i) Programme

(ii) Organisations attending

(iii) <u>Presentations</u>

(iv) Workshop Report

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS

21 November 2003

Malcolm Fendick
Chief Mechanical Engineer
Head of Vehicle Standards and Engineering
Department for Transport

Steve Gillingham
Senior Engineer
Secondary Safety Branch
Department for Transport

IMPROVED PROTECTION BY ADVANCED HELMET PERFORMANCE AND TECHNOLOGIES

21 November 2003

Andrew Mellor
Transport Research Laboratory

TRL

SCOPE

- Accident analysis
  - impact kinematics
  - head tolerance to injury
- Materials specification and evaluation
- Advanced helmet design
- Injury benefit analysis

TRL

ACCIDENT ANALYSIS

Total cases investigated	~200
Number cases replicated	21
Fatal head injury	3
Serious head injury	6
Slight head injury	7
No reported head injury	5

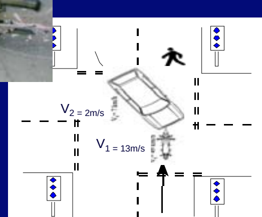
TRL

POST ACCIDENT EVIDENCE

- Accident report
  - Accident plan
  - Vehicle interactions
  - Photographic evidence
- Medical report
  - Injury data
  - Brain scan
    - fatal - brain slices
    - non fatal - CT scan
- Damaged helmet

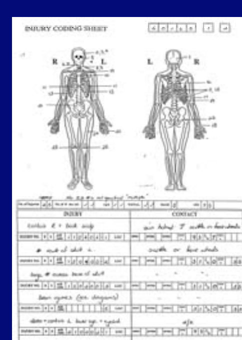
TRL

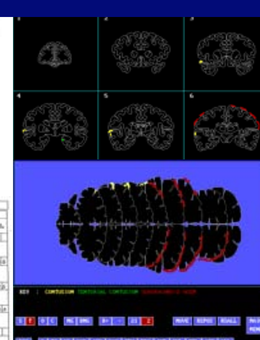
ACCIDENT REPORT



TRL

MEDICAL REPORT





TRL

HELMET

HELMET TEST FACILITY

Reconstruction of helmet (and other) damage

Hybrid II headform

HEAD IMPACT KINEMATICS

- **Velocity and direction**
- **Compliance of structures**
- **Interaction with helmet**

REPLICATION OF LINER DAMAGE

Accident   Replication

Helmet liner deformation

REPLICATION OF OTHER STRUCTURAL DAMAGE

Accident   Replication

Structural damage

REPLICATION OF SHELL DAMAGE Oblique

Accident   Replication

Helmet shell damage

REPLICATION OF SHELL DAMAGE
Linear

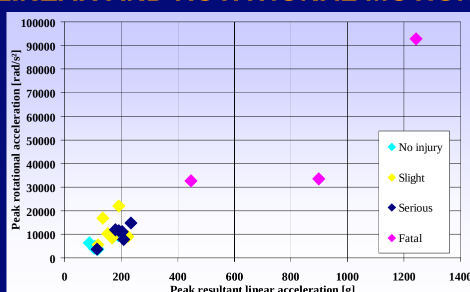
Accident

Replication

ASSESSMENT PARAMETERS

- Head injury
  - Abbreviated injury scale (AIS)
- Linear motion
  - Peak linear acceleration (g)
  - Head Injury Criterion (HIC)
- Rotational motion
  - Peak rotational acceleration (rad/s²)
  - Rotational velocity (rad/s)

RELATIONSHIP BETWEEN LINEAR AND ROTATIONAL MOTION

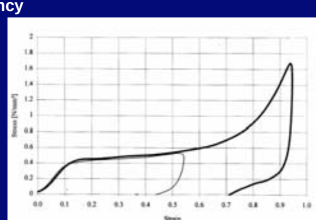


IMPROVED HELMET DEVELOPMENT

- Current geometry and mass
- Improved linear protection
- Improved rotational protection

Energy absorbing liner materials

(i) Ramping
- (ii) Nominal deformation stress
- (iii) Maximum utilisation
- (iv) Efficiency
- (v) Rebound characteristics
- (vi) Rate dependency
- (vii) Temperature



Energy absorbing liner materials

Approximately 40 Materials Investigated

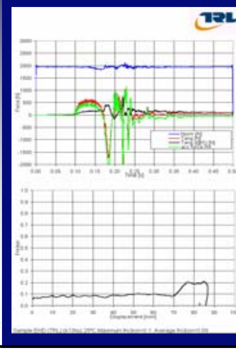
- Expanded polystyrene foam
- Expanded polyurethane foam
- Honeycomb
- Open-celled polyurethane foam
- Ceramic spheres - epoxy matrix
- Nitrile polymer closed cell foam
- Cross linked polyethylene foam

High performance shell materials

Flat shell substrate linear impact testing

High performance shell materials

Flat substrate friction testing



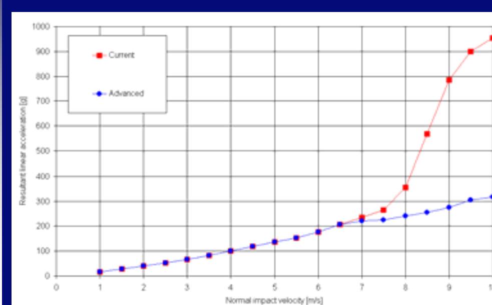
FULL GEOMETRY DEVELOPMENT

Advanced composites
Carbon - Kevlar - Hybrid

Solid and sandwich
lay-up configurations

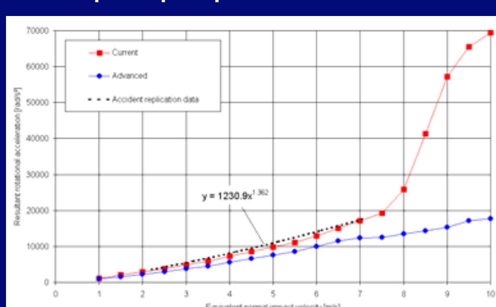
TRL Advanced Helmet Development

Linear impact performance



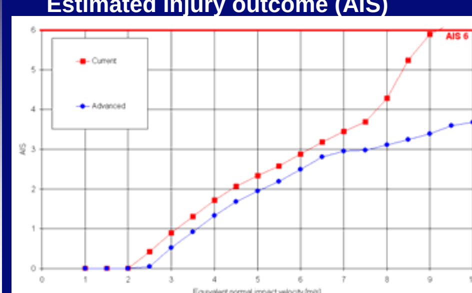
TRL Advanced Helmet Development

Oblique impact performance



TRL Advanced Helmet Development

Estimated injury outcome (AIS)



INJURY BENEFIT ANAYSIS

National M/C injury rates 600fat 7,000ser 20,000sli
EU M/C injury rates 20x

National injury reduction if 100% new helmets
94 lives saved (~20%) 434 serious prevented

760,000 motorcycles (est 152,000 helmets sold/year)
10% sales new, 76,000 helmets over 5 years

National injury reduction over 5 years
28 lives saved 130 serious prevented

OTHER SYSTEMS

- **Advanced Helmet Systems**
  - **PHPS**
  - **Schuberth Helme**
- **Advanced Materials and Processes**
  - **CFT**
- **Emergency Helmet Removal**
  - **HATS OFF**

DEMONSTRATION OF TECHNOLOGY 'STATE OF THE ART' COMPETITION HELMET

FIA ADVANCED STANDARD FOR PROTECTIVE HELMETS FOR MOTORSPORT

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Institut de Mécanique des Fluides et des Solides
UMR 7507 ULP-CNRS

BIMASS HEADFORM and ULP human haed FE model :

DEVELOPMENT, VALIDATION & INJURY CRITERIA

R. Willinger, D.Baumgartner

Willi@imfs.u-strasbg.fr

Main references

- R. Willinger, D. Baumgartner, B. Chinn : New dummy head prototype : development, validation and injury criteria . Int. J. of Crashworthiness, 2001, Vol 6, N°3, 281-294.
- R. Willinger, D. Baumgartner : Human head tolerance limits to specific injury mechanisms. Int. J. of Crashwothiness, 2003, Vol 8 N°6,605-617

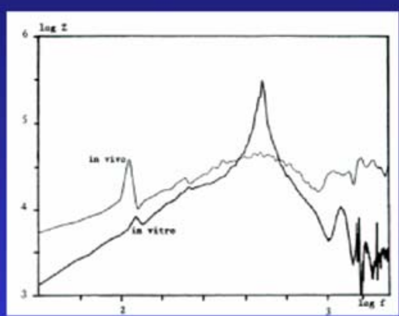
PLAN

- Biomechanical background
- Bimass headform development & validation
- Numerical approach (The ULP Head FE model)
- Accident reconstruction and injury criteria

A RIGID MASS ?

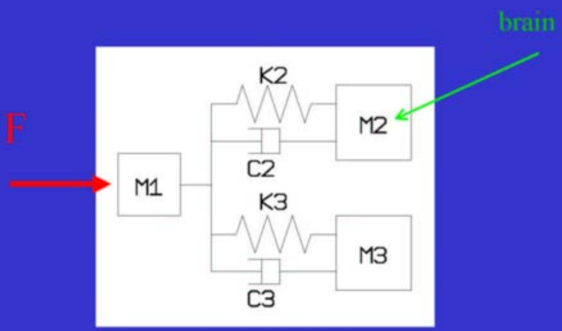
MECHANICAL IMPEDANCE IN VIVO

HUMAN HEAD MECHANICAL IMPEDANCE

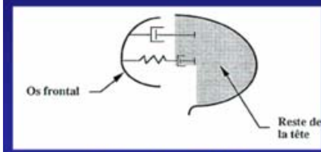


Log(Z) vs Log(f) in vivo & in vitro

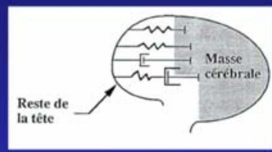
HUMAN HEAD LUMPED MODEL



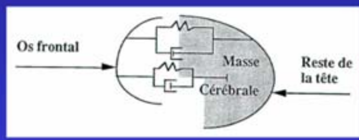
LUMPED MODELS FROM THE LITERATURE



Stalnaker - 1971



Viano - 1988

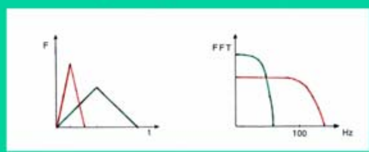


BRAIN – SKULL RELATIVE MOTION

- In the frequency domain
(Ruan – 1973, Trosseille – 1992)

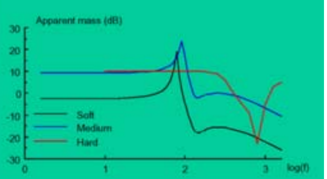
- In the time domain
(Viano – 1996, Al Bsharat & King – 1999)

Head Injury Mechanisms

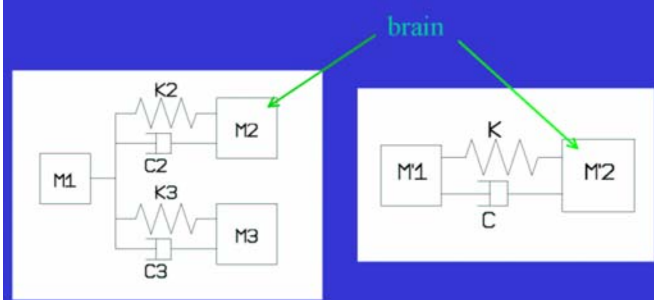


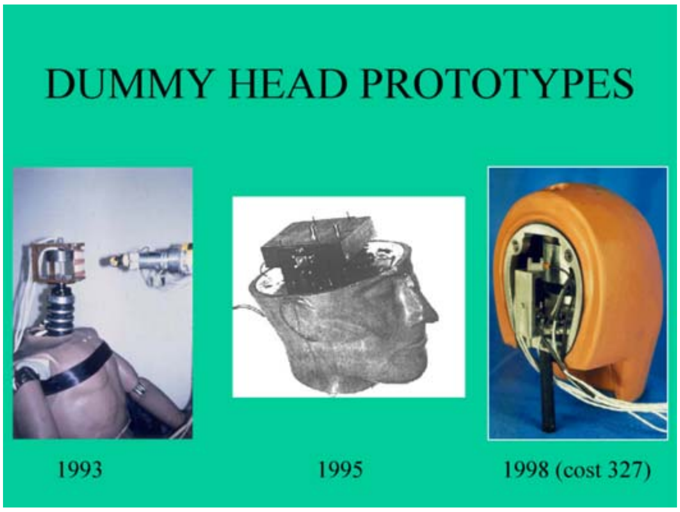
Shock	DAI	Cont. & SDH	Fractur & EDH
Long	++	-	-
Middle	+	++	-
short	+	+	++

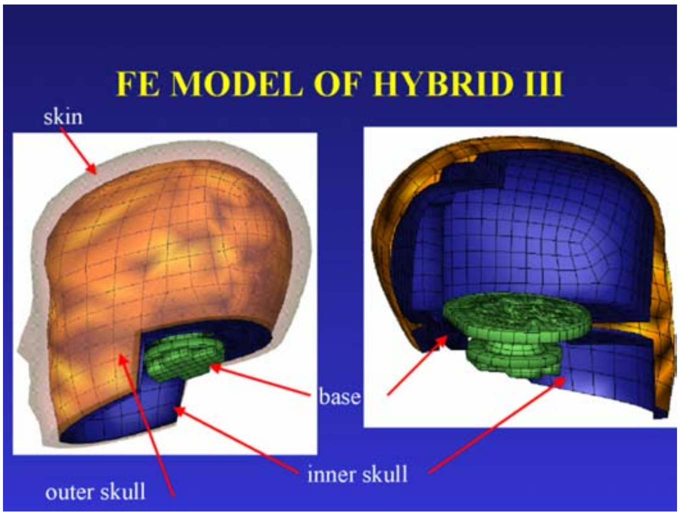
Dynamic Analysis of Impacted Structurs

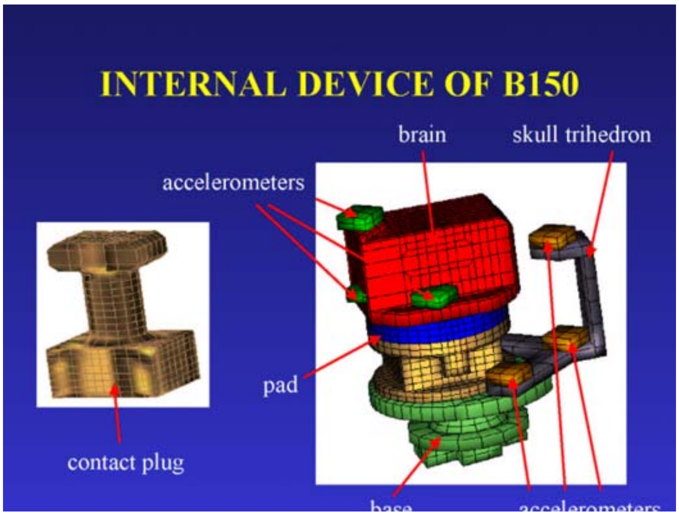


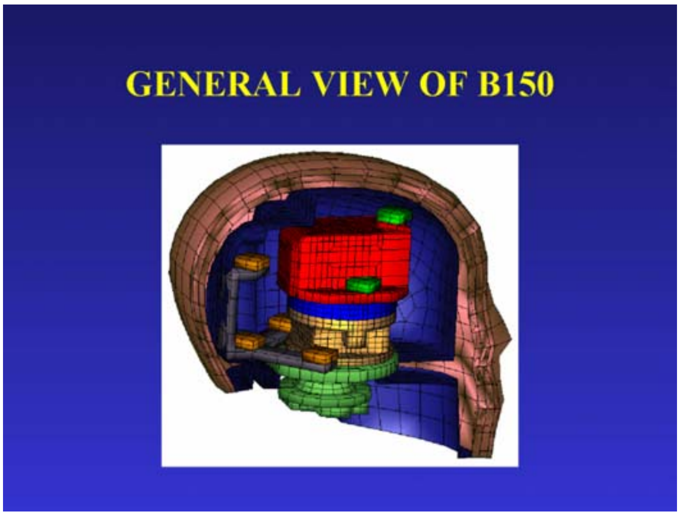
FROM THE TRIMASS TO THE BIMASS

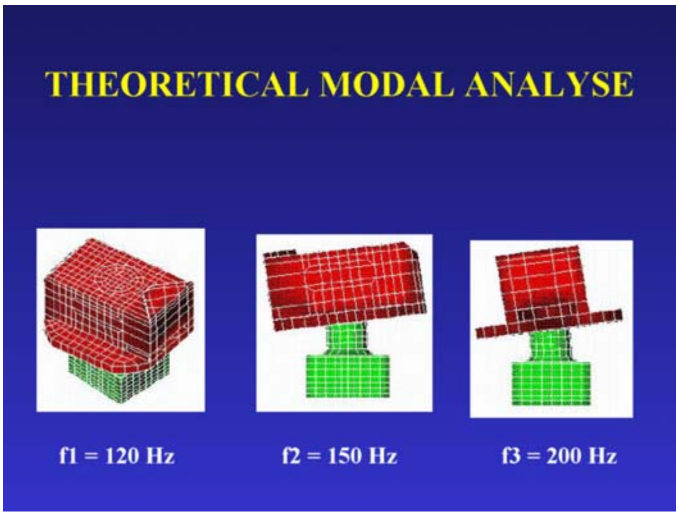


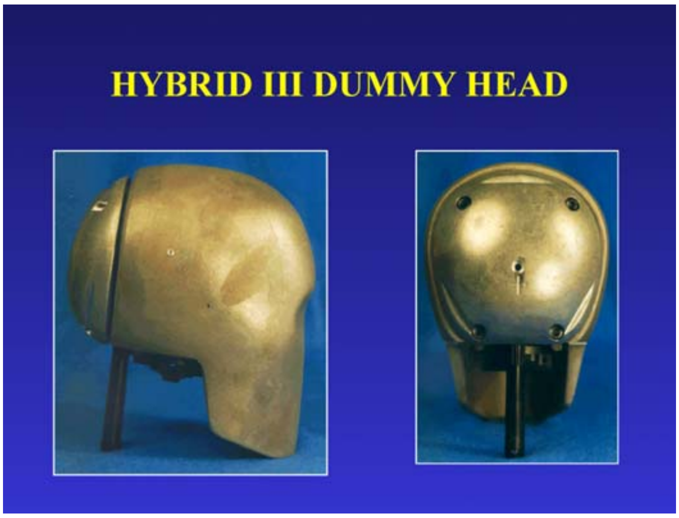

DUMMY HEAD PROTOTYPES
1993
1995
1998 (cost 327)

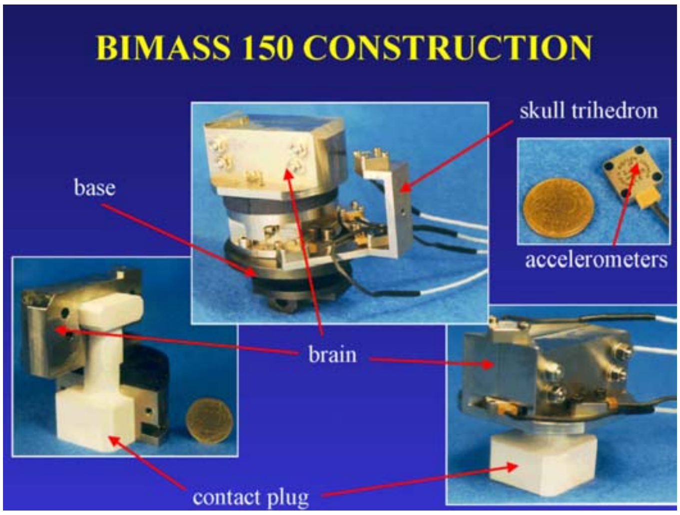

FE MODEL OF HYBRID III
skin
base
inner skull
outer skull

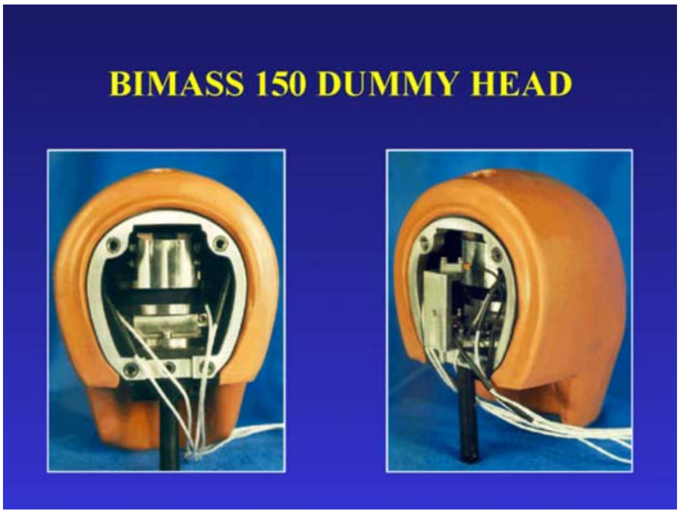

INTERNAL DEVICE OF B150
brain
skull trihedron
accelerometers
pad
contact plug
base
accelerometers

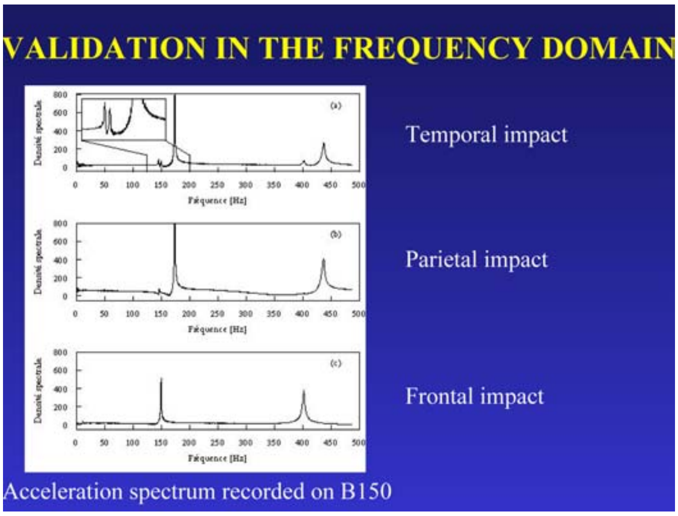

GENERAL VIEW OF B150

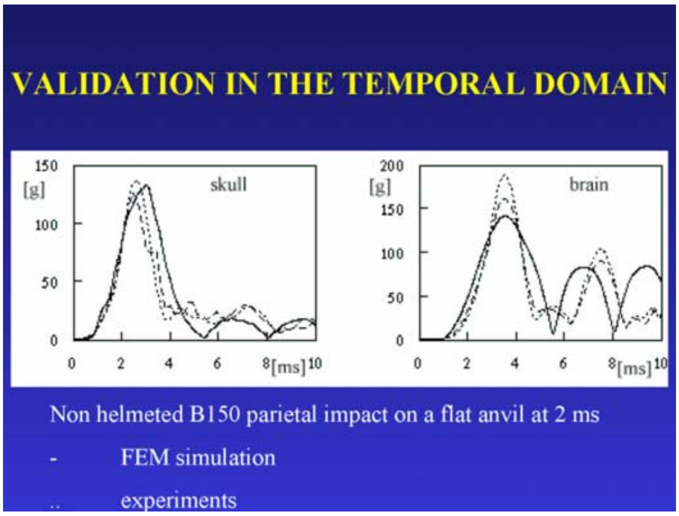

THEORETICAL MODAL ANALYSE
f1 = 120 Hz
f2 = 150 Hz
f3 = 200 Hz

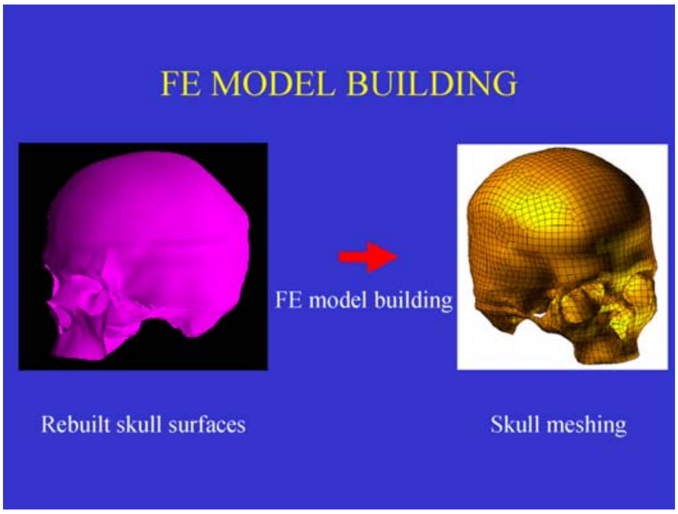

HYBRID III DUMMY HEAD

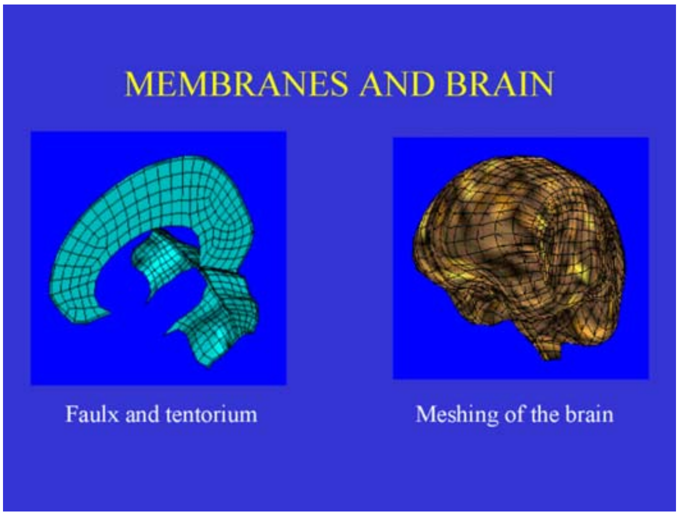

BIMASS 150 CONSTRUCTION
skull trihedron
base
accelerometers
brain
contact plug

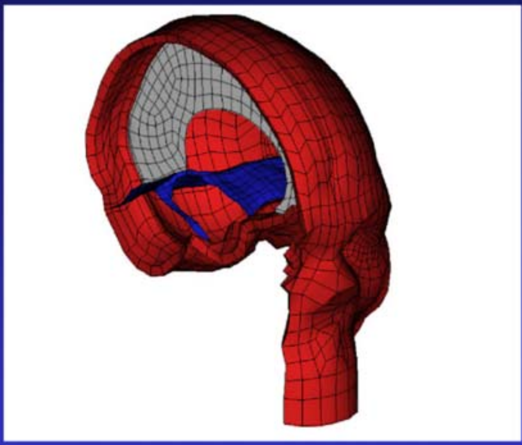

BIMASS 150 DUMMY HEAD


VALIDATION IN THE FREQUENCY DOMAIN
Temporal impact
Parietal impact
Frontal impact
Acceleration spectrum recorded on B150

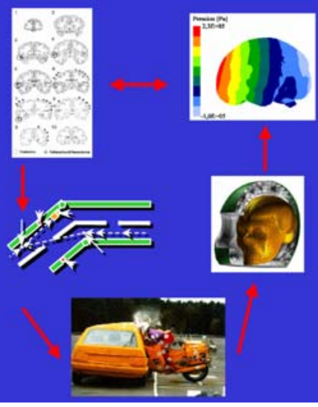

VALIDATION IN THE TEMPORAL DOMAIN
skull
brain
[g]
[ms]
Non helmeted B150 parietal impact on a flat anvil at 2 ms
- FEM simulation
.. experiments


FE MODEL BUILDING
FE model building
Rebuilt skull surfaces
Skull meshing


MEMBRANES AND BRAIN
Faulx and tentorium
Meshing of the brain

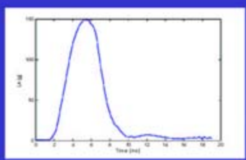


ACCIDENT RECONSTRUCTION

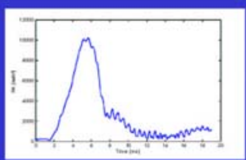


EXPERIMENTAL INPUTS - CASE G174

Damaged helmet

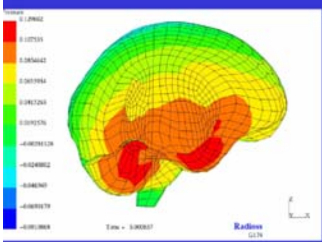


Input linear acceleration

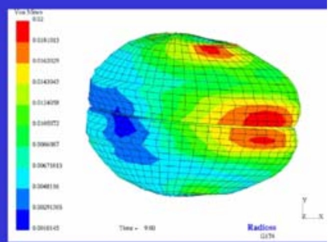


Input rotationn acceleration

NUMERICAL RESULTS (2) - CASE G174



Brain pressure field at 5 ms



Brain Von mises stress field at 9 ms

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Strasbourg - France

2000 - 2003

Experimental accident replication

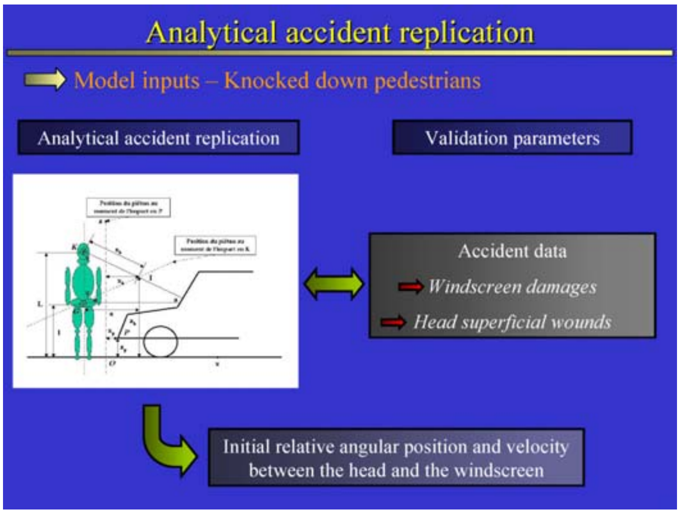
Model inputs – Helmeted american footballers

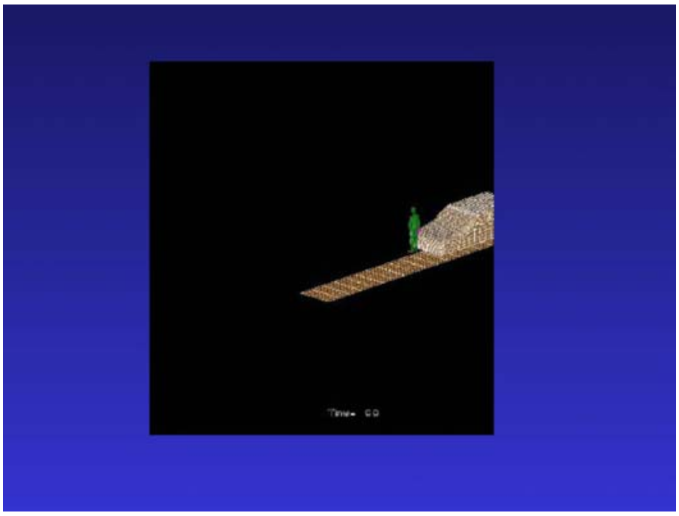
Experimental accident replication

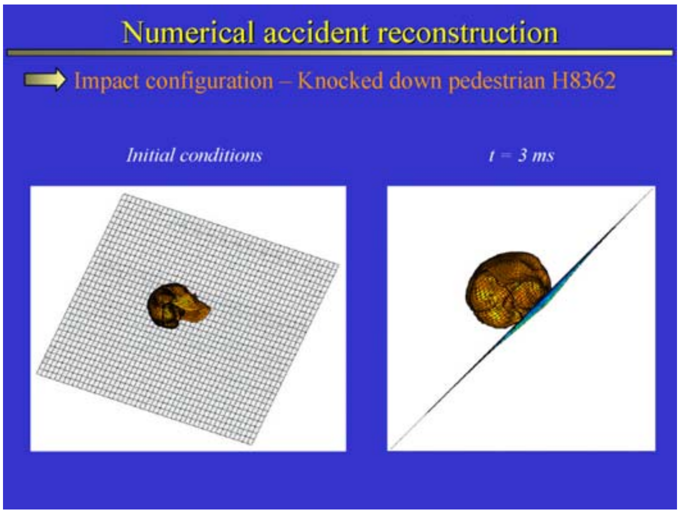
Validation parameters

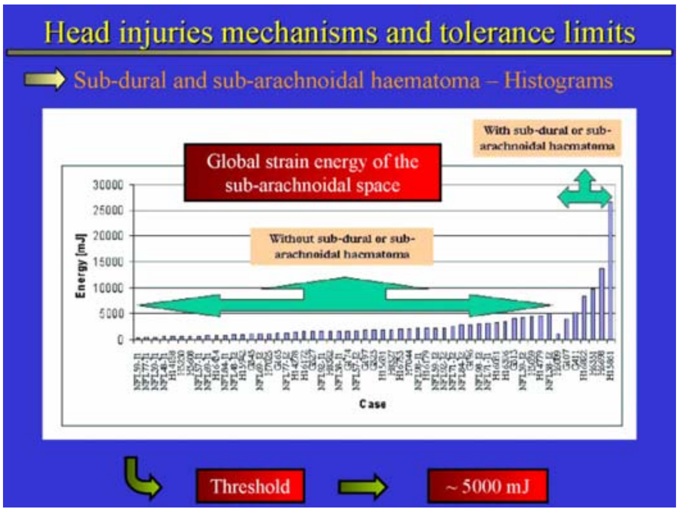
Measured dummy head acceleration field

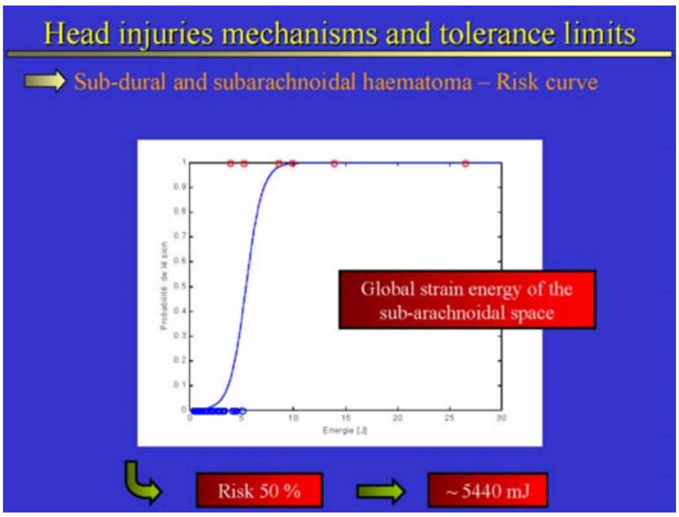
Rigid skull applied velocity field

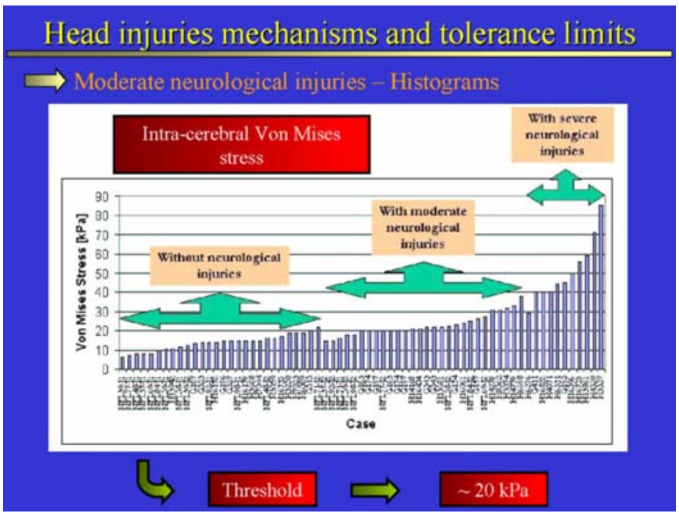

Analytical accident replication
Model inputs – Knocked down pedestrians
Analytical accident replication
Validation parameters
Accident data
Windscreen damages
Head superficial wounds
Initial relative angular position and velocity between the head and the windscreen




Numerical accident reconstruction
Impact configuration – Knocked down pedestrian H8362
Initial conditions
t = 3 ms

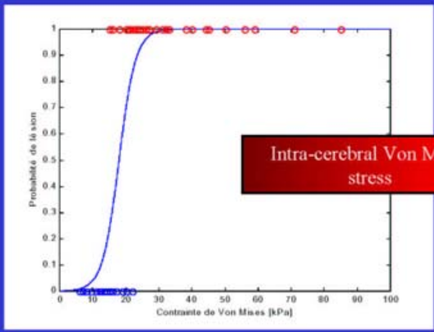

Head injuries mechanisms and tolerance limits
Sub-dural and sub-arachnoidal haematoma – Histograms
Global strain energy of the sub-arachnoidal space
With sub-dural or sub-arachnoidal haematoma
Without sub-dural or sub-arachnoidal haematoma
Energy [mJ]
Case
Threshold
~ 5000 mJ


Head injuries mechanisms and tolerance limits
Sub-dural and subarachnoidal haematoma – Risk curve
Global strain energy of the sub-arachnoidal space
Risk 50 %
~ 5440 mJ


Head injuries mechanisms and tolerance limits
Moderate neurological injuries – Histograms
Intra-cerebral Von Mises stress
With severe neurological injuries
With moderate neurological injuries
Without neurological injuries
Von Mises Stress [kPa]
Case
Threshold
~ 20 kPa

Head injuries mechanisms and tolerance limits

Moderate neurological injuries – Risk curve

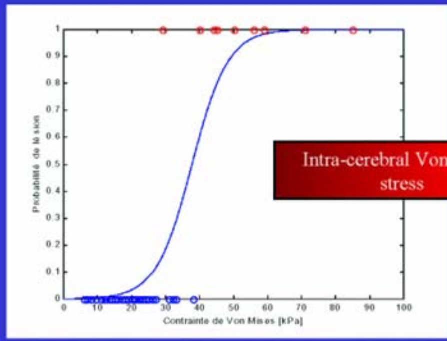


Intra-cerebral Von Mises stress

Risk 50 % → ~ 18 kPa

Head injuries mechanisms and tolerance limits

Severe neurological injuries – Risk curve

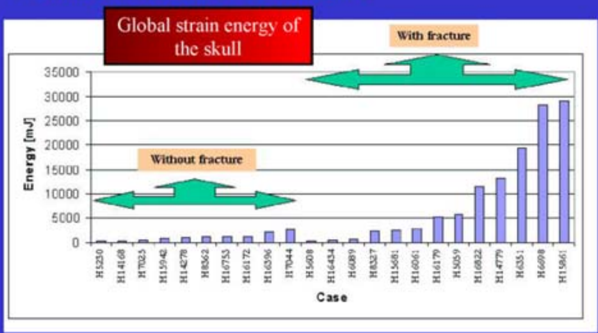


Intra-cerebral Von Mises stress

Risk 50 % → ~ 38 kPa

Head injuries mechanisms and tolerance limits

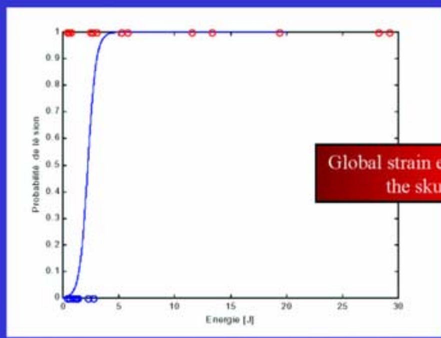
Skull bones fractures – Histograms



Threshold → ~ 3000 mJ

Head injuries mechanisms and tolerance limits

Skull bones fractures – Risk curve



Global strain energy of the skull

Risk 50 % → ~ 2230 mJ

Conclusions (1)

Proposition of head injuries mechanisms and head tolerance limits for human living beeings

- Injury risk curves belonging to specific Injury Mechanisms
- Sub-arachnoidal haematoma
  - Global strain energy of the sub-arachnoidal space > 5.44 J
- Moderate neurological injuries
  - Intra-cerebral Von Mises stress > 18 kPa

Conclusions (2)

- Severe neurological injuries
  - Intra-cerebral Von Mises stress > 38 kPa
- Dome and base of the skull bones fractures
  - Global strain energy of the skull > 2.23 J

    Or impact force > 5.5 kN

Results are relative to the ULP Head Model (can be provided)

Zhou et al. – 96 and Kang et al. 97 : 11 and 16 kPa shearing

Anderson et al. 2000 : 27 and 43 kPa shearing

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Strasbourg - France

BIMASS – Huamn Head FE model

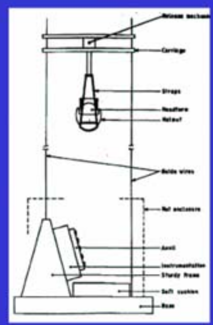
Coupling

Experimental reconstruction with BIMASS

Asservissement du modèle – Accidents de motocyclistes

Réplication expérimentale

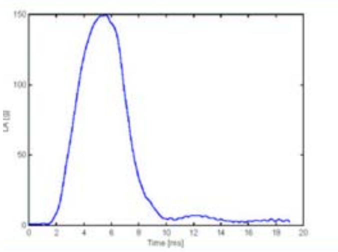
Paramètres de validation



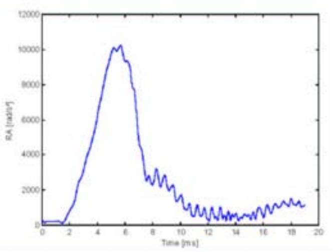
Champ d'accélérations mesurées

Champ de vitesses appliquées au crâne rigide

EXPERIMENTAL INPUTS FROM TRL

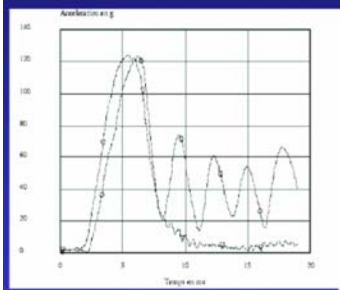


Linear acceleration [g] vs time [ms]

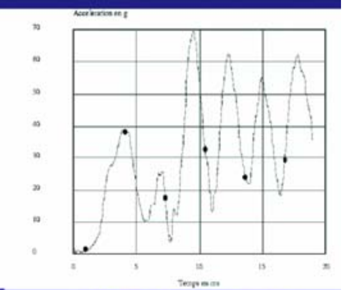


Rotational acceleration [rad/s²] vs time [ms]

BIMASS 150 RESPONSE

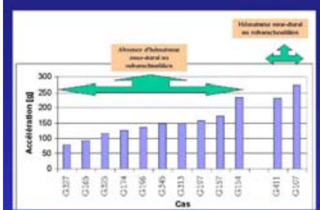


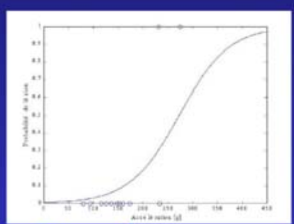
Brain (o) & Skull (^) acceleration [g] vs time [ms]



Brain – Skull relative acceleration [g] vs time [ms]

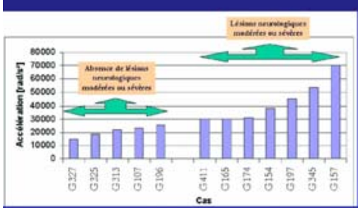
Experimental criteria for SDH

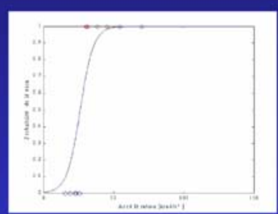




Linear brain acceleration
50 % risk :273 g

Experimental criteria neurological injury





Rotational brain acceleration
50 % risk : 25970 rad/s²

First Results

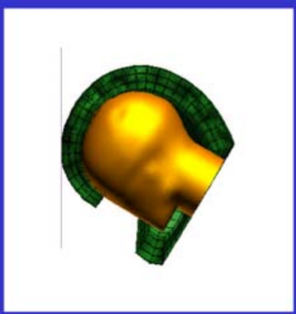
- Biomechanical background of an improved dummy head
- Brain-skull relative motion
- Development and validation of a new prototype
- Repeatability and robustness
- Conformity of experimental and finite element simulation
- New injury criteria (first attempts)

FUTUR DEVELOPMENTS

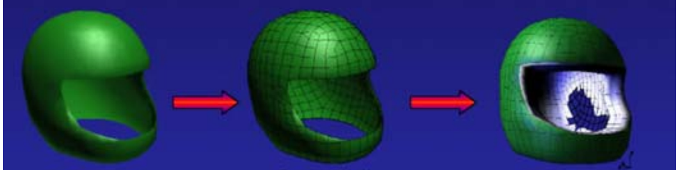
- The limit of AIS recording
- FEM and Bimass coupling
- Toward injury criteria for specific injury

Criteria	Mechanism
Brain-Skull acceleration	SDH & Focal contusion
Brain acceleration	DAI & ICH
Skull acceleration or def.	EDH & Fracture

PROTECTIVE HELMETS



Helmet Finite Element Model



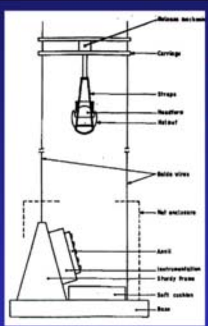
External surface of the Helmet

Outer Shell (524 Shell elements) Thickness 4mm

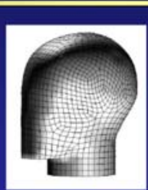
Foam (1675 Brick elements)

Component	Material	Model	E [GPa]	v	ρ [kg/m3]	Comment
Outer shell	Thermo-plastic	linear-elastic	1,5	0,35	1055	Thickness = 4mm
Protective padding	Expanded polystyrene	elasto-plastic	1,5.e-3	0,05	25	Thickness = 40mm Yield stress = 0,35MPa
Headform	aluminium	rigid	27	0,3	_	Mass = 4,27 kG

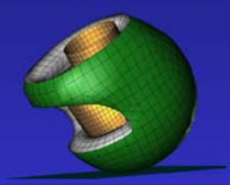
Helmet Model Validation (1)



V=7.5 m/s



FEM of the Headform (2208 nodes et 1652 shell

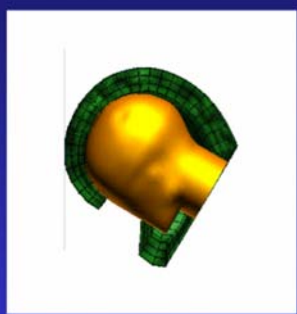


Frontal impact configuration

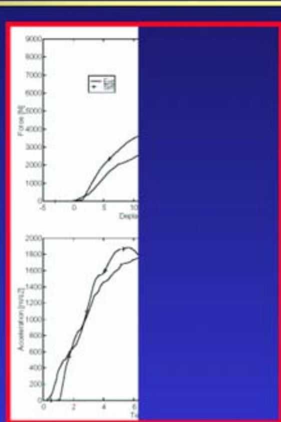
HEAD ACCELERATION < 270g

$$HIC = (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a\,dt\right]^{2.5} < 2400$$

Helmet Model Validation (2)



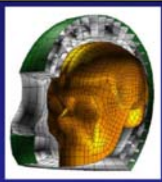
V=7.5 m/s

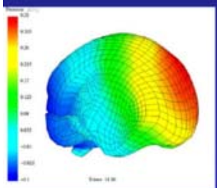


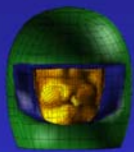
Coupling with the ULP human head FEM

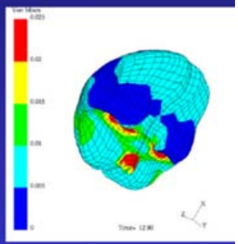
Pressure

Von Mises









Coup : 350 Kpa
Contre-coup : -90 KPa

Maximum Von Mises : 31 KI

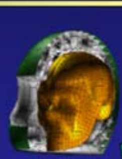
Helmet optimisation

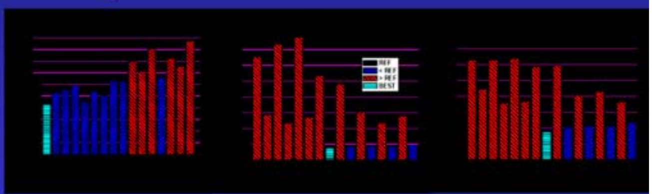
Parameters	Values	
	-	+
A Young modulus of the foam	1.05 MPa	1.95 MPa
B Shell thickness	2.8 mm	5.2 mm
C Young modulus of the shell	10.5 GPa	19.5 GPa
D Foam elastic limit	0.21 MPa	0.455 MPa

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
A	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+
B	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+
C	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+
D	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+

Simulation protocol indicating for each of the 16 simulations, the helmet characteristics retained : +/- stand +30% or –30% of the reference helmet properties.

Results in terms of HIC, brain pressure and Von Mises





Main Conclusions (helmet)

The optimisation against headform's response versus HIC and human head's response in terms of intra_cerebral stesses does not lead to the same optimum helmet.

Laboratoire des Systèmes BioMécaniques

Institut de Mécanique des Fluides et des Solides
UMR 7507 ULP-CNRS
Strasbourg - France

Thank you

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Helmet Retention and Physiology

Paul Brühwiler
Laboratory for Protection and Physiology
Swiss Laboratories for Materials Testing and Research, St. Gallen

Outline

- Helmet Retention
  - Background
  - Results
- Helmet Physiology
  - Heat
    - ALEX, a heated, perspiring manikin headform
    - Motorcycle helmet ventilation
    - Bicycle helmets, the question of head angle
  - CO_2—Subject study
- Conclusions and Outlook

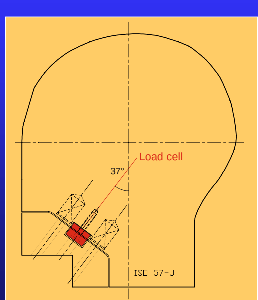
Helmet Retention: Test for Effectiveness of Retention System (“Roll-off Test”)

B. Chinn et al., COST 327 Final Report.

Background, Strategy

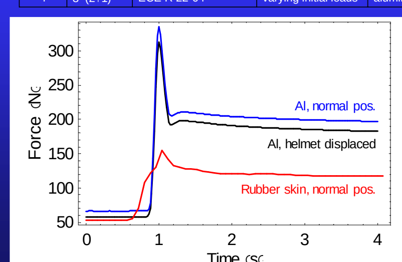
- Helmets of motorcyclists are lost in 14% of the accident cases, mainly after the first or the second impact of the head: COST 327.
- Present Norms: BS 6658:1985 and ECE R22-04
- EMPA has a long history in impact protection testing
- Goal: Examine the headform-dependence of the testing results
- New Aspect: Measure forces on the chin

The Headform (A. Descrovi)



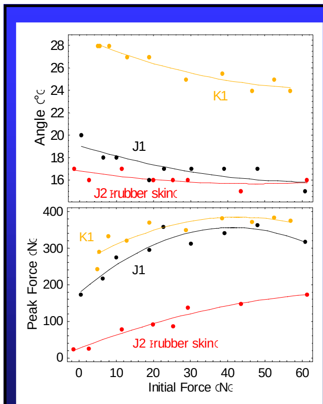
A built-in load cell allows the measurement of static and dynamic forces exerted on the chin.

Test series	Tested helmets	Helmet positioning	Attachment of the retention system	Headform surface
1	18 (2×9)	displacement 25mm toward the front of the headform	normal (tight)	smooth aluminium surface
2	18 (2×9)	ECE R 22-04	normal (tight)	smooth aluminium surface
3	18 (2×9)	ECE R 22-04	normal (tight)	headform covered with a rubber skin
4	3 (2+1)	ECE R 22-04	varying initial loads	aluminium and rubber surface



Test Protocol, Results

Summary of the Results



- The Roll-off Test is sensitive to the particulars of the headform and the initial force
- The peak force on the chin is even more sensitive to these parameters

See B. Chinn et al., COST 327 Final Report, for more details.

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Helmet Physiology: Heat

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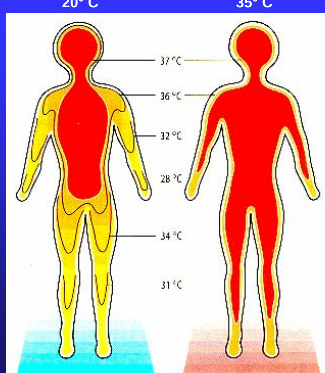
External Temperature

20° C **35° C**



Steady-State Temperature Distribution of the Nude Body

Core temperature and skin temperature drive the thermal regulation of the body.

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Thermal Sensitivity of the Head/Face

- In hyperthermia, the head is the strongest local sensor for heating, and for discomfort due to heating or cooling. (Cotter et al., 1996)
- The head is the most sensitive part of the body to draughts. (Fanger & Christensen, 1986)
- In hyperthermia, cooling the face by fanning (air) cools the body and skin. Thermal comfort follows a combination of T_{face} and T_{core}. (Kato et al., 2001)
- Cooling the head lowers sweat rates for the entire body. (Desruelle et al., 2000)

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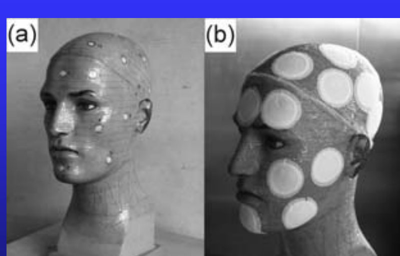
Heated Manikin Headform: "ALEX"



A. Hering et al., Proc. 4IMMM (2001).
P. A. Brühwiler, Meas. Sci. Technol. **14**, 217-227 (2003).

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"ALEX" at home

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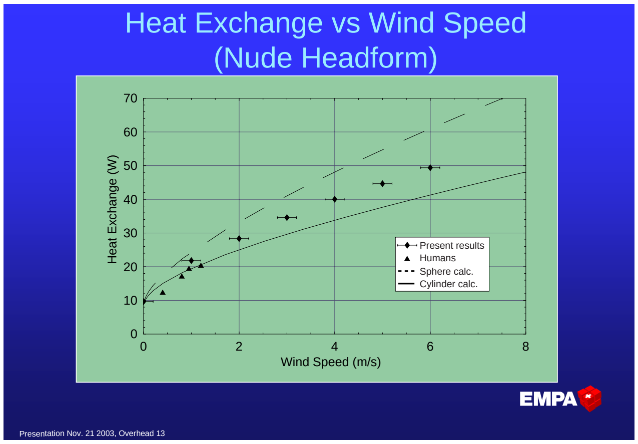
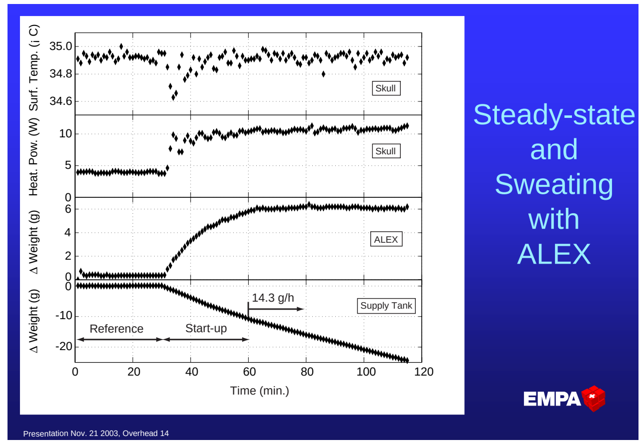
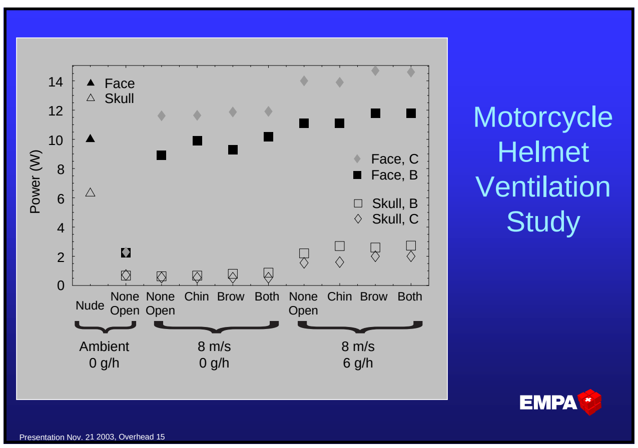
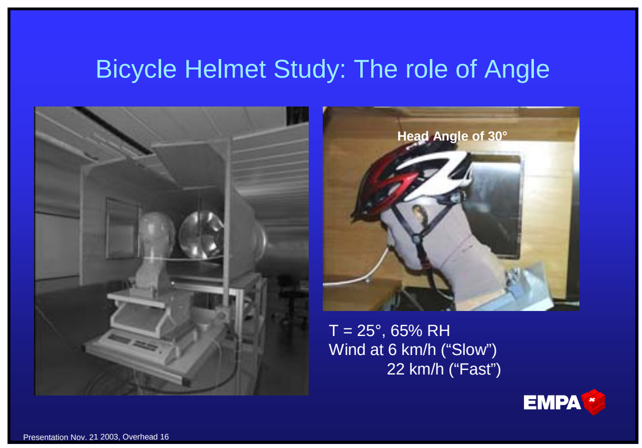
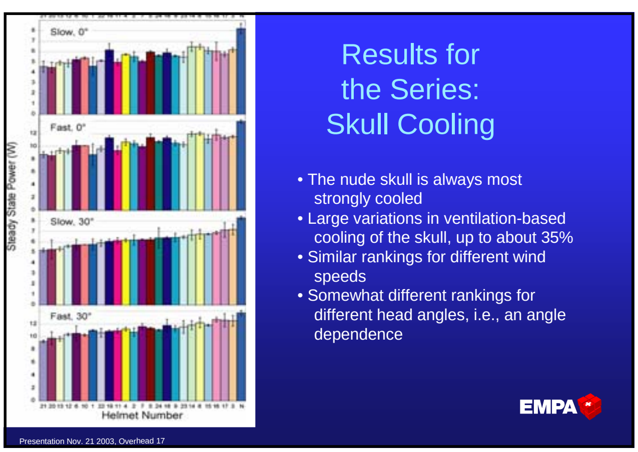

Heat Exchange vs Wind Speed
(Nude Headform)
Heat Exchange (W)
Wind Speed (m/s)
70
60
50
40
30
20
10
0
0
2
4
6
8
Present results
Humans
Sphere calc.
Cylinder calc.
EMPA
Presentation Nov. 21 2003, Overhead 13


Steady-state and Sweating with ALEX
Surf. Temp. (¡ C)
35.0
34.8
34.6
Skull
Heat. Pow. (W)
10
5
0
Skull
Δ Weight (g)
6
4
2
0
ALEX
Δ Weight (g)
0
-10
-20
14.3 g/h
Supply Tank
Reference
Start-up
0
20
40
60
80
100
120
Time (min.)
EMPA
Presentation Nov. 21 2003, Overhead 14


Motorcycle Helmet Ventilation Study
Power (W)
14
12
10
8
6
4
2
0
Face
Skull
Face, C
Face, B
Skull, B
Skull, C
Nude
None Open
None Open
Chin
Brow
Both
None Open
Chin
Brow
Both
Ambient
0 g/h
8 m/s
0 g/h
8 m/s
6 g/h
EMPA
Presentation Nov. 21 2003, Overhead 15


Bicycle Helmet Study: The role of Angle
Head Angle of 30°
T = 25°, 65% RH
Wind at 6 km/h ("Slow")
22 km/h ("Fast")
EMPA
Presentation Nov. 21 2003, Overhead 16


Results for the Series: Skull Cooling
• The nude skull is always most strongly cooled
• Large variations in ventilation-based cooling of the skull, up to about 35%
• Similar rankings for different wind speeds
• Somewhat different rankings for different head angles, i.e., an angle dependence
Steady State Power (W)
Slow, 0°
Fast, 0°
Slow, 30°
Fast, 30°
Helmet Number
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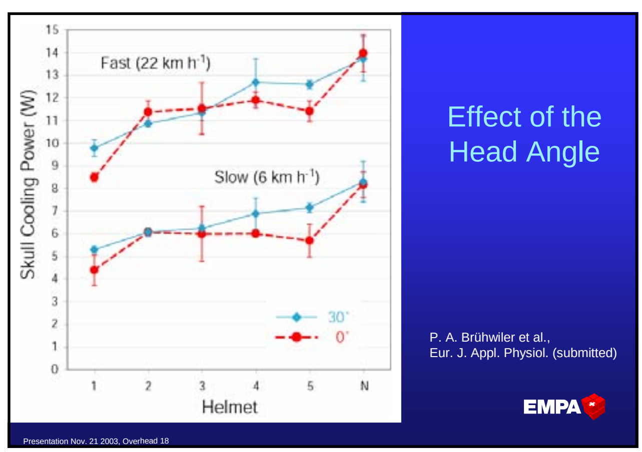
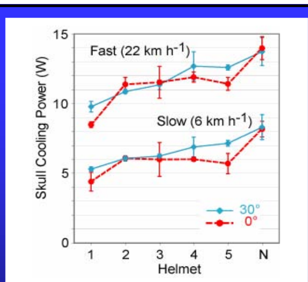

Effect of the Head Angle
Skull Cooling Power (W)
Fast (22 km h⁻¹)
Slow (6 km h⁻¹)
30°
0°
1
2
3
4
5
N
Helmet
P. A. Brühwiler et al.,
Eur. J. Appl. Physiol. (submitted)
EMPA
Presentation Nov. 21 2003, Overhead 18

Subject Tests



Median Ranking	2	0	0	3	3
Mean*	2.5	0.6	-0.2	2.9	2.0
Std. Dev.	0.6	0.8	1.1	2.0	0.9
Preference	30°	-	-	30°	30°

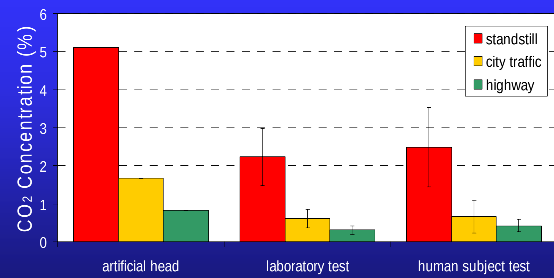
- Head angle (0° or 30°) varied until the subject could decide if one angle was better in ventilating the skull.
- The ranking varied from -8 (0° much better) to +8 (30° much better).

Results

- No helmet is better at 0° than at 30°; several are better at 30°.
- The level of improvement generally follows the results with ALEX.

EMPA

CO_2 Concentrations in Motorcycle Helmets



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Summary and Outlook

- Retention tests could be more realistic, lead to improved retention systems; comfort?
- Systematic study of helmet ventilation pays
- New aspects emerge: e.g., the head angle affects the ventilation by up to 20%
- Human subjects are sensitive to this
- Current and future studies aimed at development
- CO_2; good ventilation reduces this problem

EMPA

Workshop on future motorcycle helmets and visors

Ventilation, Noise and Vision

Nick Vaughan

Health and Safety Laboratory

Sheffield / Buxton

Ventilation, Noise and Vision

- **Who are HSL?**
- **Why are we involved?**
- **Why are these aspects important?**
- **What can be done?**

Health and Safety Laboratory

HSL CAPABILITIES

Fire, Explosions & Process Safety

Occupational & Environmental Health

Engineering Control

Work Environment

Risk Assessment

Behavioural & Social Sciences

Specialist Photographic & Technical Services

Field Scientific Support Unit

Why we are involved

- **Background in occupational health and safety**
- **Transferable knowledge and skills**
- **Involvement with development of standards and test methods for PPE**
- **Past experience of collaborative EU-funded projects**

Ventilation

Factors affected:

- **Thermal comfort of the wearer**
- **Dead space (stuffiness)**
- **Misting of visor**

Thermal comfort of the wearer

Ventilation = cooling

In hot conditions
cool = comfortable

Comfort = more helmet wearing
= greater safety

Thermal comfort of the wearer

Aim for a simple means of testing / classifying helmets for ventilation:

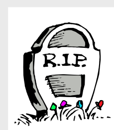
- **need not be fully realistic – for classification only**
- **will complement information from EMPA (fully instrumented sweating headform)**
- **removes subjectivity from comfort assessment**

Thermal comfort of the wearer

Ties in with work already underway to develop a <u>simple</u> ventilation test for other protective helmets

Validate against human subjects

Dead space – rebreathed air



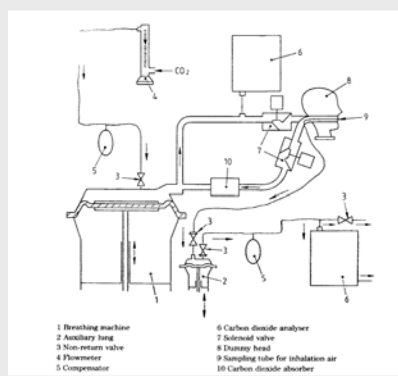
Increased levels of CO_2
Decreased levels of O_2

Leads to:
- Fuzzy head/drowsiness
- Loss of concentration
- Feeling of claustrophobia
- Discomfort

Dead space – rebreathed air

Suitable test methods and equipment already exist in RPE Standards (eg EN 270 – airline hood BA)

Limits for CO_2 already established



Vision

Resistance to internal misting

Shedding of external rain and spray

HEALTH & SAFETY LABORATORY

Misting of visors

A function of:

- Dead space
- Ventilation
- Visor materials
- Surface treatments
- External environment
- Durability of treatments

HEALTH & SAFETY LABORATORY

Misting of visors

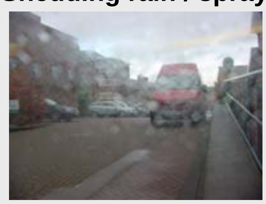
Existing test method and classification system for misting of goggles / spectacles (SMT-4)

Adapt for testing of motorcycle helmets / visors:

- warm wet exhalation
- facing air movement

HEALTH & SAFETY LABORATORY

Shedding rain / spray



Function of:

- Visor surface properties
- Aerodynamics
- (speed)

HEALTH & SAFETY LABORATORY

Shedding rain / spray

Set up spray system in wind tunnel

Test at one or more air velocities

Assess visibility as for misting

HEALTH & SAFETY LABORATORY

Vision

Control of glare

HEALTH & SAFETY LABORATORY

Noise

Noise attenuation:
✓ reduction of engine / road noise
✘ isolation from warning sounds / signals
- OPTIMIZE

Noise generation:
• function of speed and aerodynamics
✘ reduces signal-to-noise ratio / awareness
- AIM TO REDUCE

HEALTH & SAFETY LABORATORY

Noise attenuation

Intrinsic property of the helmet
Can be assessed in the laboratory
Can be validated with human subjects

Classify as for ear defenders:
- octave band data
- HML frequency
- SNR (single number rating)

HEALTH & SAFETY LABORATORY

Noise generation

Laboratory wind tunnel measurements:
• air speeds up to 100 mph
• acoustic headform
• objective quantitative noise measurement

Correlate with rider tests:
• real riders, real conditions
• in-ear noise measurement system worn
• compare subjective / objective results

HEALTH & SAFETY LABORATORY

Outcomes

HEALTH & SAFETY LABORATORY

Future Motorcycle Helmets and Visors

Impact testing, criteria and limits

Vincent St.Clair

Impact testing, criteria and limits

Aim –

20% reduction in motorcycle fatalities

Motorcycle helmet test protocols

COST 327 research complete
- provisional test protocols

Advanced helmet technology
- differentiate performance advances

Advanced test tools

COST 327 HELMET TEST SPECIFICATION

Table 10.1 COST 327 Helmet Test Specification

Cost 327 Helmet Test Specification	Test Anvil	Headform Type and Size: Metal	Headform Type and Size: Bimass[1]	Test Sites on Helmet[2]: B	X	R	P	S	Projections
Impact Velocity[3] (m/s)	F (flat)	A E J M O A E M O	 J J	8.5 6.0	8.5 6.0	8.5 6.0	8.5 6.0	5.5[3] 5.5	-
	K (kerbstone)	A E J M O A E M O	 J J	8.5 6.0	8.5 6.0	8.5 6.0	8.5 6.0	5.5[3] 5.5	-
	A (abrasive)	-	J	8.5	8.5	8.5	8.5	8.5	-
	B (bar)	-	J	-	-	-	-	-	8.5
Test Limits[4,5]	HIC			1000 at 6.0m/s and 2400 at 5.5m/s (S) and 8.5m/s					metal headform only
	Peak Linear Acceleration			180g at 6.0m/s and 5.5m/s (S) 180g at 6.0m/s and 275g at 8.5m/s and 5.5m/s(S)					brain for Bimass, resultant for metal headform
	Peak Relative Linear Acceleration			80g at 6.0m/s and 5.5m/s(S)					Bimass headform o only
	Peak Relative Rotational Acceleration			35 000 rad/s^2,					Bimass headform only

[1]based on Hybrid III Motorcycle Anthropometric Test Dummy headform
[2]as defined in UN ECE R22.05, paragraphs 7.3.4.2, 7.4.1.3 and 7.4.2.3 Helmet test sites: front - B
side - X
rear - R
crown - P
chin - S

[3]as defined in UN ECE R22.05.
[4] metal headform commensurate with AIS 2 and AIS 5/6
[5]Bimass commensurate with AIS2

Test protocol requirements

Test requirements

- Appropriate
- Economically viable
- Repeatable
- Reproducible

Assessment parameters

- Linear impact performance
- Oblique impact performance
  (surface friction and projections)
- Helmet retention
- Vision
- Ventilation
- Noise

Linear Impact Performance

COST 327

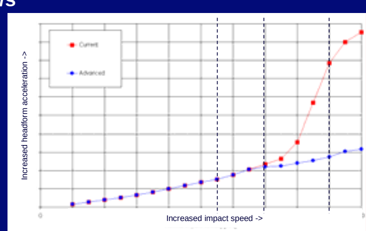
24% increase energy absorption > Reduced injury severity AIS 5-6 to AIS 2-4 (20%cases)

Linear Impact Performance

- Test variables
  - Headforms
  - Velocity
  - Impact surfaces
  - Impact sites
  - Conditioning
- Test criteria
  - Peak acceleration
  - HIC

Linear Impact Performance

- Two test velocities
  - (based on COST 327 and advanced helmet)
- High 8.5m/s to 10m/s
- Low 6.0m/s



Oblique Impact Performance (Surface Friction and Projections)

- Head loading
  - Correlation with head injury
- Advanced helmets
  - reduced head rotation
- Measurement –
  - External loads
  - Direct measurement

Oblique Impact Performance (Surface Friction and Projections)

- Method A

Tangential load and impulse limits

- Method B

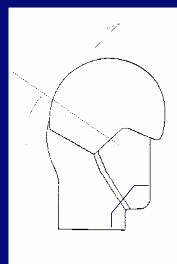
Energy absorption limits

Oblique Impact Performance (Surface Friction and Projections)

- New test limits
  - Reduced tangential force/ impulse limits (Method A)
  - Reduced energy input (Method B)
- Alternative test methods

Retention

- COST 327 findings
  - high ejection rate
- Future research
  - identify mechanisms
- Modification of existing method



Summary

- Promote next generation helmets
- New test protocols to improve helmet performance
- Delivery mechanisms

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS
21 November 2003

DELIVERY MECHANISMS

Steve Gillingham
Senior Engineer
Secondary Safety Branch
Department for Transport

Dr Bryan Chinn
Consultant
TRL

DELIVERY MECHANISMS

Routes to Improving Helmet Safety

- Legislation (but minimum standard)
- Marketing advantage
- Avoid marketing disadvantage
- Product Liability Issues
- Consumer Information

DELIVERY MECHANISMS

How to bring about
better helmets and visors?

1. Department for Transport Project
2. Collaborative Projects
3. Regulations or Standards
4. Consumer Information Scheme

1. DEPARTMENT FOR TRANSPORT PROJECT

- Workshop
- Regulatory Impact Assessment
- Test methods and performance criteria
- Innovative helmets and visors
- Test Protocols (Regulations, Standards or Consumer Information Scheme)

2. COLLABORATIVE PROJECTS

- Potential Partners
- Key players - Common goals
- Technology Transfer
- Include Helmets-Visors + Test Tools
- EC Framework Proposal 6 (2004)

2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Background to FP6

- EC desires to *strengthen* and *integrate* the European Research Area (ERA)
- Aim is to compete with research *critical mass* of US and Japan
- Thereby address societal needs and increase European competitiveness

2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Qualifying Rules

- Consortium including
  - Manufactures
  - Research organisations
  - Testing organisations
  - Increasingly SME
- Funding
  - 50% EC - 50% contribution in kind or other source

2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Integration of Projects

- Activities:
  - Research
  - Technological Development/Demonstration
  - Training
  - Dissemination
- Budget of €10s of millions
- Duration 3-5 years

2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Structure of the 6FWP

Seven Priority Themes:

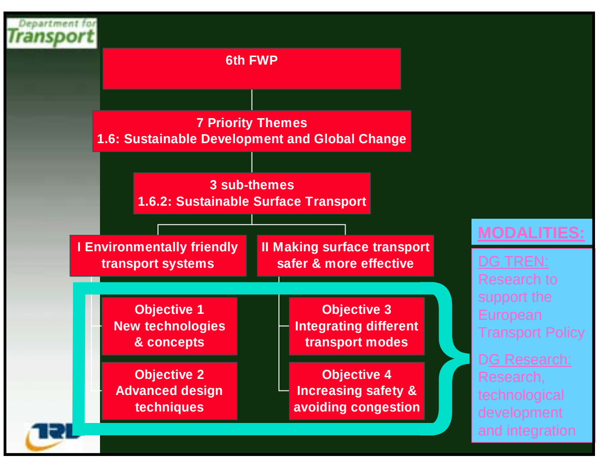
- 1.1 Genomics and Biotechnology for Health
- 1.2 Information Society
- 1.3 Nanotechnologies, intelligent materials, new production processes
- 1.4 Aeronautics and Space
- 1.5 Food Safety and Health Risks
- 1.6 Sustainable Development and Global Change
- 1.7 Citizens and Governance in the Knowledge Society

1.6: Sustainable Development and Global Change

Three Sub-Themes:

- 1.6.1 Sustainable Energy Systems
- 1.6.2 Sustainable Surface Transport
- 1.6.3 Global Change and Ecosystems

- 1.6.2 Sustainable Surface Transport:
  - I Environmentally friendly transport systems and means of transport
  - II Making surface transport safer, more effective and more competitive



2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Budget Distribution (EC ~60%)

Car accidents	€ 2.8M
Car-heavy truck accidents	€ 1.3M
Pedestrian/pedal cyclist accidents	€ 2.4M
Motor cycle accidents	€ 1.1M
Injury Biomechanics + dummies	€ 3.0M
Enabling technologies	€ 2.3M
Virtual testing	€ 2.5M
Other	€ 3.3M
TOTAL	€17.8M

2. COLLABORATIVE PROJECTS

EUROPEAN COMMISSION
FRAMEWORK PROPOSAL 6

Sub-Project: 1.6.2

- Motorcycle Accidents
- Two-wheeled motor vehicles vs. Car
- Motorcyclist vs. Road Infrastructure
- Motorcyclist Protective Devices

3. REGULATIONS AND STANDARDS

- UN ECE Regulation 22
- UN ECE Regulation XXX ?
- BS 6658 : 1985
- BS 4110 : 1999
- BSI Product Approval Specification ?

3. REGULATIONS AND STANDARDS

UN ECE Regulation 22

- - protective helmets and visors for motor cycle and moped users
- - currently at 05 series of amendments, 06 series of amendments in 2005?

3. REGULATIONS AND STANDARDS

UN ECE Regulation XXX ?

- - new regulation for ‘high performance’ protective helmets and visors for motor cycle and moped users.

3. REGULATIONS AND STANDARDS

- BS 6658 : 1985
- - protective helmets for vehicle users
- - currently at Amendment No.1, Amendment No.2 in 2005?

3. REGULATIONS AND STANDARDS

BS 4110 : 1999

- - visors for vehicle users
- - Amendment No.1 in 2005?

3. REGULATIONS AND STANDARDS

BSI Product Approval Specification ?

- New stand-alone Specification

4. CONSUMER INFORMATION SCHEME

EuroNCAP Aims

- Reduce Road Accident Casualties
- Consumer buying information
- Incentive to manufacturers
- Recognition of excellence
- Empower safety engineers

4. CONSUMER INFORMATION SCHEME

Formation of EuroNCAP

Developed by TRL and VSC for DETR

TWG and Industrial Liaison

Current Sponsors:

European Commission	
UK	AIT - FIA
Sweden	ICRT
Netherlands	ADAC
Germany	
France	

4. CONSUMER INFORMATION SCHEME

EuroNCAP Test Procedures

- Frontal Impact

- Side Impact
- Side Impact Pole test

- Pedestrian Protection

4. CONSUMER INFORMATION SCHEME

EuroNCAP Car Selection

- Best selling model
- Standard EU safety equipment
- Anonymous purchase
- Manufacturer funded tests
  - Car Model not tested by EuroNCAP
  - Car with additional safety features
  - Re-tests with improvements

4. CONSUMER INFORMATION SCHEME

Manufacturer Involvement

- Supply set up information
- Witness the tests
- Compare results with own data
- Attend “One to One” meeting

- Regular TWG meetings with industry

4. CONSUMER INFORMATION SCHEME

Performance Assessment

- Dummy data
- Dummy movement
- Vehicle deformation
- Inspection Modifiers
- Compatibility of safety equipment

4. CONSUMER INFORMATION SCHEME

Star Rating

4. CONSUMER INFORMATION SCHEME

BRITISH EQUESTRIAN FEDERATION HELMET ASSESSEMENT PROGRAMME

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS
21 November 2003

DELIVERY MECHANISMS

Steve Gillingham
Senior Engineer
Secondary Safety Branch
Department for Transport

Dr Bryan Chinn
Consultant
TRL

WORKSHOP ON FUTURE MOTORCYCLE HELMETS AND VISORS

21 November 2003

WAY FORWARD
AND DISCUSSIONS

- **SHORT TERM [2005]**

Linear impact performance - High speed and low speed
Test limits based on COST 327
Oblique impact performance
Method A vs Method B. More stringent limits.
Method A - Instrumented head. Must ensure alignment with Method B.
Helmet retention - Mechanisms? Point of Sale advice.
Vision
Durability of 'advanced' materials

- **MEDIUM TERM [2008]**

Real world accident simulation
Alternative tools (headforms)
Bi-mass (inc Bi-mass test limits)
NOCSAE Headform
FE simulation
Ventilation and noise research

- **LONG TERM [2013]**

Smart materials
Ventilation and noise delivery

Appendix A. Workshop reports

(i) Programme

(ii) Organisations attending

(iii) Presentations

(iv) Workshop Report

WORKSHOP ON
MOTORCYCLE HELMETS AND VISORS:

21st November 2003
London

Note of the workshop held on 21st November 2003

Version 1.0
August 2004

Steve Gillingham
Department for Transport

Andrew Mellor
Transport Research Laboratory

www.mhap.info

CONTENTS

WORKSHOP ON MOTORCYCLE HELMETS AND VISORS:
Evaluation of Future Helmets

Date:	Friday November 21st, 2003
Venue	Department for Transport Great Minster House, Marsham Street, London SW1P 4DR

The workshop was chaired by Mr GILLINGHAM (Department for Transport).

Secretariat Mr MELLOR (Transport Research Laboratory)

1. Welcome and Introduction

A welcome and introduction was given by Mr FENDICK (Department for Transport). The presentation slides are provided separately.

2. Background Work

A presentation on the background research conducted by TRL including the EC COST 327 programme was given by Dr CHINN. The presentation slides are provided separately.

No questions or comments were raised.

3. Improved protection by advanced helmet performance and technologies

A presentation on the research conducted by TRL into improved helmets and technologies was given by Mr MELLOR. The presentation slides are provided separately.

In response to a question about the unit costs it was explained that the current unit cost was approximately €3000 but this could be expected to drop to €300 due to economies of scale. A report entitled 'Improved Motorcycle Helmet Design. Part 4. performance assessment, injury savings and helmet costs' available on the website presents an increased cost of £150 per helmet*.

* Authors comment

Dr PHILLIPS (PPHS) commented that a helmet which had many of the performance advantages of the TRL helmet was ready for production at a unit cost in the upper-middle price category.

In response to a question about the injury savings versus wearing rates it was explained that the maximum fatality-reduction of 20% assumed a 100% wearing rate. In response to a question about comfort, noise, visor misting, peripheral vision it was explained that these issues would be discussed in the next sessions.

In response to a question about which test headforms had been used to show the performance advantages of the new helmet, it was explained that the helmet would give improved results with any appropriate headform or test methodology including the ECE free-motion and the BS/USA guided methods.

In response to a question asking whether, as the new technology was some distance from market, a consumer information scheme would yield earlier benefits, it was explained that such an approach would be discussed during the Delivery Mechanisms session.

In response to a question about the shelf life of the new materials it was explained that this was at least the same if not better. It was noted that an extended shelf or operation life could absorb some of the cost element. It was also noted that a durability cycle may be important to preclude materials that would damage easily.

4. Improved test procedures

• Bi-mass headform

A presentation on research into the Bi-mass headform conducted by Universite Louis Pasteur (Strasbourg) was given by Professor WILLINGER. The presentation slides are provided separately.

In response to a question asking whether the axis of rotation should be the CoG for the FE simulation, it was explained that as the impact duration was very short, in fact less than 10ms, there was no time for the neck to be involved.

• Helmet retention and physiology

A presentation on aspects of visor performance and helmet physiology was given by Mr BRUEHWILER from EMPA. The presentation slides are provided separately.

In response to a question asking whether the 14% of ejected helmets were fitted correctly it was explained that this was not known. However, a study by TRL, programmed for 2004 would investigate the effect of helmet fit and retention on a sample of volunteer subjects.

It was commented that during military studies it was found that the mass of a helmet had a strong influence on the physiological effects. Also the sweat rate was important.

It was commented that there was a probable correlation between exertion and sweat rate and that the highest level of exertion was manoeuvring a motorcycle rather than riding a motorcycle.

In response to a question regarding the difference between hair and non-hair it was explained that this was work in progress at EMPA.

In response to a question regarding the effect of exhausting humidity versus stagnating humidity, it was explained that temperature by itself was important and that it was possible to overheat without a build up of sweat or humidity.

- **Ventilation, noise and vision**

  A presentation on test methods for assessing helmet retention and helmet physiology was given by Dr VAUGHAN from Health and Safety Laboratory. The presentation slides are provided separately.

In response to a question asking whether the standard head shapes represented the real population it was commented that a suite of headforms may be required.

In response to a question regarding visor contamination with fine sticky particulates it was explained that “Arizona Road Dust” was prescribed in certain standards.

In response to a question regarding the strength of the information that motorcycling causes hearing loss it was explained that current levels (*as measured experimentally**) are within those published to cause hearing loss.

** authors comment*

- **Impact testing, criterion and limits**

  A presentation on helmet impact testing methodologies was given by Mr St. CLAIRE from TRL. The presentation slides are provided separately.

In response to a comment that the penetration test may be important, it was explained that if the current research rediscovers that penetration is important then this will not be ignored.

In response to a question whether the “current” performance was on polycarbonate and GRP helmets it was explained that “current” was based on a generic performance which included both.

In response to a question about the life span of helmets there was some discussion as to whether carbon fibre was more or less durable than current materials. It was established that a durability test would be considered.

In response to a question whether additional protection of the advanced helmet should be added to the high-velocity or mid-velocity range it was explained that the helmet system was tuned to achieve a fatality reduction rather than an injury reduction but that the system could be tuned to achieve different optimisations.

In response to a question whether peak acceleration and HIC are the best injury measures it was commented that advanced helmet performance could be evaluated against new parameters.

In response to a question whether the 20% fatality reduction may be achieved by a 20% reduction in the motorcycle fleet it was explained that the target reduction assumed the number of motorcycles, motorcycle kilometres and motorcycle accidents remained constant. *If the exposure changed significantly then the effects would be considered*.*

** authors comment in italics*

In response to a comment regarding ventilation and retention that a hotter rider may have a slacker strap and that most riders may have the strap insufficiently tight it was explained that there was no evidence as to the mechanism for the 14% ejection rate. *However, the loss before first impact was only 1.3% and the loss during the impact sequence was 12.9%**

** authors comment in italics*

5. Delivery mechanisms - DfT projects, collaborative projects, regulations and consumer information scheme

A presentation on potential delivery mechanisms was given by Mr GILLINGHAM and Dr CHINN. The presentation slides are provided separately.

It was commented that the Euro-NCAP comparison was interesting and liaison with the consumer associations was very important to the success of Euro-NCAP. It was noted that there was no-one present at the Workshop from the motorcycle rider consumer associations. In response, it was explained that consumer associations had been invited. *Representatives from BMF, MCIA and RMIF were in attendance. The Consumers' Association (Which?), MCN and RiDE magazine had been invited (cf list of invitees and list of attendees separately).*

** authors comment in italics*

It was commented that a rapid implementation could be achieved by a Type A or Type B approach. Or by a rolling series of amendments to Regulation 22-05 (ie 06, 07 etc). *This approach would require a formal proposal to GRSP from the informal group on Regulation 22*.*

** authors comment in italics*

In response to a question about the date of Regulation 22-06 it was explained that 2005 was the proposed date for the committee to reach collective agreement on the new standard. The arrival of new helmets on the market would probably be somewhat later.

In response to a question regarding the source of the data for the BEF – ENHAP programme, it was explained that the BEF developed the protocol, the testing was conducted by HPE and TRL analysed and reported the results.

It was commented that FEMA had, in recent times, had difficulty in securing EC funding following recent organisational changes. It was explained that the DfT had committed funding to create the FW6 opportunity and it would be extremely important to liaise closely with those delegates overseeing the FW programme.

It was commented that a New European Standard may be an option rather than a revision to Regulation 22. It was explained that the United Nations ECE Regulation 22 was adopted by all the EU states including the UK (and some non EU countries) and that this is, in effect, the European Standard. There are no current plans for an EN (European Norm) alternative.

It was commented that work on an EN ceased and was removed from the PPE Directive because no agreement was met. It was also explained that this was one point of view although the issue was complex. *The creation of an EN was considered unnecessary given the prior existence of Regulation 22*.*

** authors comment in italics*

It was commented that the BS6658 was still active and a number of helmets were still being homologated to this Standard.

CLOSE OF MORNING SESSION

6. Way forward and discussions

This session was chaired by Mr GILLINGHAM and an active summary of the discussions was prepared by Mr MELLOR. A summary is provided as a separate file.

This discussion considered how improvements may be achieved and implemented over three time frames:

Short term	2005
Medium term	2008
Long term	2013

The discussions included methods and protocols for head protection, ergonomics and physiology. The following tasks were outlined for each of the time frames:

1. SHORT TERM [2005]

Linear impact performance to include high speed and low speed

Test limits based on COST 327

More stringent limits for oblique impact testing

Development of instrumented head for Method A and correlation with Method B

Helmet retention – evaluation of mechanisms and preparation of point of sale advice

Vision – specification for light reactive visor materials

Durability of ‘advanced’ materials

2. MEDIUM TERM [2008]

Real world accident simulation

Alternative tools (including advanced headforms)

Bi-mass (including Bi-mass test limits)

NOCSAE Headform

FE simulation

Ventilation and noise research

3. LONG TERM [2013]

Smart materials

Ventilation and noise delivery

7. Conclusions

Based on the above and subsequent meetings between Mr Gillingham and Mr Mellor the work programme set out in Figure 1 has been developed with the respective partner organisations together with a proposal for a collaborative project to be submitted to the European Commission for Framework Programme 6 funding."

A proposed content for the work programme is set out in Figure 1 and comprises six main elements as follows.

HEAD PROTECTION S0232-VF (to December 2005)

HEAD PROTECTION PART 1 (July 2005 to December 2006)

HEAD PROTECTION PART 2 (July 2007 to December 2008)

Partners to include; Industry, Research, Academia, Testing and Certification

(Lead Partners: TRL, ULP-Strasbourg, CFT, MERL, others pending)

ERGONOMICS AND PHYSIOLOGY S0232-VF (to December 2005)

ERGONOMICS AND PHYSIOLOGY PART 1 (July 2005 to December 2006)

ERGONOMICS AND PHYSIOLOGY PART 2 (July 2007 to December 2008)

Partners to include; Industry, Research, Academia, Testing and Certification, user groups and road safety groups.

(Lead Partners: TRL, EMPA, HSL, ESRI, others pending)

The next workshop event is scheduled for spring 2005, subject to progress.

S0232VF = Current DfT contract
HP = Head Protection
E&P = Ergonomics and Physiology

			2003				2004				2005				2006				2007				2008			
			1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
		Funding				DFT	DFT	DFT	DFT	DFT	DFT	DFT	DFT	DFT												
Element	**Decription**	Funding									FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6
S0232 VF	Inception Workshop																									
S0232 VF	6th Framework																									
S0232 VF	Regulatory Impact Assesment																									
S0232 VF	Revisions to retention tests and other regulatory tests																									
S0232 VF	Advanced Test Protocols	Bi-mass evaluation																								
S0232 VF	Advanced helmets	Evaluation of innovative helmet concepts*																								
S0232 VF	Advanced Test Protocols	Consumer information scheme*																								
S0232 VF	Advanced helmets	Durability of 'advanced' materials																								
S0232 VF	Advanced Test Protocols	Reproducability/repeatability																								
S0232 VF	Evaluation of innovative visor concepts for low sun and glare																									
S0232 VF	Specification for light reactive visors																									
S0232 VF	Evaluation of helmet retention mechanisms																									
Partners	TRL - UK	Universite Louis Pasteur - F																								
	HSL - UK	EMPA - CH																								
	Newton / HPE - I/UK	CFT - UK																								
	Phillips Helmets - UK																									
HP1	Advanced Test Protocols	Method A instrumented head																								
HP1	Advanced Test Protocols	Method A and B correlation																								
HP1	Advanced Test Protocols	Bi-mass evaluation																								
HP1	Advanced Test Protocols	Reproducability/repeatability																								
HP1	Advanced helmets	Evaluation of innovative helmet concepts																								
HP1	Advanced Test Protocols	Consumer information scheme*																								
HP1	Advanced helmets	Durability of 'advanced' materials																								
HP1	Advanced helmets	Economies for advanced performance																								
Partners	TRL-UK	Universite Louis Pasteur - F																								
	UTAC-F	SG Studio - I																								
	INSPEC-UK	Newton / HPE - I/UK																								
	MERL-UK	CFT - UK																								
	Phillips Helmets-UK	IDC - UK																								

* High and low test speeds with limits based on COST 327

Figure 1. Proposed Work Programme (continued over sheet)

S0232VF = Current DfT contract
HP = Head Protection
E&P = Ergonomics and Physiology

					2003				2004				2005				2006				2007				2008			
					1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
				Funding				DFT	DFT	DFT	DFT	DFT	DFT	DFT	DFT	DFT												
	Element	**Decription**		Funding									FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6	FP6
	HP2	Real world accident simulation to evaluate advanced headforms																										
	HP2	Alternative test tools (Including Bi-Mass and NOCSAE)																										
	HP2	FE simulation to determine next generation peformance																										
	HP2	Development and evaluation of advanced 'smart' materials																										
	HP2	Future helmet concepts																										
	HP2	Economies for advanced performance																										
Partners		TRL-UK	Universite Louis Pasteur - F																									
		UTAC-F	SG Studio - I																									
		INSPEC-UK	Newton / HPE - I/UK																									
		MERL-UK	CFT - UK																									
		Phillips Helmets-UK	IDC - UK																									
	E&P1	Evaluation of innovative visor concepts for low sun and glare																										
	E&P1	Specification for light reactive visors																										
	E&P1	Ventiliation and noise test protocols																										
	E&P1	Evaluation of helmet retention mechanisms																										
	E&P1	Advanced vision requirements																										
Partners		TRL - UK	EMPA - UK																									
		HSL - UK	BMF - UK																									
	E&P2	Ventilation and noise development																										
	E&P2	Delivery of advanced E&P systems																										
Partners		TRL - UK	EMPA - CH																									
		HSL - UK	BMF - UK																									
		ACEC - I	QinetiQ - UK																									

* High and low test speeds with limits based on COST 327

Figure 1. Proposed Work Programme (continued from previous sheet)

Appendix B. Test methods

(i) COST 327 Proposals

(ii) Helmet Retention

(iii) Impact Sites

Appendix B. Test methods

(i) <u>COST 327 Proposals</u>

(ii) Helmet Retention

(iii) Impact Sites

COST 327 Helmet Test Specification

Cost 327 Helmet Test Specification	Test Anvil	Headform Type and Size		Test Sites on Helmet[2]					
		Metal	Bimass[1]	B	X	R	P	S	Projection
Impact Velocity[3] (m/s)	F (flat)	A E J M O A E M O	 J J	8.5 6.0	8.5 6.0	8.5 6.0	8.5 6.0	5.5[3] 5.5	-
	K (kerbstone)	A E J M O A E M O	 J J	8.5 6.0	8.5 6.0	8.5 6.0	8.5 6.0	5.5[3] 5.5	-
	A (abrasive)	-	J	8.5	8.5	8.5	8.5	8.5	-
	B (bar)	-	J	-	-	-	-	-	8.5
Test Limits[4,5]	HIC			1000 at 6.0m/s and 2400 at 5.5m/s (S) and 8.5m/s metal headform only					
	Peak Linear Acceleration			180g at 6.0m/s and 5.5m/s (S) brain for Bimass, 180g at 6.0m/s and 275g at 8.5m/s and 5.5m/s(S) resultant for metal headform					
	Peak Relative Linear Acceleration			80g at 6.0m/s and 5.5m/s(S) Bimass headform only					
	Peak Relative Rotational Acceleration			35 000 rad/s^2, Bimass headform only					

[1]based on Hybrid III Motorcycle Anthropometric Test Dummy headform
[2]as defined in UN ECE R22.05, paragraphs 7.3.4.2, 7.4.1.3 and 7.4.2.3: Front – B, Side – X, Rear – R, Crown – P, Chin - S
[3]as defined in UN ECE R22.05.
[4] metal headform commensurate with AIS 2 and AIS 5/6
[5]Bimass commensurate with AIS2

Appendix B. Test methods

(i) COST 327 Proposals

(ii) <u>Helmet Retention</u>

(iii) Impact Sites

(ii) Helmet Retention subject assessment results

Subject 1 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Subject Number: BMF_001
Survey date: 21 May 2005
Venue: BMF Peterborough

Rider details

Age ~~____ years~~ sex male [x] female [ ]

Hair description: SHORT

Head geometry
- horizontal circumference: 58 cm
- coronal plance circumference: 66 cm
- longditudal length: 19.8 cm
- lateral length: 16.5 cm

Helmet details

Make: Schuberth
Model: CONCEPT
Age: Ø years/months (approx)
Stipulated size: 54/55 cm

Standard: BS 6658 (A [ ], B [ ]) / Reg 22 [x] & Rev: / Other
Condition: New [ ] Avg. [ ] Poor [ ]
Padding: Complete Y [x] N [ ]; Condition: Good [x] Fair [ ] Poor [ ]

Chinstrap design: Double ring [ ] QR plug [x] Other [ ]
Chincup fitted: Y [ ] N [x]
Chinstrap condition: New [x] Avg. [ ] Poor (abuse) [ ]

Helmet fit/stability

Rear pull
Removed: Y [ ] N [ ]
Rotation: 5° degrees
Resistance: H e.g. high / low

Lateral rotation
Rotation: ± 5 degrees
Resistance: ____

Front pull
Removed: Y [ ] N [ ]
Rotation: 10° degrees
Resistance: ____ e.g. high / low

"Anything goes" (to discomfort level)
Removed: Y [ ] N [x]
Resistance: ____

OFFICE USE ONLY
Ejection with further force
Likelihood: High [ ] Low [ ]
Comments: ____ e.g. mechanism

Chinstrap fasteing
Correct fastening: Y [ ] N (misuse) [ ]
Chin strap fit: Loose (gap) [ ] Tight (no gap) [ ] In tension [ ]
FINGER GAP.

Photos

Side: Helmet [x] No-helmet [ ]
Front: Helmet [ ] No-helmet [ ]
Chinstrap: Helmet [ ]

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y [x] N [ ]

Did/would this influence subjects choice of helmet? Y [ ] N [x]
NOISE /Comfort Engineering

Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y [ ] N [ ]

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 2 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Subject Number:	BMF_002
Survey date:	21 May 2005
Venue:	BMF Peterborough

Rider details

Age [ ] years — sex: male ☐ female ☑

Hair description: SHORT / MEDIUM

Head geometry

horizontal circumference 54.8 cm — longditudal length 19.8 cm

coronal plance circumference 60 cm — lateral length 14.2 cm

Helmet details

Make: SHARK — Age: 0 years/months (approx)

Model: S800 — Stipulated size: XS cm

Standard: BS 6658 (A ☐, B ☐) — Reg 22 & Rev: ☑ ACU GOLD — Other

Chinstrap design: Double ring ☐ — QR plug ☑ — Other ☐

Condition: New ☑ — Avg. ☐ — Poor ☐

Chincup fitted: Y ☐ — N ☑

Padding: Complete Y ☑ N ☐ — Condition: Good ☑ Fair ☐ Poor ☐

Chinstrap condition: New ☑ — Avg. ☐ — Poor (abuse) ☐

Helmet fit/stability

Rear pull

Removed: Y ☐ N ☐

Rotation 5° degrees

Resistance ______ e.g. high / low

Lateral rotation

Rotation 5° degrees

Resistance ______

Front pull

Removed: Y ☐ N ☐

Rotation 10° degrees

Resistance ______ e.g. high / low

"Anything goes" (to discomfort level)

Removed: Y ☐ N ☑

Resistance: V. GOOD.

OFFICE USE ONLY

Ejection with further force

Likelihood: High ☐ Low ☐

Comments ______ e.g. mechanism

Chinstrap fasteing

Correct fastening: Y ☑ N (misuse) ☐

Chin strap fit: Loose (gap) ☐ Tight (no gap) ☑ In tension ☐

Photos

	Side	Front	Chinstrap
Helmet	☑	☐	☐
No-helmet	☐	☐	

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐

Did/would this influence subjects choice of helmet? Y ☐ N ☑

Thank you for taking part.

OFFICE USE ONLY

Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 3 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Subject Number:	BMF_003
Survey date:	21 May 2005
Venue:	BMF Peterborough

Age [ ] years — sex: male ☑ / female ☐

Hair description: SHORT / NO BALACLAVA

Head geometry

horizontal circumference 58 cm — longditudal length 21 cm

coronal plance circumference 68 cm — lateral length 16 cm

Helmet details

Make: CABERG — Age: 2yrs years/months (approx) 17mths

Model: JUSTISSIMO — Stipulated size: L 58/60 cm

Standard: BS 6658 A ☐, B ☐ — Reg 22 ☑ & Rev: 05 — Other: ACU

Chinstrap design: Double ring ☐ — QR plug ☑ — Other ☐

Condition: AS New ☑ — Avg. ☐ — Poor ☐

Chincup fitted: Y ☐ — N ☑

Padding: Complete Y ☐, N ☐ — Condition: Good ☐ Fair ☐ Poor ☐

Chinstrap condition: AS New ☑ — Avg. ☐ — Poor (abuse) ☐

Helmet fit/stability

Rear pull

Removed: Y ☐ — N ☑

Rotation: 50 degrees

Resistance ______ e.g. high / low

Lateral rotation

Rotation: 5° degrees

Resistance ______

Front pull

Removed: Y ☐ — N ☑

Rotation: 10° degrees

Resistance ______ e.g. high / low

"Anything goes" (to discomfort level)

Removed: Y ☐ — N ☑

Resistance ______

OFFICE USE ONLY

Ejection with further force

Likelihood: High ☐ — Low ☐

Comments ______ e.g. mechanism

Chinstrap fasteing

Correct fastening: Y ☑ — N (misuse) ☐

Chin strap fit: Loose (gap) ☑ — Tight (no gap) ☐ — In tension ☐

Large Gap

Photos

Side	*Front*	*Chinstrap*
Helmet ☑	Helmet ☐	Helmet ☐
No-helmet ☐	No-helmet ☐	

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ — N ☐

Did/would this influence subjects choice of helmet? Y ☑ — N ☐

Thank you for taking part.

OFFICE USE ONLY

Does helmet meet ACU scrutineer requirements? Y ☐ — N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 4 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Age [ ] years ______ sex: male ☐ female ☑

Hair description: MEDIUM

Subject Number: BMF_004
Survey date: 21 May 2005
Venue: BMF Peterborough

Head geometry
- horizontal circumference: 55 cm
- coronal plance circumference: 65 cm
- longditudal length: 20.5 cm
- lateral length: 16.0 cm

Helmet details

- Make: CABERG
- Model: " SUSTISSIMO
- Age: 2 years years/months (approx)
- Stipulated size: M 57-58 cm
- Standard: BS 6658 (A ☐, B ☐) ☐; Reg 22 & Rev: ☑ ACU GOLD; Other ☐
- Condition: New ☑ AS; Avg. ☐; Poor ☐
- Padding: Complete Y ☑ N ☐; Condition: Good ☑ Fair ☐ Poor ☐
- Chinstrap design: Double ring ☐; QR plug ☑; Other ☐
- Chincup fitted: Y ☐ N ☑
- Chinstrap condition: New ☑ AS; Avg. ☐; Poor (abuse) ☐

Helmet fit/stability

Rear pull
- Removed: Y ☐ N ☑
- Rotation: 10° degrees
- Resistance: ______ e.g. high / low

Lateral rotation
- Rotation: 6° degrees
- Resistance: ______

Front pull
- Removed: Y ☐ N ☑
- Rotation: 12° degrees
- Resistance: ______ e.g. high / low

"Anything goes" (to discomfort level)
- Removed: Y ☑ N ☐
- Resistance: CHIN STRAP OVER CHIN

OFFICE USE ONLY
Ejection with further force
- Likelihood: High ☐ Low ☐
- Comments: ______ e.g. mechanism

Chinstrap fasteing
- Correct fastening: Y ☐ N (misuse) ☐
- Chin strap fit: Loose (gap) ☑ 4 fingers; Tight (no gap) ☐; In tension ☐

Photos

	Side	Front	Chinstrap
Helmet	☑	☐	☐
No-helmet	☐	☐	

ACU specific question

- Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐
- Did/would this influence subjects choice of helmet? Y ☑ N ☐

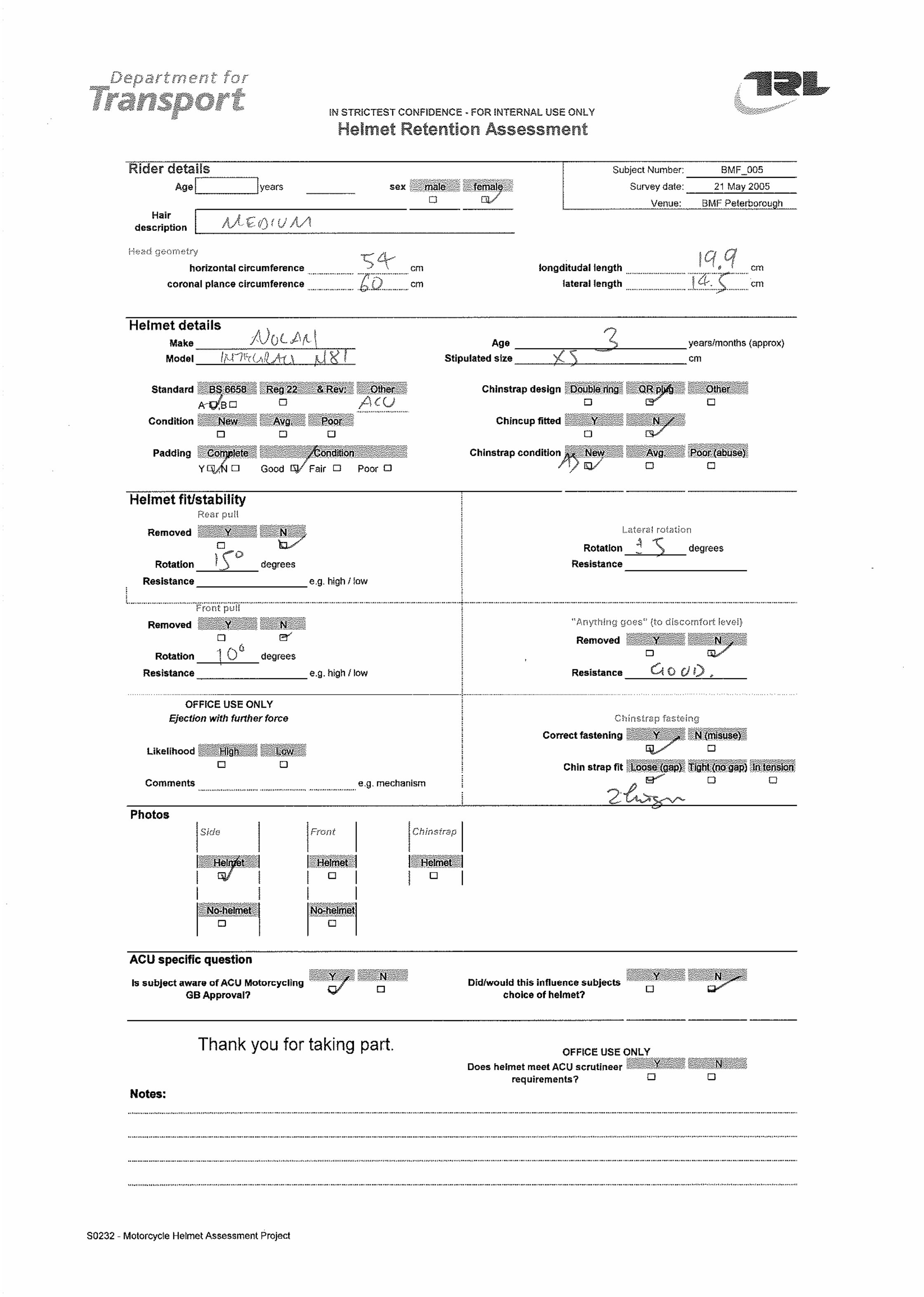
Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 5 – report



Department for Transport

TRL

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Age [ ] years — sex: male ☐ female ☑

Subject Number: BMF_005
Survey date: 21 May 2005
Venue: BMF Peterborough

Hair description: MEDIUM

Head geometry
horizontal circumference 54 cm
coronal plance circumference 60 cm
longditudal length 19.9 cm
lateral length 14.5 cm

Helmet details

Make: NOLAN
Model: INTEGRAL N81
Age: 3 years/months (approx)
Stipulated size: XS cm

Standard: BS 6658 (A ☑ B ☐) — Reg 22 ☐ — & Rev: — Other: ACU
Chinstrap design: Double ring ☐ — QR plug ☑ — Other ☐
Condition: New ☐ — Avg. ☐ — Poor ☐
Chincup fitted: Y ☐ — N ☑
Padding: Complete Y ☑ N ☐ — Condition: Good ☑ Fair ☐ Poor ☐
Chinstrap condition: New ☑ — Avg. ☐ — Poor (abuse) ☐

Helmet fit/stability

Rear pull
Removed: Y ☐ N ☑
Rotation: 15° degrees
Resistance: ______ e.g. high / low

Lateral rotation
Rotation: 15 degrees
Resistance: ______

Front pull
Removed: Y ☐ N ☑
Rotation: 10° degrees
Resistance: ______ e.g. high / low

"Anything goes" (to discomfort level)
Removed: Y ☐ N ☑
Resistance: GOOD.

OFFICE USE ONLY
Ejection with further force
Likelihood: High ☐ Low ☐
Comments: ______ e.g. mechanism

Chinstrap fasteing
Correct fastening: Y ☑ N (misuse) ☐
Chin strap fit: Loose (gap) ☑ Tight (no gap) ☐ In tension ☐
2 fingers

Photos

Side	Front	Chinstrap
Helmet ☑	Helmet ☐	Helmet ☐
No-helmet ☐	No-helmet ☐	

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐
Did/would this influence subjects choice of helmet? Y ☐ N ☑

Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 6 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Subject Number: BMF_006
Survey date: 21 May 2005
Venue: BMF Peterborough

Age ____ years ____ **sex** male ☑ female ☐

Hair description No. 5

Head geometry

horizontal circumference 56 cm
coronal plance circumference 62.5 cm
longditudal length 20.4 cm
lateral length 15.6 cm

Helmet details

Make NITRO
Model N800-V
Age 1 years/months (approx)
Stipulated size ____ cm

Standard BS 6658 A ☐, B ☐ | Reg 22 & Rev: ☑ (5) | Other ACU GOLD
Condition New ☑ (GOOD) | Avg. ☐ | Poor ☐
Padding Complete Y ☑ N ☐ | Condition Good ☑ Fair ☐ Poor ☐

Chinstrap design Double ring ☑ | QR plug ☐ | Other ☐
Chincup fitted Y ☐ | N ☑
Chinstrap condition New ☑ (GOOD) | Avg. ☐ | Poor (abuse) ☐

Helmet fit/stability

Rear pull
Removed Y ☐ N ☑
Rotation 10 degrees
Resistance ____ e.g. high / low

Lateral rotation
Rotation 35 degrees
Resistance ____

Front pull
Removed Y ☐ N ☑
Rotation 15 degrees
Resistance ____ e.g. high / low

"Anything goes" (to discomfort level)
Removed Y ☐ N ☑
Resistance GOOD.

OFFICE USE ONLY
Ejection with further force
Likelihood High ☐ Low ☐
Comments ____ e.g. mechanism

Chinstrap fasteing
Correct fastening Y ☑ N (misuse) ☐
Chin strap fit Loose (gap) ☑ Tight (no gap) ☐ In tension ☐
2 fingers

Photos

	Side	Front	Chinstrap
Helmet	☑	☐	☐
No-helmet	☐	☐	

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐

Did/would this influence subjects choice of helmet? Y ☑ N ☐
V. IMPORTANT (TRACK DAYS) & SAFETY

Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 7 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Subject Number:	BMF_007
Survey date:	21 May 2005
Venue:	BMF Peterborough

Rider details

Age 10 years sex male ☑ female ☐

Hair description NO. 4.

Head geometry

horizontal circumference 55.5 cm longditudal length 19.8 cm

coronal plance circumference 61 cm lateral length 15.1 cm

Helmet details

Make HJC Age 0 years/months (approx)

Model CL8 SCAMBLER Stipulated size M 58 cm

Standard: BS 6658 A ☐, B ☐ Reg 22 & Rev: ☑ 5 Other: ACU GOLD

Chinstrap design: Double ring ☑ QR plug ☐ Other ☐

Condition: New ☑ Avg. ☐ Poor ☐

Chincup fitted: Y ☐ N ☑

Padding: Complete Y ☑ N ☐ Condition Good ☑ Fair ☐ Poor ☐

Chinstrap condition: New ☑ Avg. ☐ Poor (abuse) ☐

Helmet fit/stability

Rear pull

Removed Y ☐ N ☑

Rotation 10° degrees

Resistance ______ e.g. high / low

Lateral rotation

Rotation ±2.5° degrees

Resistance ______

Front pull

Removed Y ☐ N ☑

Rotation 10° degrees

Resistance HIGH e.g. high / low

"Anything goes" (to discomfort level)

Removed Y ☑ N ☐

Resistance CHIN STRAP OVER CHIN

OFFICE USE ONLY

Ejection with further force

Likelihood High ☐ Low ☐

Comments ______ e.g. mechanism

Chinstrap fasteing

Correct fastening Y ☑ N (misuse) ☐

Chin strap fit Loose (gap) ☑ Tight (no gap) ☐ In tension ☐

2½ fingers

Photos

Side: Helmet ☑ No-helmet ☐

Front: Helmet ☐ No-helmet ☐

Chinstrap: Helmet ☐

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐

Did/would this influence subjects choice of helmet? Y ☑ N ☐

HIGHER STANDARD.

Thank you for taking part.

OFFICE USE ONLY

Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 8 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Subject Number: BMF_008
Survey date: 21 May 2005
Venue: BMF Peterborough

Age ____ years — sex: male ☑ / female ☐

Hair description: SHORT.

Head geometry

horizontal circumference 58 cm — longditudal length 20.8 cm

coronal plance circumference 66 cm — lateral length 16.5 cm

Helmet details

Make: SHOET
Model: SYNCHRO TECH II
Age: 2 years / (3yrs life) years/months (approx)
Stipulated size: XL 61-62 cm

Standard: BS 6658 (A ☐, B ☐) — Reg 22 ☑ & Rev: 05 — Other: ACU DEBADGED

Chinstrap design: Double ring ☐ — QR plug ☑ — Other ☐

Condition: New ☐ — Avg. ☐ — Poor ☐

Chincup fitted: Y ☐ — N ☑

Padding: Complete Y ☑, N ☐ — Condition: Good ☑ Fair ☐ Poor ☐

Chinstrap condition: New ☑ — Avg. ☐ — Poor (abuse) ☐

Helmet fit/stability

Rear pull

Removed: Y ☐ — N ☑
Rotation: 15° degrees
Resistance: ________ e.g. high / low

Lateral rotation

Rotation: ±10° degrees
Resistance: ________

Front pull

Removed: Y ☐ — N ☑
Rotation: 10° degrees
Resistance: ________ e.g. high / low

"Anything goes" (to discomfort level)

Removed: Y ☑ — N ☑ BECAUSE OF LANYARD
Resistance: ________

OFFICE USE ONLY

Ejection with further force

Likelihood: High ☐ — Low ☐

Comments: ________ e.g. mechanism

Chinstrap fasteing

Correct fastening: Y ☑ — N (misuse) ☐

Chin strap fit: Loose (gap) ☑ — Tight (no gap) ☐ — In tension ☐

(long over chin) ?

Photos

Side: Helmet ☑ — No-helmet ☐
Front: Helmet ☐ — No-helmet ☐
Chinstrap: Helmet ☐

ACU specific question

HOME OFFICE APPROVED.

Is subject aware of ACU Motorcycling GB Approval? Y ☑ — N ☐

Did/would this influence subjects choice of helmet? Y ☑ — N ☐ FOR SAFETY

Thank you for taking part.

OFFICE USE ONLY

Does helmet meet ACU scrutineer requirements? Y ☐ — N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 9 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Rider details

Age ______ years ______ sex male ☑ female ☐

Subject Number: BMF_009
Survey date: 21 May 2005
Venue: BMF Peterborough

Hair description: V. SHORT.

Head geometry

horizontal circumference 58.5 cm
coronal plance circumference 64.5 cm
longditudal length 20.9 cm
lateral length 16.2 cm

Helmet details

Make: AS PREVIOUS,
Model:
Age: 1 1/2 years/months (approx)
Stipulated size: L 58-60 cm

Standard: BS 6658 (A ☐, B ☐) / Reg 22 & Rev: ☐ / Other

Chinstrap design: Double ring ☐ / QR plug ☐ / Other ☐

Condition: New ☐ / Avg. ☐ / Poor ☐

Chincup fitted: Y ☐ / N ☐

Padding: Complete Y ☐, N ☐ / Condition Good ☐ Fair ☐ Poor ☐

Chinstrap condition: New ☐ / Avg. ☐ / Poor (abuse) ☐

Helmet fit/stability

Rear pull

Removed: Y ☐ / N ☑
Rotation 10° degrees
Resistance ______ e.g. high / low

Lateral rotation

Rotation ±5° degrees
Resistance

Front pull

Removed: Y ☐ / N ☑
Rotation 10° degrees
Resistance ______ e.g. high / low

HELMET FIT NOT STRAP !

"Anything goes" (to discomfort level)

Removed: Y ☐ / N ☑
Resistance GOOD

GOOD DESIGN

OFFICE USE ONLY
Ejection with further force

Likelihood: High ☐ / Low ☐
Comments ______ e.g. mechanism

Chinstrap fasteing

Correct fastening: Y ☐ / N (misuse) ☑ ?

Chin strap fit: Loose (gap) ☑ / Tight (no gap) ☐ / In tension ☐

HARD

Photos

Side: Helmet ☑ / No-helmet ☐
Front: Helmet ☐ / No-helmet ☐
Chinstrap: Helmet ☐

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ / N ☐

Did/would this influence subjects choice of helmet? Y ☑ / N ☐

SAFETY

Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y ☐ / N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Subject 10 – report

Department for Transport

IN STRICTEST CONFIDENCE - FOR INTERNAL USE ONLY

Helmet Retention Assessment

Subject Number: BMF_010
Survey date: 21 May 2005
Venue: BMF Peterborough

Rider details

Age ____ years ____ sex male ☑ female ☐

Hair description: MEDIUM

Head geometry

horizontal circumference 59 cm
coronal plance circumference 63 cm
longditudal length 21.3 cm
lateral length 15.7 cm

Helmet details

Make: SHOEI
Model: XR-900
Age: 1 YEAR years/months (approx)
Stipulated size: M 57-58 cm

Standard: BS 6658 A ☐, B ☐ | Reg 22 & Rev: ☑ 5 | Other: ACU GOLD

Condition: New ☑ | Avg. ☐ | Poor ☐

Padding: Complete Y ☑ N ☐ | Condition: Good ☑ Fair ☐ Poor ☐

Chinstrap design: Double ring ☐ | QR plug ☑ | Other ☐

Chincup fitted: Y ☐ | N ☑

Chinstrap condition: New ☑ | Avg. ☐ | Poor (abuse) ☐

Helmet fit/stability

Rear pull
Removed: Y ☐ N ☑
Rotation 25 degrees
Resistance ____ e.g. high / low

Lateral rotation
Rotation ±30° degrees
Resistance ____

Front pull
Removed: Y ☐ N ☑
Rotation 15° degrees
Resistance ____ e.g. high / low

"Anything goes" (to discomfort level)
Removed: Y ☑ N ☐
Resistance [GOOD]

OFFICE USE ONLY
Ejection with further force
Likelihood: High ☐ Low ☐
Comments ____ e.g. mechanism

Chinstrap fasteing
Correct fastening: Y ☑ N (misuse) ☐
Chin strap fit: Loose (gap) ☑ | Tight (no gap) ☐ | In tension ☐
1 finger

Photos

	Side	Front	Chinstrap
Helmet	☑	☐	☐
No-helmet	☐	☐	

ACU specific question

Is subject aware of ACU Motorcycling GB Approval? Y ☑ N ☐

Did/would this influence subjects choice of helmet? Y ☑ N ☐ SAFETY

Thank you for taking part.

OFFICE USE ONLY
Does helmet meet ACU scrutineer requirements? Y ☐ N ☐

Notes:

S0232 - Motorcycle Helmet Assessment Project

Appendix B (ii) Helmet Retention ACU and BMF fitment guide

TEN FITTING TESTS FOR HELMETS

1. Obtain correct size by measuring the circumference of the head immediately above the eyes in cm.
2. Check there is no side to side movement.
3. Tighten strap securely.
4. With head forward attempt to pull up back of helmet to ensure helmet cannot be removed in this way.
5. Check ability to see clearly over shoulder.
6. Make sure nothing impedes your breathing in the helmet and never cover nose or mouth.
7. Never wind scarf around neck so that air is stopped from entering the helmet. Never wear a scarf under the retention strap.
8. Ensure that visor can be opened with one gloved hand.
9. Satisfy yourself that the back of your helmet is designed to protect your neck.
10. Always buy the best you can afford.

Make sure that the helmet has an ACU Approval Stamp affixed.★

NEVER BUY FROM MAIL-ORDER unless you are satisfied with the above tests. Do not hesitate to return the helmet unused if it does not fit you.

ACU Handbook recommendations

★ BMF differ to the ACU requirements by stipulating

" Make sure the helmet is approved to BS6658 or UN ECE 22.05 Standard"

Appendix B. Test methods

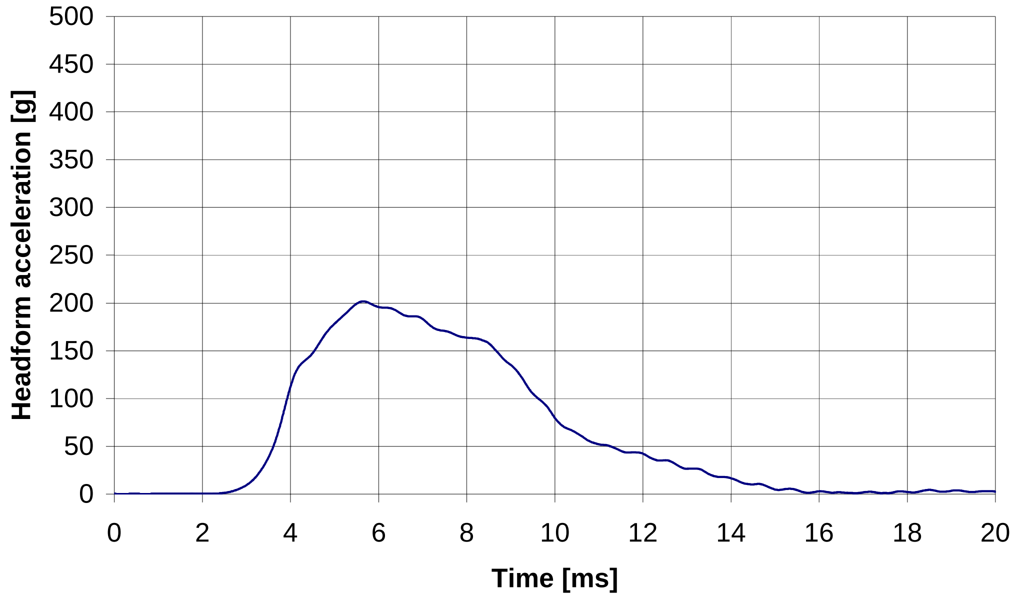
(i) COST 327 Proposals

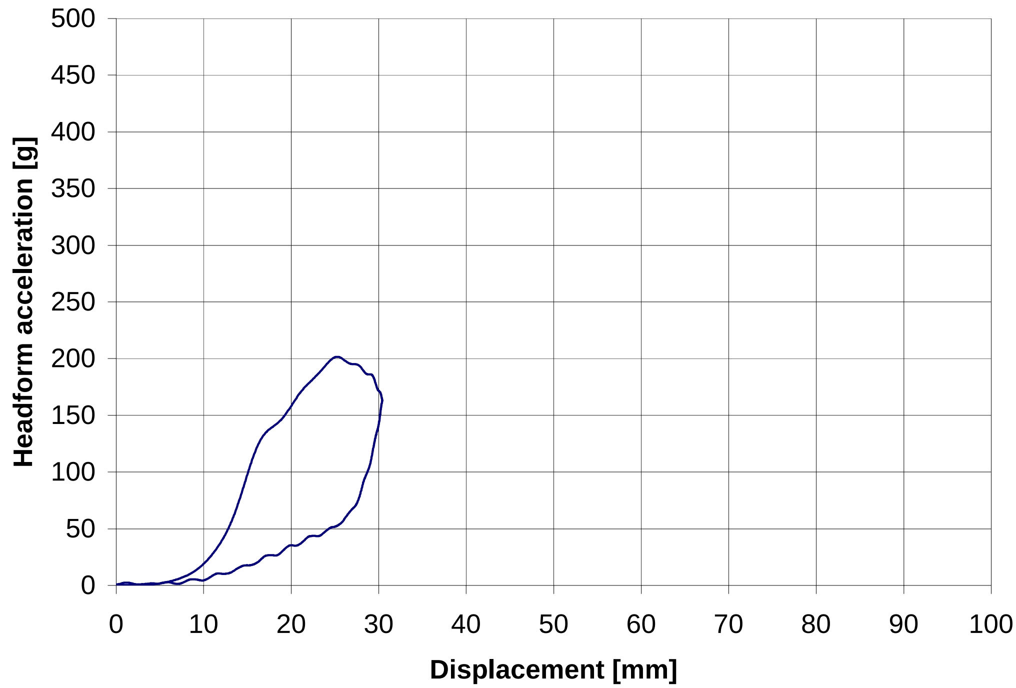
(ii) Helmet Retention

(iii) <u>Impact Sites</u>

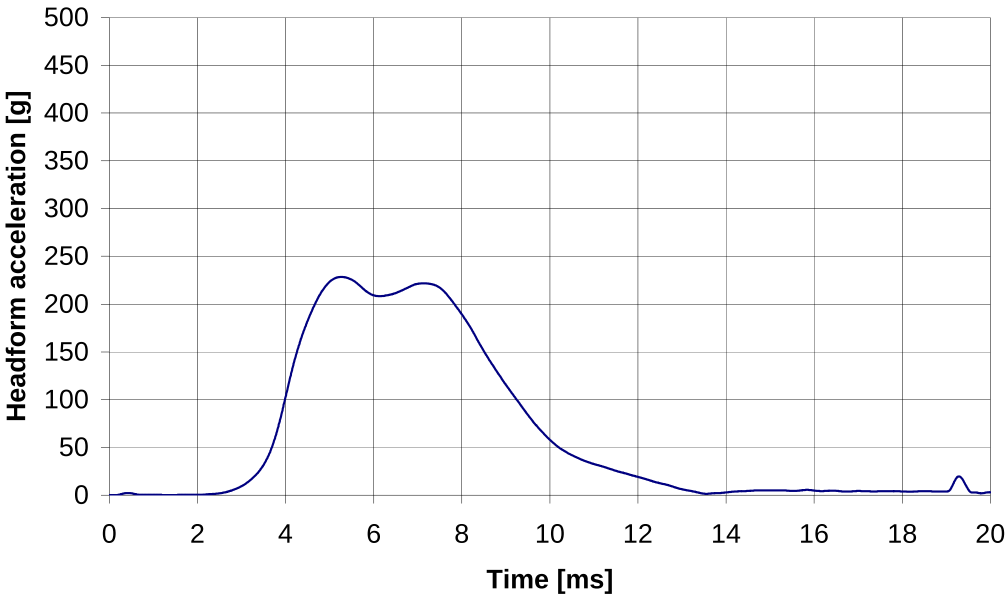
(iii) Impact sites test data

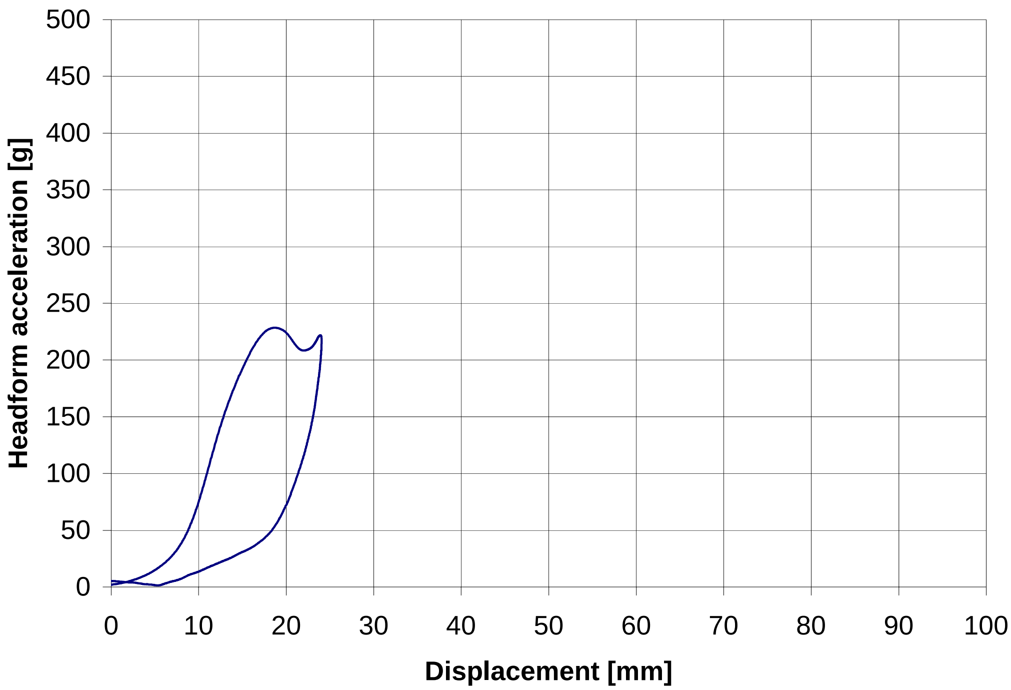
Client	DfT - S0232-VF		
Helmet	MTR-S6, size 57	Test reference	a04kx
Impact energy [J]	132	Peak acceleration [g]	202
Impact anvil	Kerb	HIC	1985
Impact site	Front	Displacement [mm]	30





Client	DfT - S0232-VF		
Helmet	MTR-S6, size 57	Test reference	d04kx
Impact energy [J]	132	Peak acceleration [g]	228
Impact anvil	flat	HIC	2658
Impact site	"high side"	Displacement [mm]	24

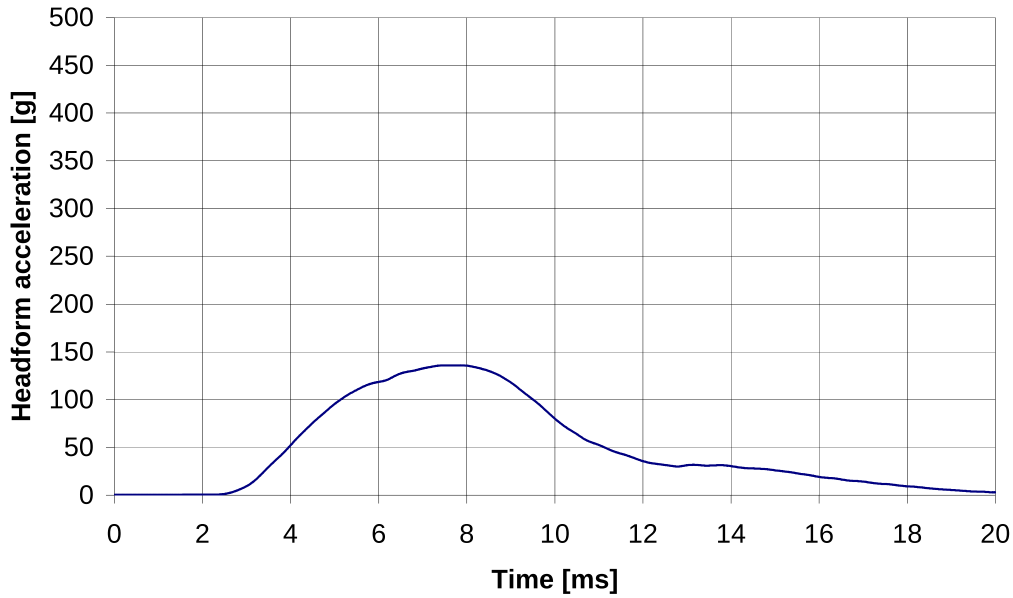


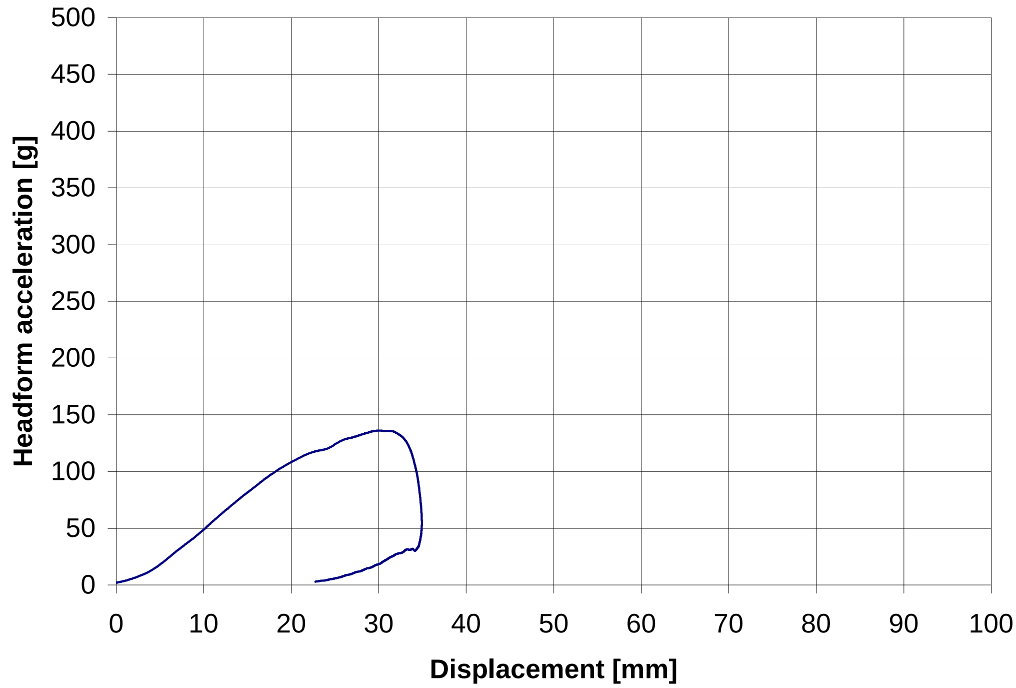


S0232 - VF - ECE reg 22 linear tests (off site)

www.trl.co.uk

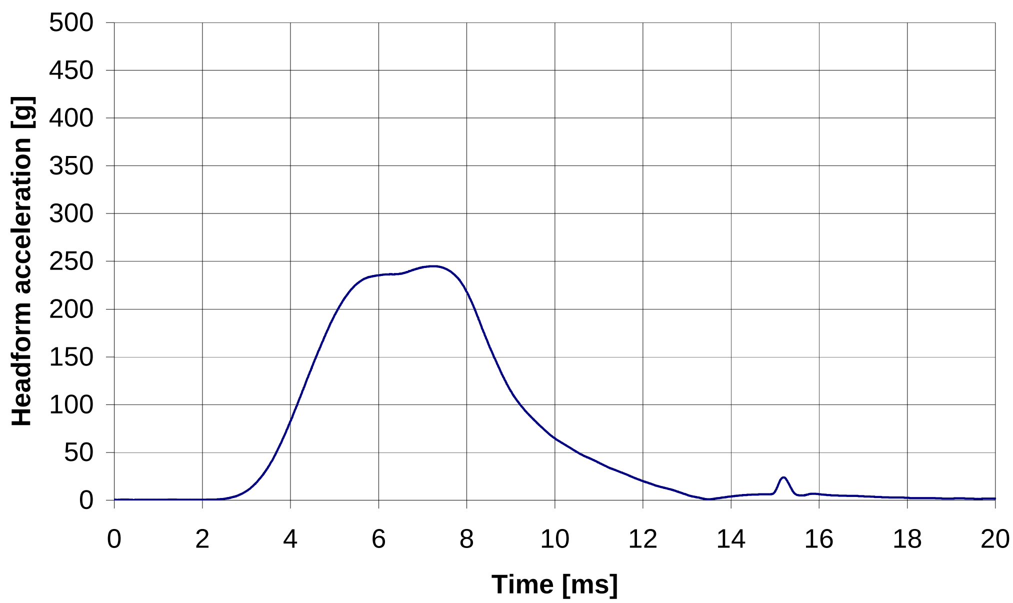
Client	DfT - S0232-VF		
Helmet	MTR-S6, size 57	Test reference	b04kx
Impact energy [J]	132	Peak acceleration [g]	136
Impact anvil	Kerb	HIC	816
Impact site	"low side"	Displacement [mm]	35

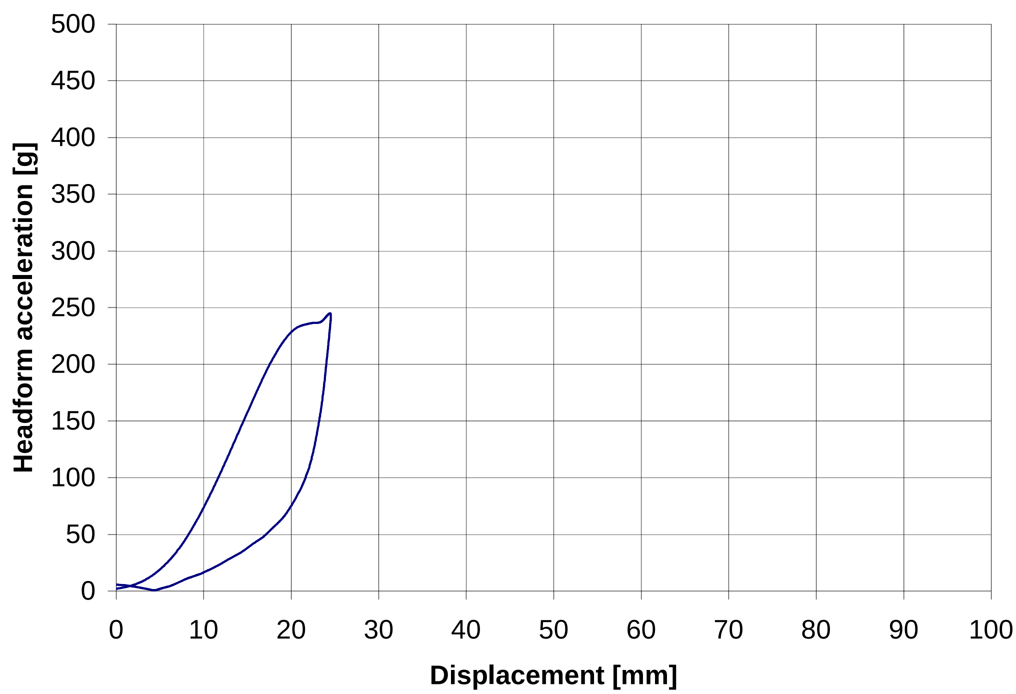




S0232 - VF - ECE reg 22 linear tests (off site) www.trl.co.uk

Client	DfT - S0232-VF		
Helmet	MTR-S6, size 57	Test reference	c04kx
Impact energy [J]	132	Peak acceleration [g]	245
Impact anvil	flat	HIC	2905
Impact site	rear	Displacement [mm]	25

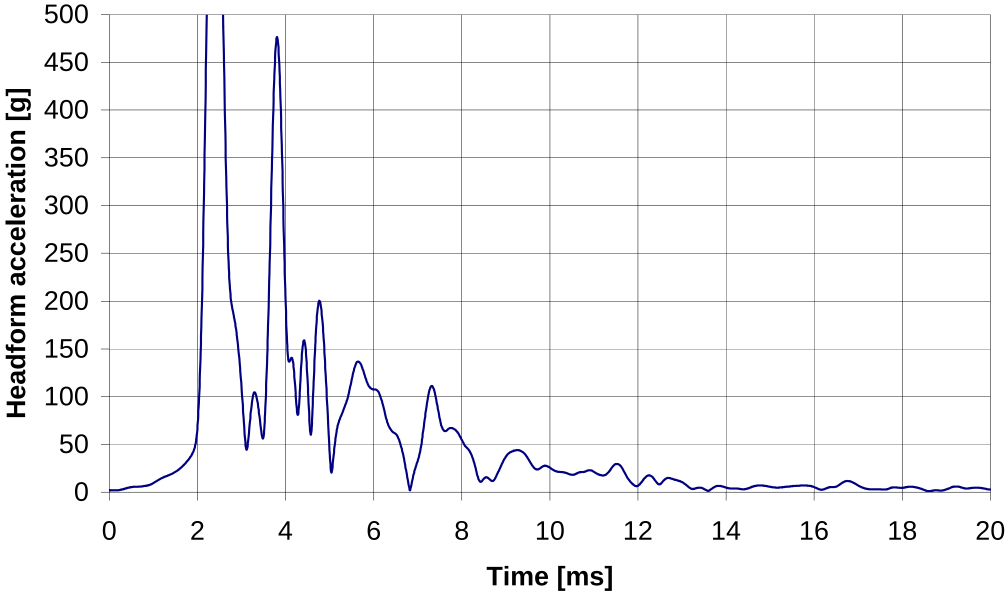


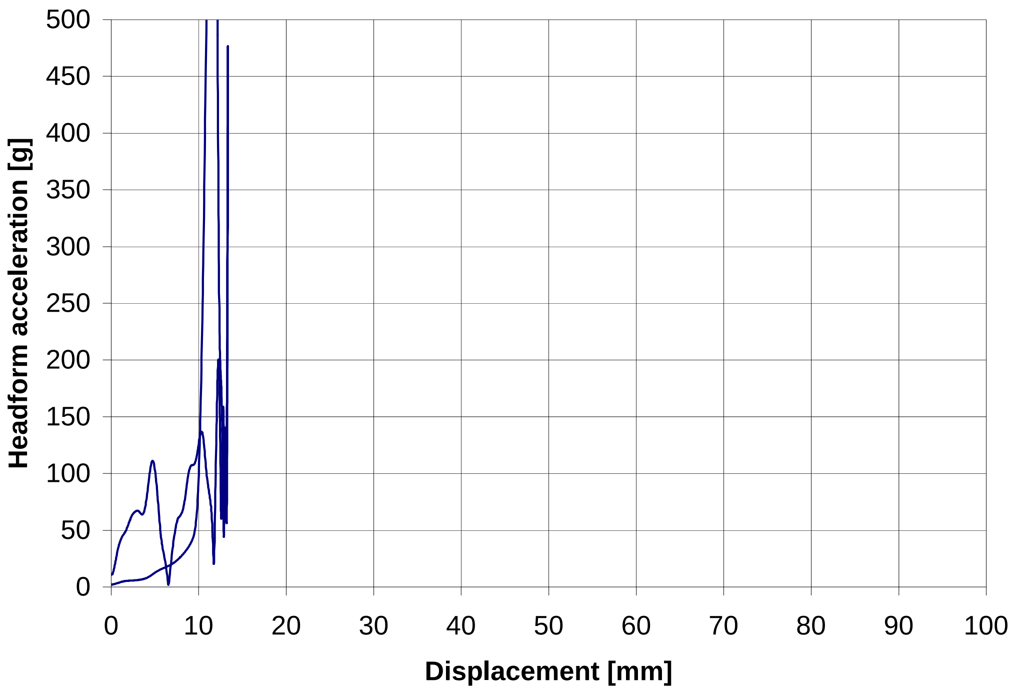


S0232 - VF - ECE reg 22 linear tests (off site)

www.trl.co.uk

Client	DfT - S0232-VF		
Helmet	MTR-S6, size 57	Test reference	a23cy
Impact energy [J]	132	Peak acceleration [g]	907
Impact anvil	Flat	HIC	5720
Impact site	Chinguard	Displacement [mm]	13

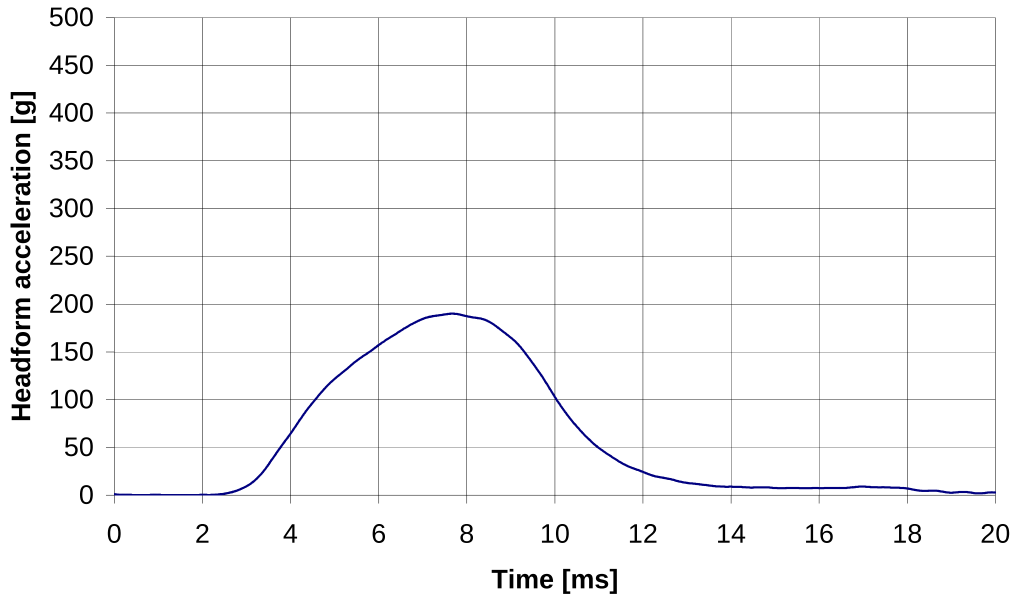


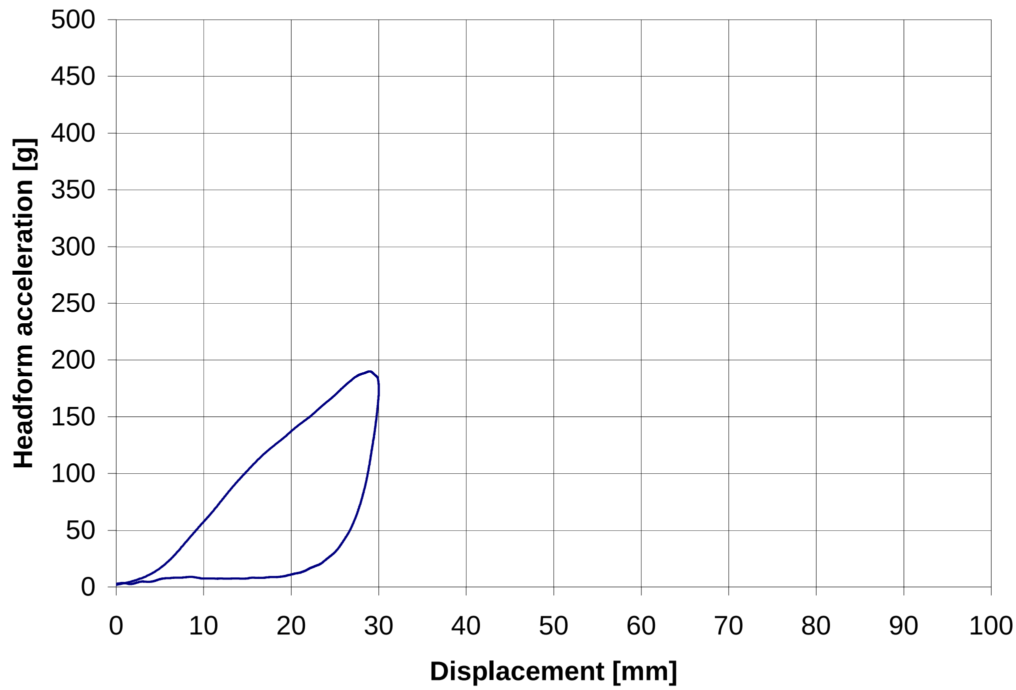


S0232 - VF - ECE reg 22 linear tests (off site)

www.trl.co.uk

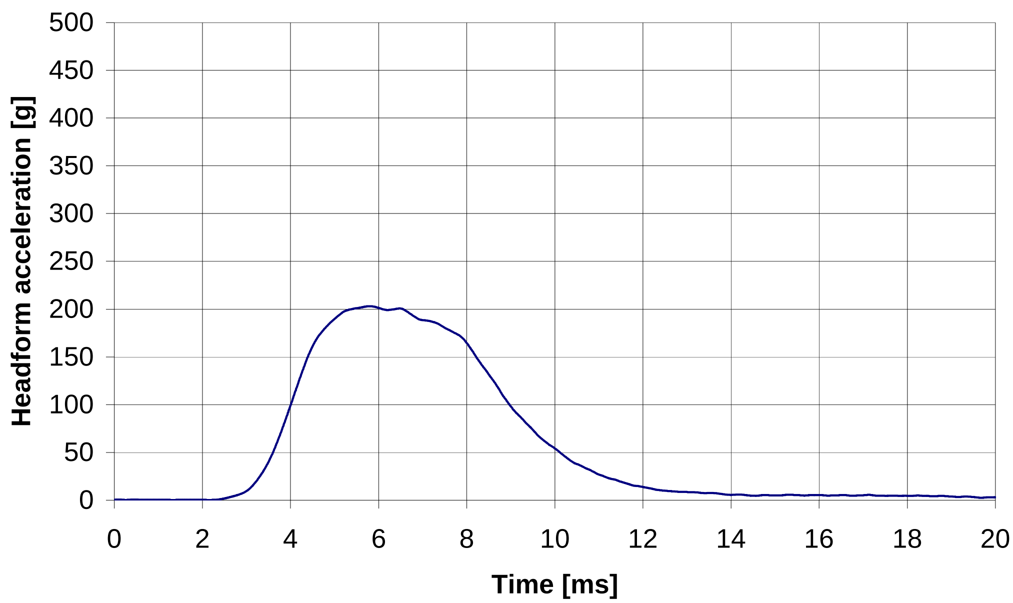
Client	DfT - S0232-VF		
Helmet	Nitro, size 57	Test reference	i04kx
Impact energy [J]	132	Peak acceleration [g]	190
Impact anvil	kerb	HIC	1737
Impact site	front	Displacement [mm]	30

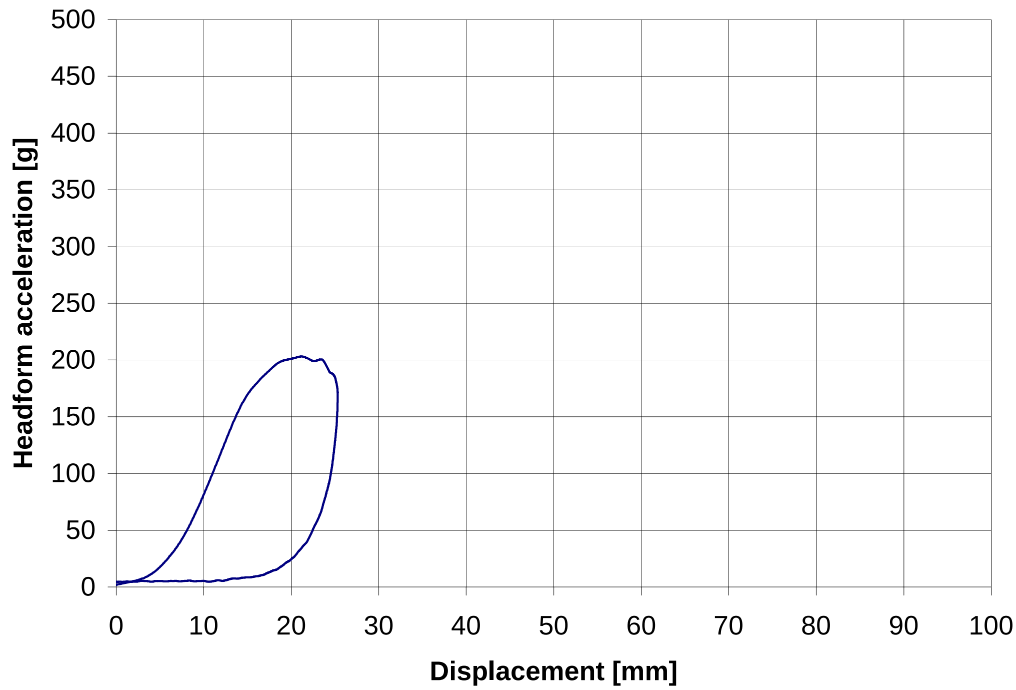




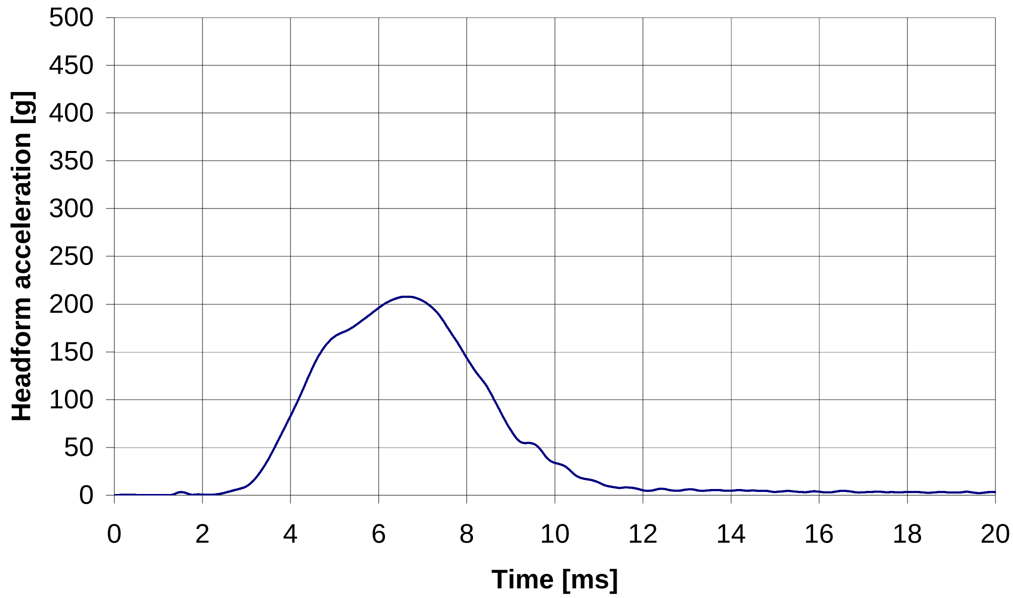
S0232 - VF - ECE reg 22 linear tests (off site)

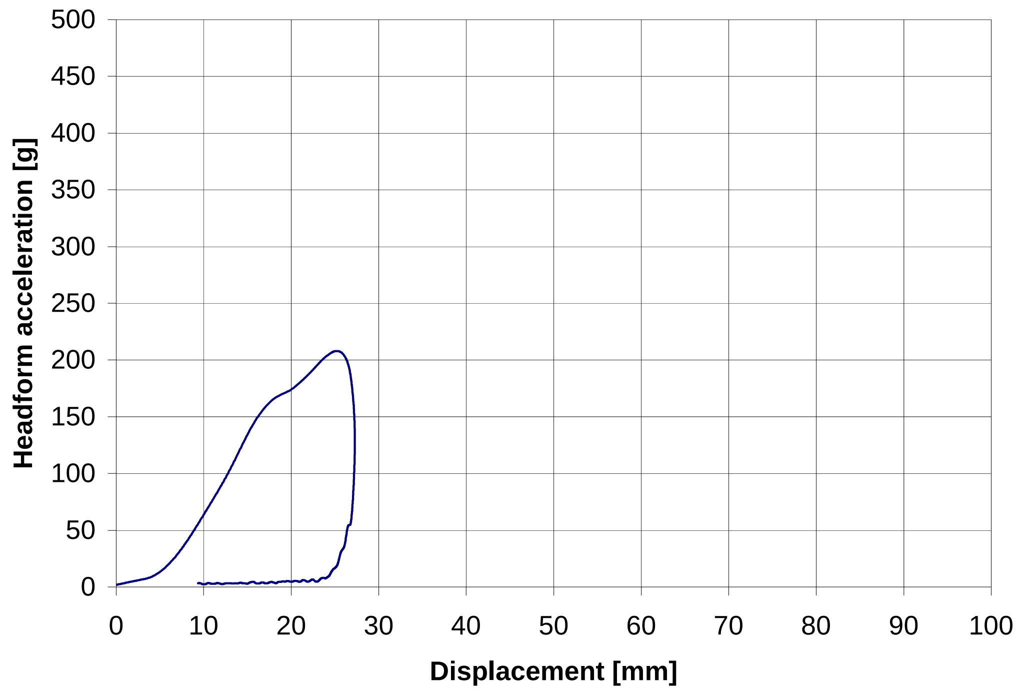
Client	DfT - S0232-VF		
Helmet	Nitro, size 57	Test reference	I04kx
Impact energy [J]	132	Peak acceleration [g]	203
Impact anvil	flat	HIC	1953
Impact site	high side	Displacement [mm]	25





Client	DfT - S0232-VF		
Helmet	Nitro, size 57	Test reference	j04kx
Impact energy [J]	132	Peak acceleration [g]	208
Impact anvil	kerb	HIC	1655
Impact site	low side	Displacement [mm]	27





S0232 - VF - ECE reg 22 linear tests (off site)

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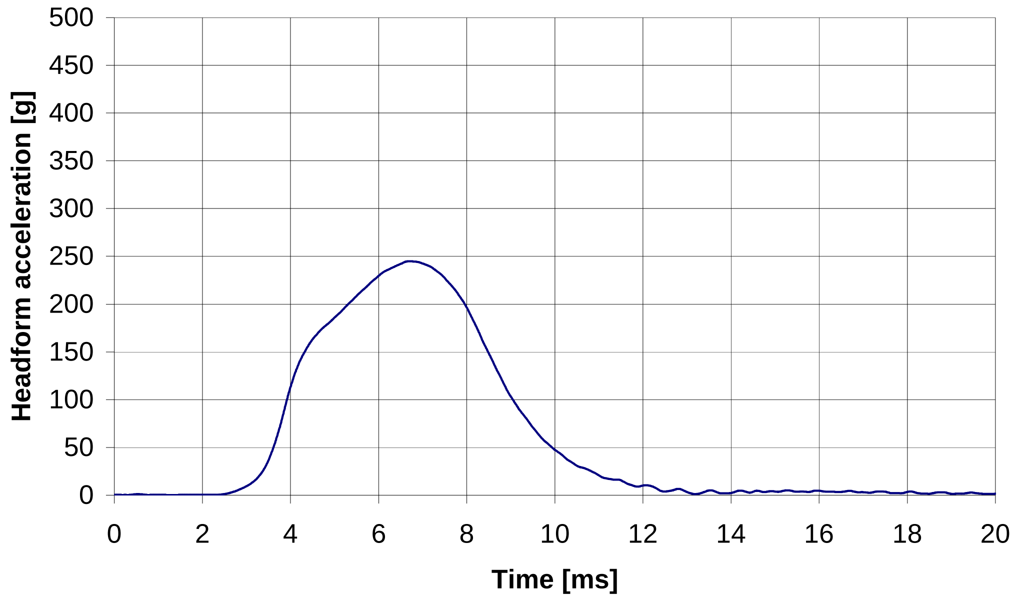
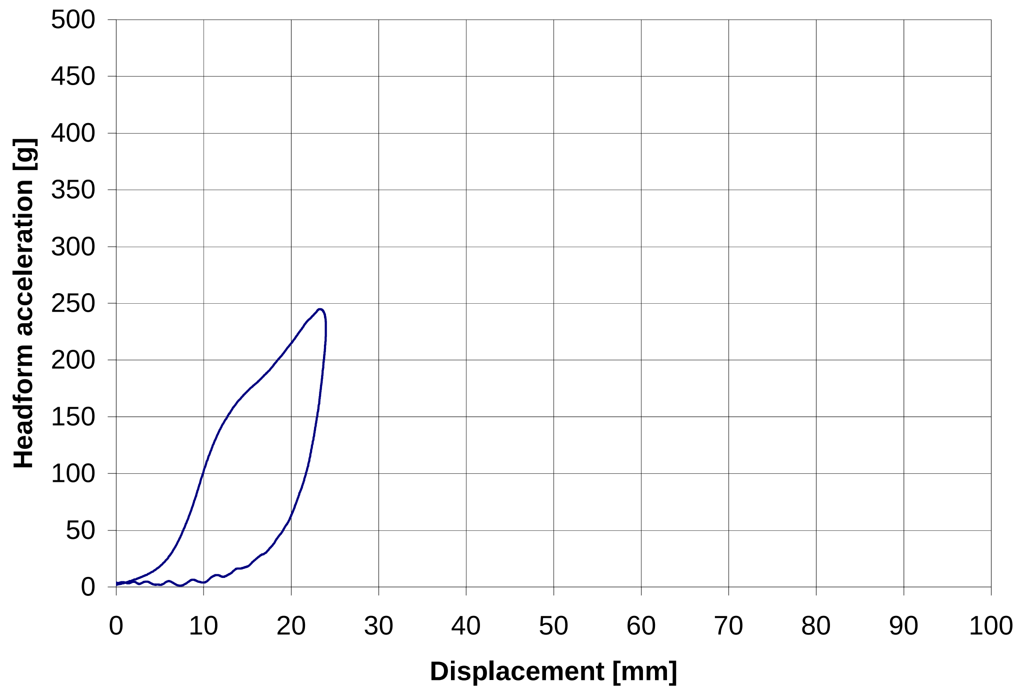
Client	DfT - S0232-VF		
Helmet	Nitro, size 57	Test reference	k04kx
Impact energy [J]	132	Peak acceleration [g]	245
Impact anvil	flat	HIC	2701
Impact site	rear	Displacement [mm]	24





S0232 - VF - ECE reg 22 linear tests (off site)

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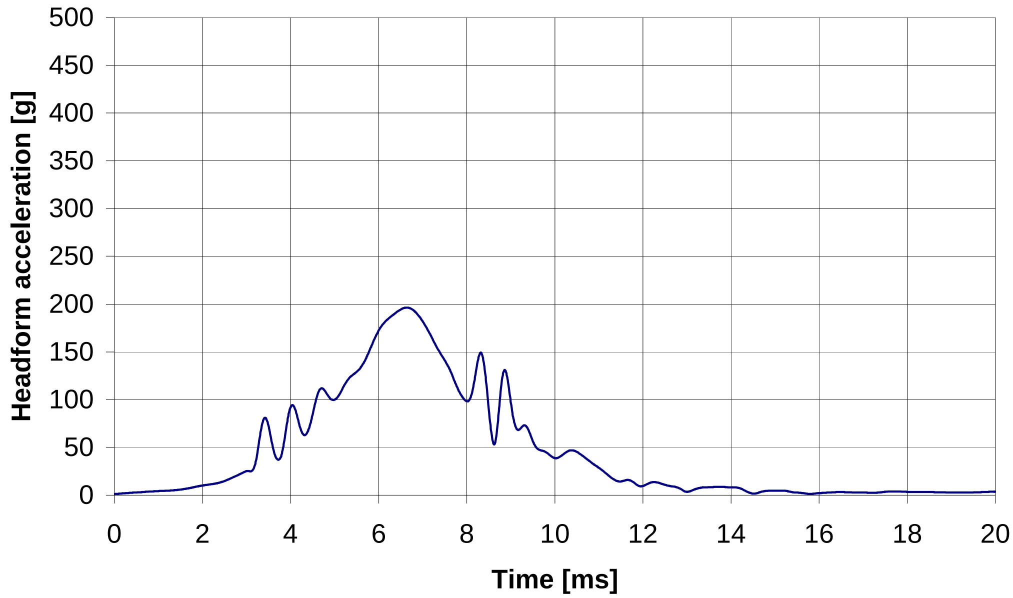
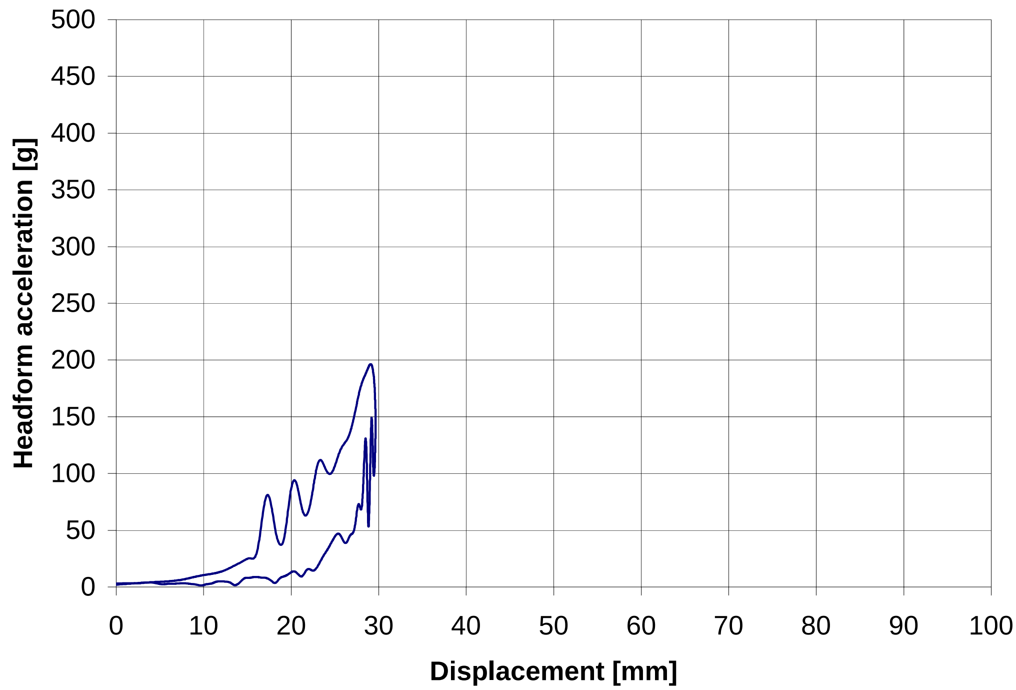
Client	DfT - S0232-VF		
Helmet	Nitro, size 57	Test reference	b23cy
Impact energy [J]	132	Peak acceleration [g]	196
Impact anvil	Flat	HIC	1003
Impact site	Chinguard	Displacement [mm]	30





S0232 - VF - ECE reg 22 linear tests (off site)

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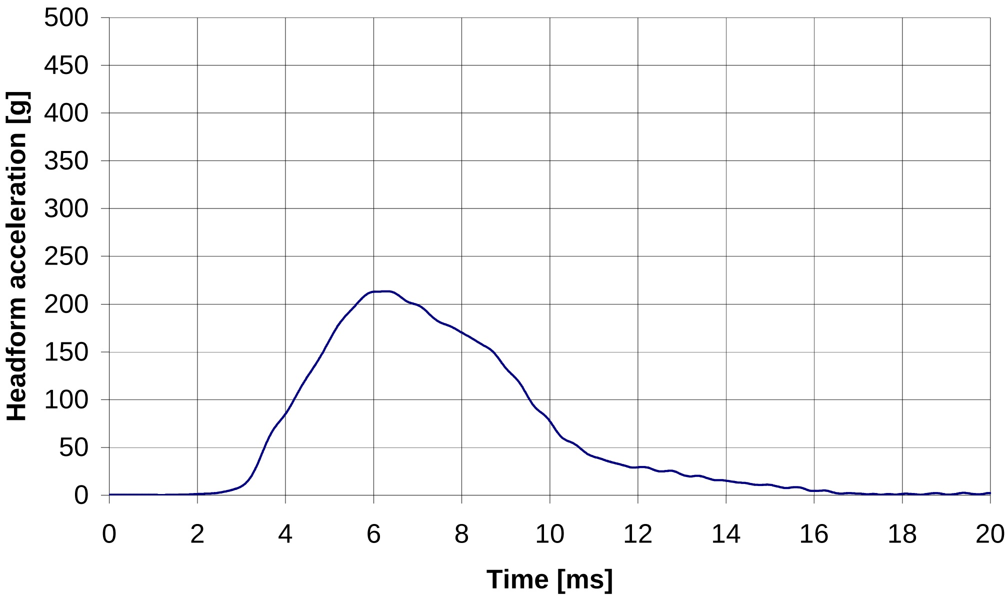
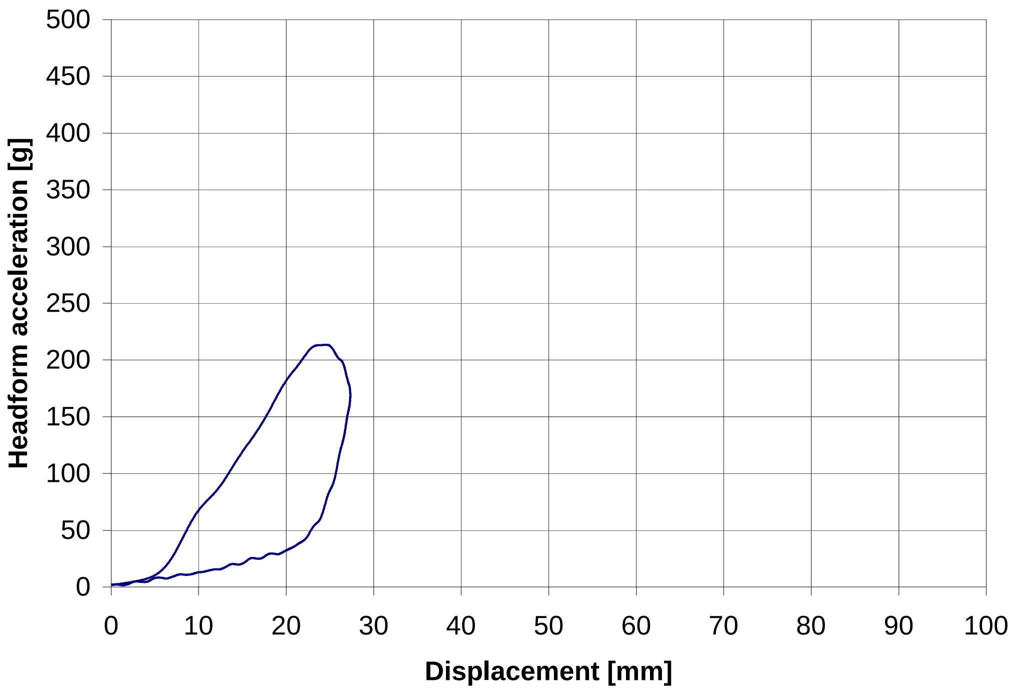
Client	DfT - S0232-VF		
Helmet	Shark S800, size 57	Test reference	e04kx
Impact energy [J]	132	Peak acceleration [g]	213
Impact anvil	kerb	HIC	2015
Impact site	front	Displacement [mm]	27





S0232 - VF - ECE reg 22 linear tests (off site)

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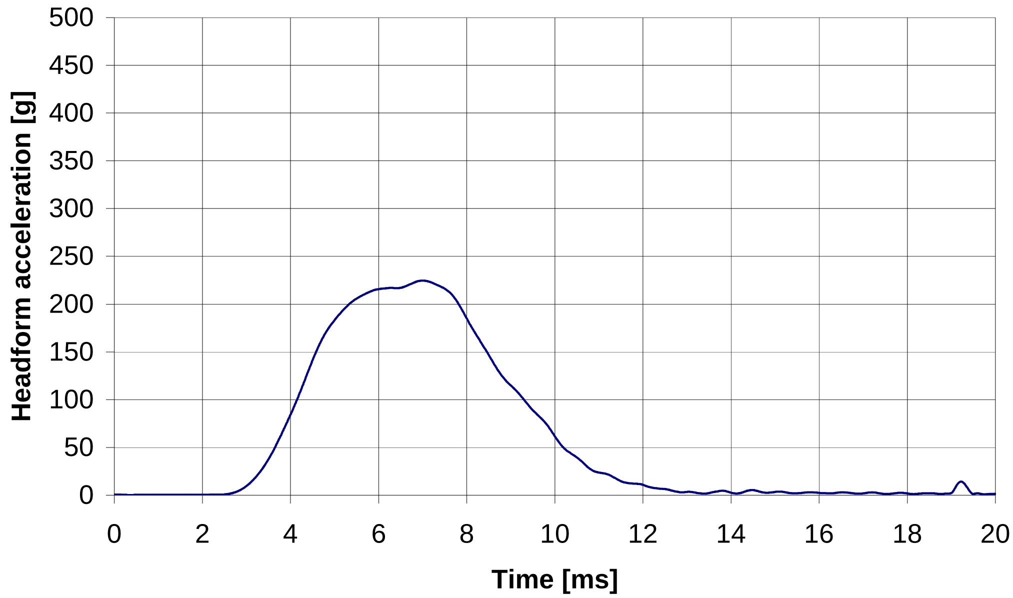
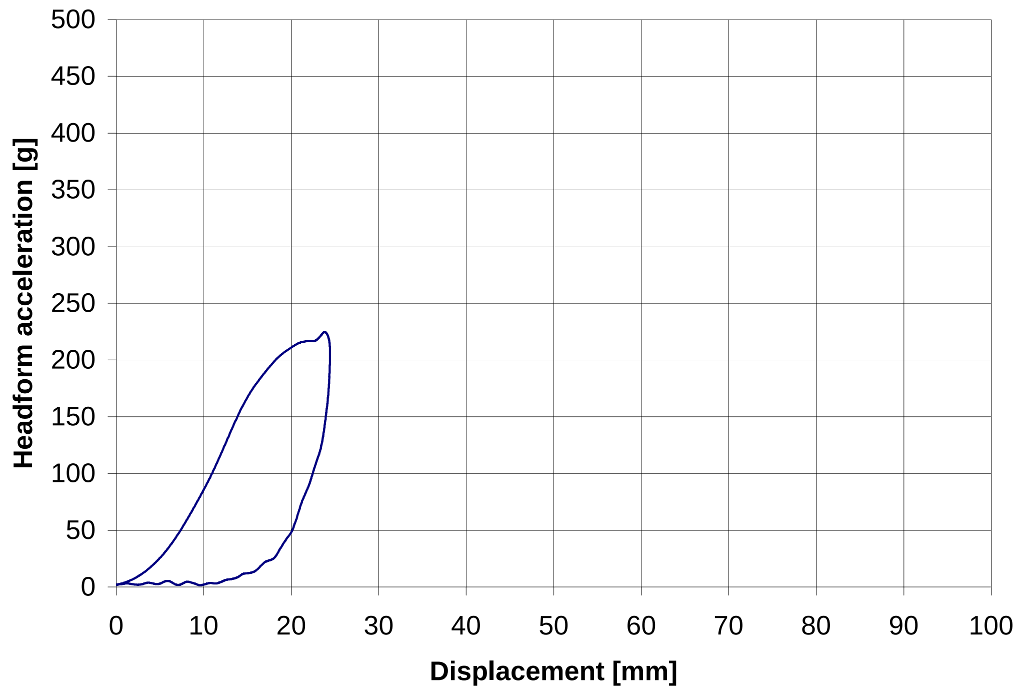
Client	DfT - S0232-VF		
Helmet	Shark S800, size 57	Test reference	h04kx
Impact energy [J]	132	Peak acceleration [g]	225
Impact anvil	flat	HIC	2318
Impact site	high side	Displacement [mm]	24





S0232 - VF - ECE reg 22 linear tests (off site)

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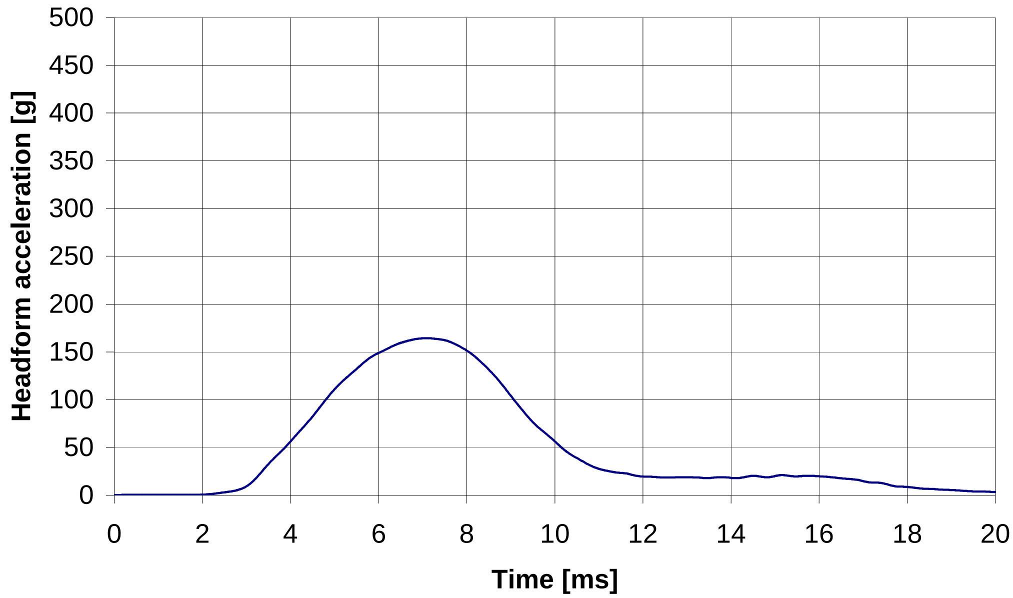
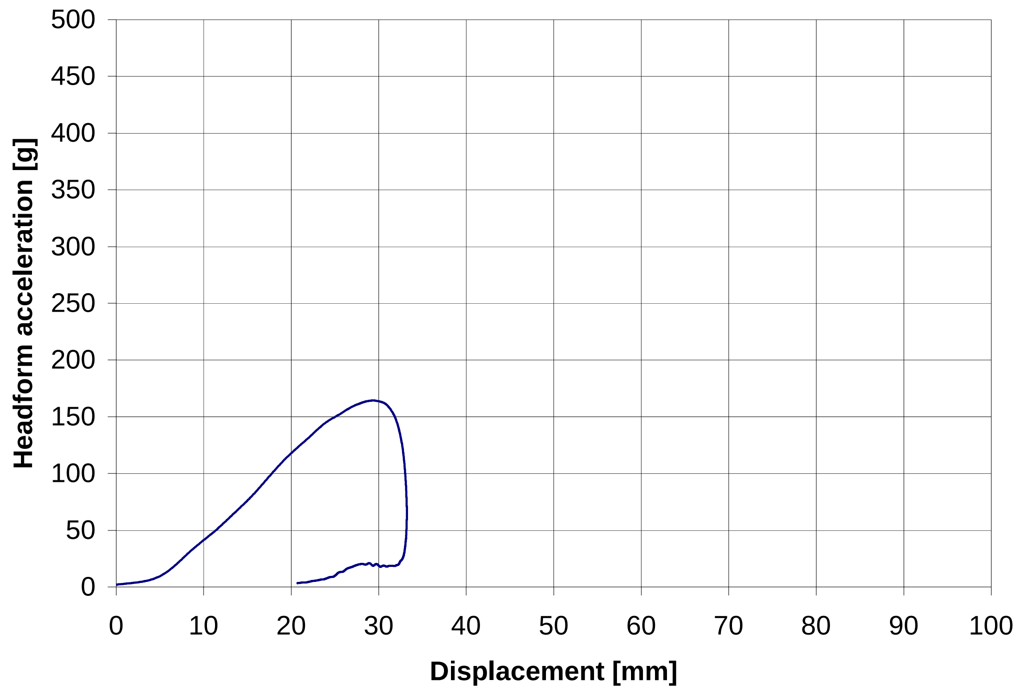
Client	DfT - S0232-VF		
Helmet	Shark S800, size 57	Test reference	f04kx
Impact energy [J]	132	Peak acceleration [g]	164
Impact anvil	kerb	HIC	1055
Impact site	low side	Displacement [mm]	33





S0232 - VF - ECE reg 22 linear tests (off site)

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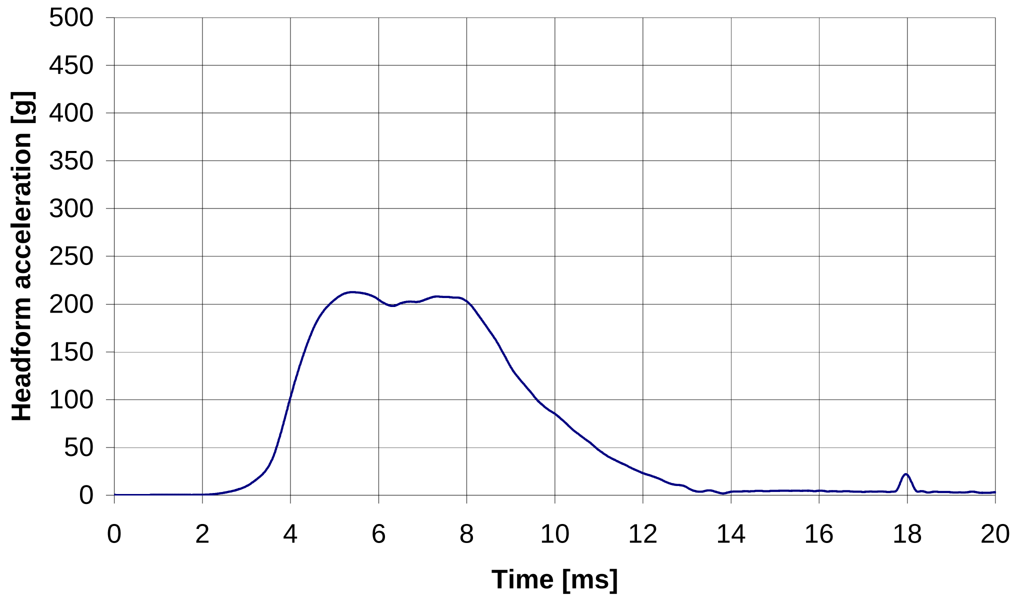
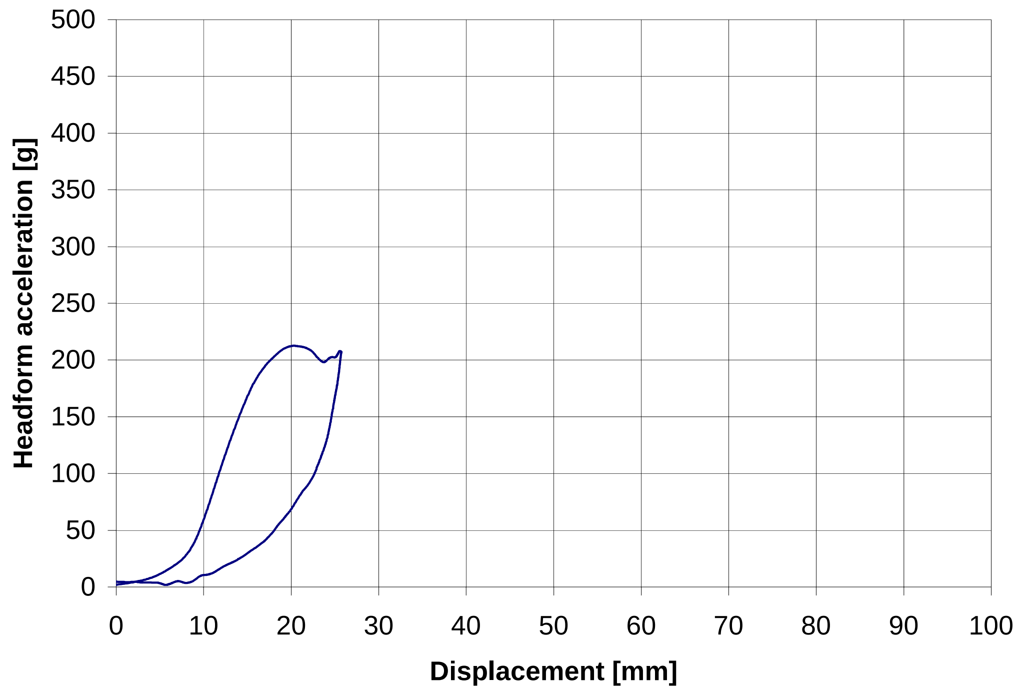
Client	DfT - S0232-VF		
Helmet	Shark S800, size 57	Test reference	g04kx
Impact energy [J]	132	Peak acceleration [g]	213
Impact anvil	flat	HIC	2542
Impact site	rear	Displacement [mm]	26





S0232 - VF - ECE reg 22 linear tests (off site)

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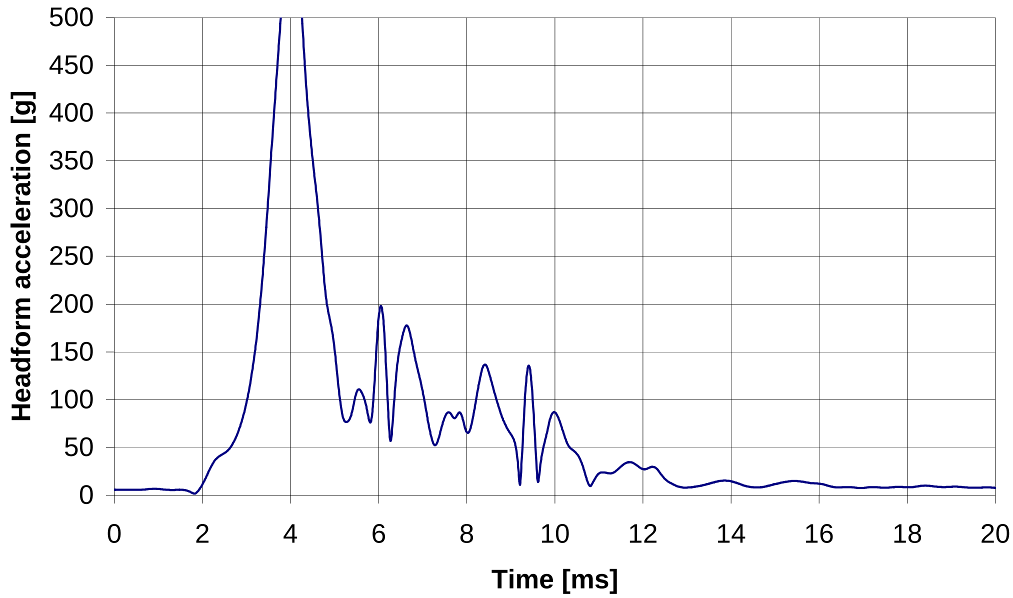
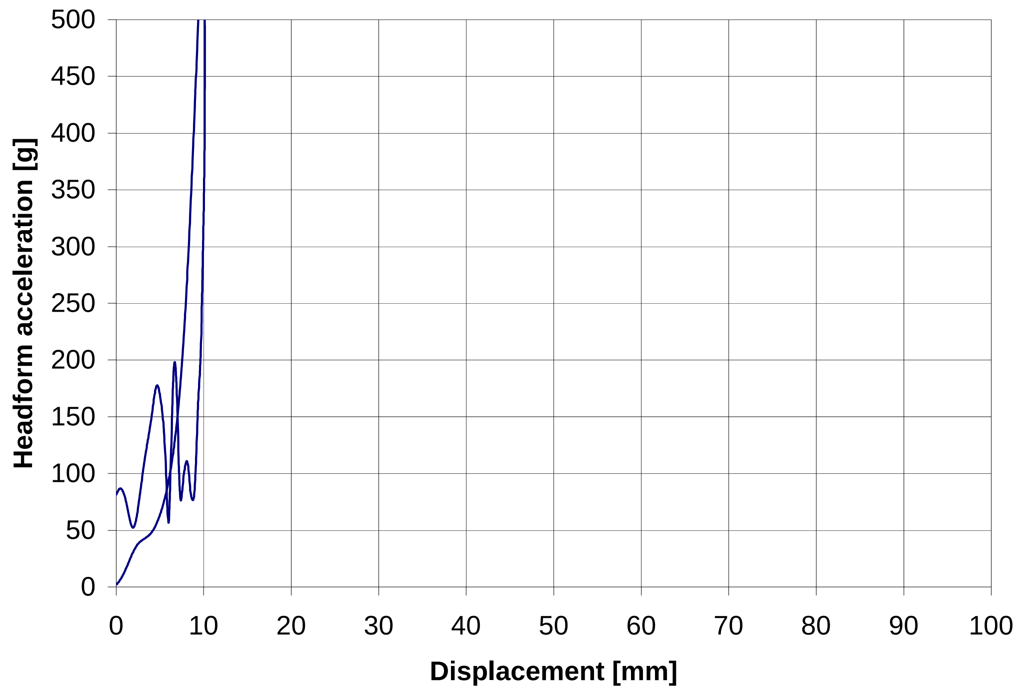
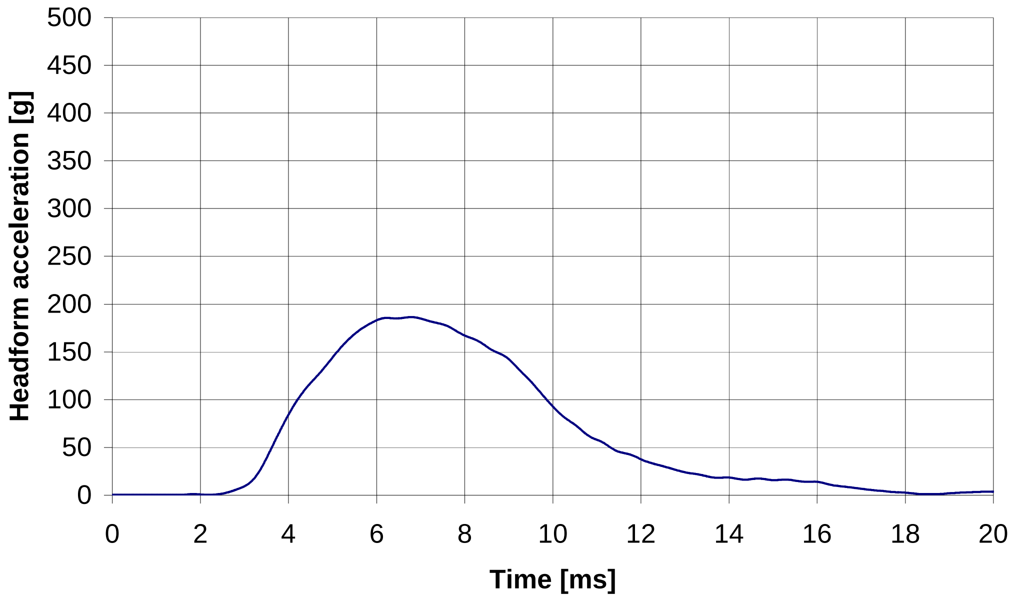
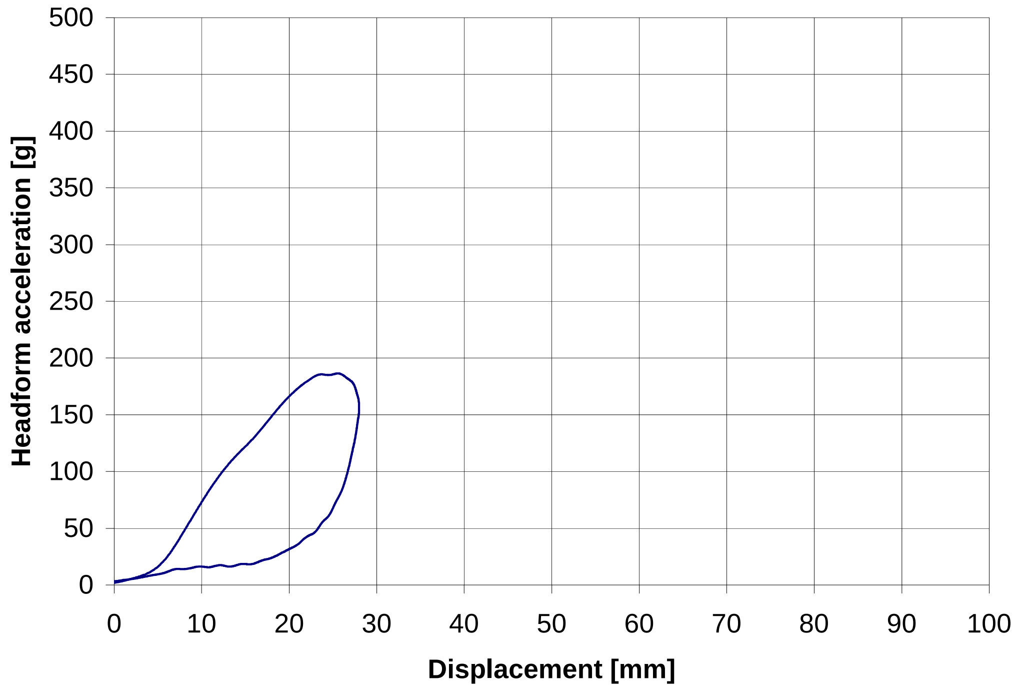
Client	DfT - S0232-VF		
Helmet	Shark, size 57	Test reference	c23cy
Impact energy [J]	132	Peak acceleration [g]	632
Impact anvil	Flat	HIC	5565
Impact site	Chinguard	Displacement [mm]	10





Client	DfT - S0232-VF		
Helmet	Probiker, size 57	Test reference	m04kx
Impact energy [J]	132	Peak acceleration [g]	186
Impact anvil	kerb	HIC	1746
Impact site	front	Displacement [mm]	28





S0232 - VF - ECE reg 22 linear tests (off site)

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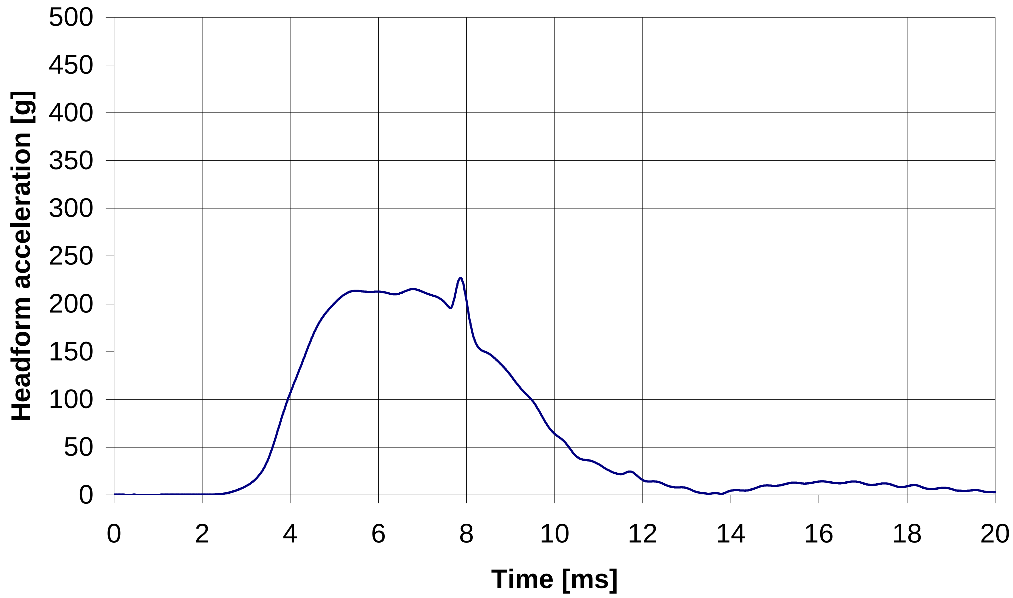
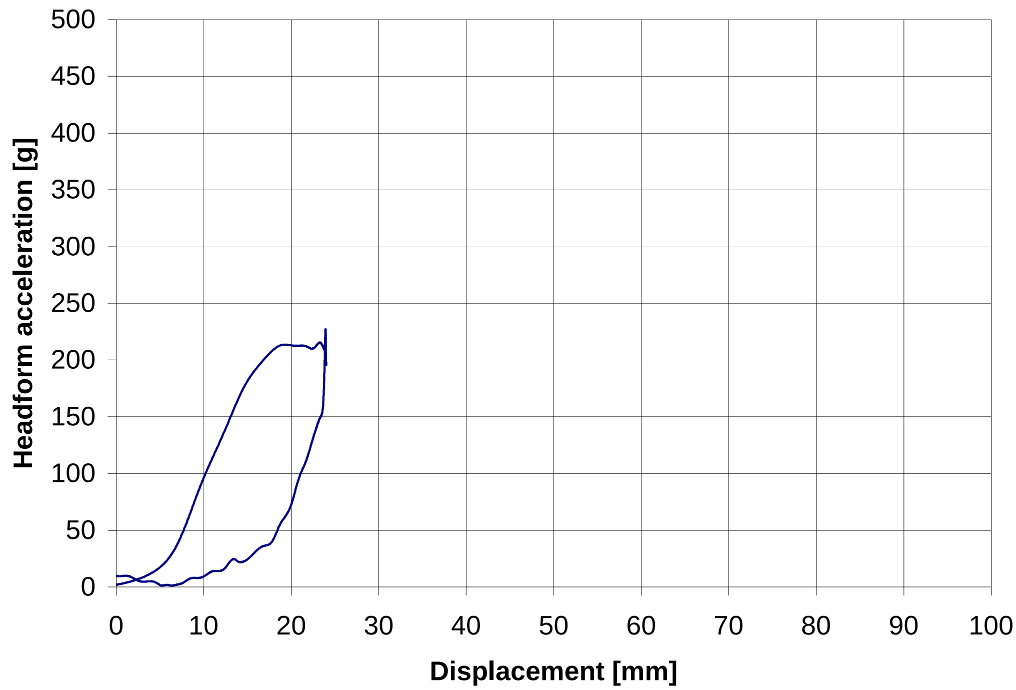
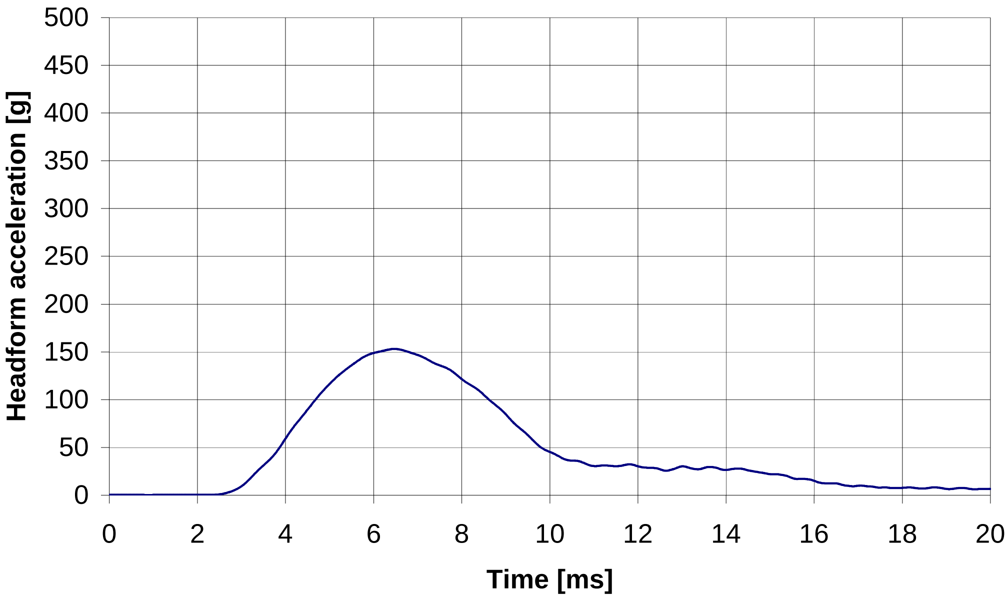
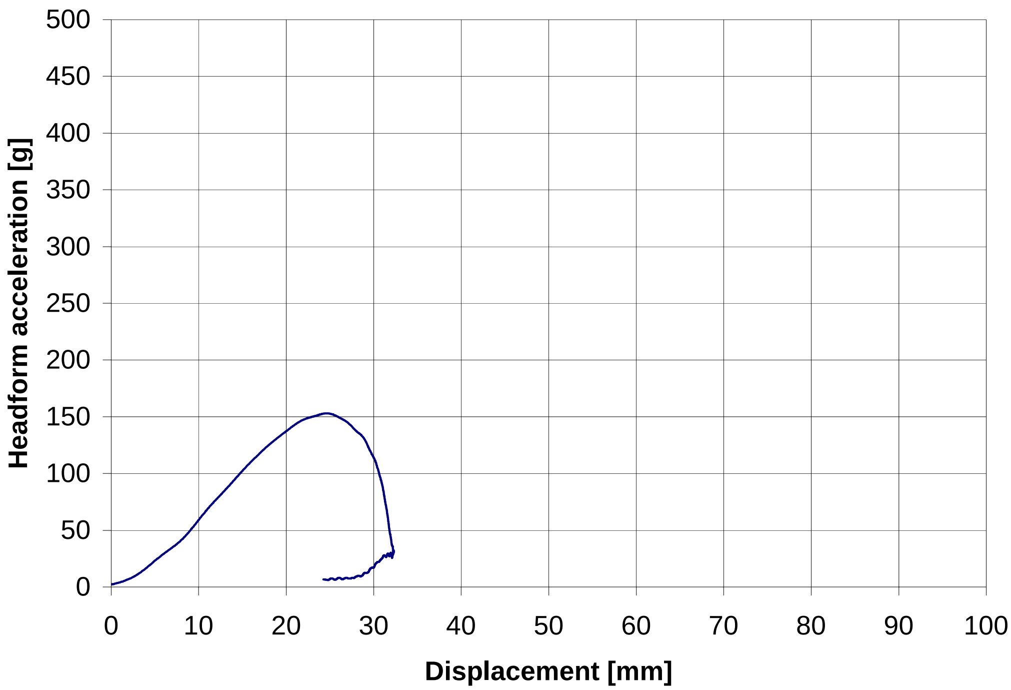
Client	DfT - S0232-VF		
Helmet	Probiker, size 57	Test reference	p04kx
Impact energy [J]	132	Peak acceleration [g]	227
Impact anvil	flat	HIC	2453
Impact site	high side	Displacement [mm]	24



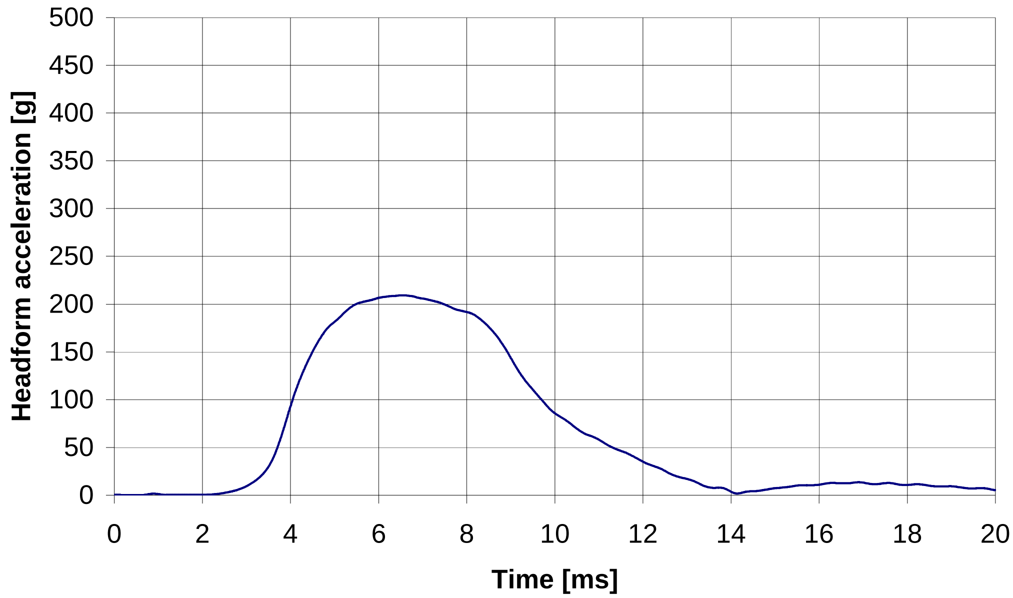


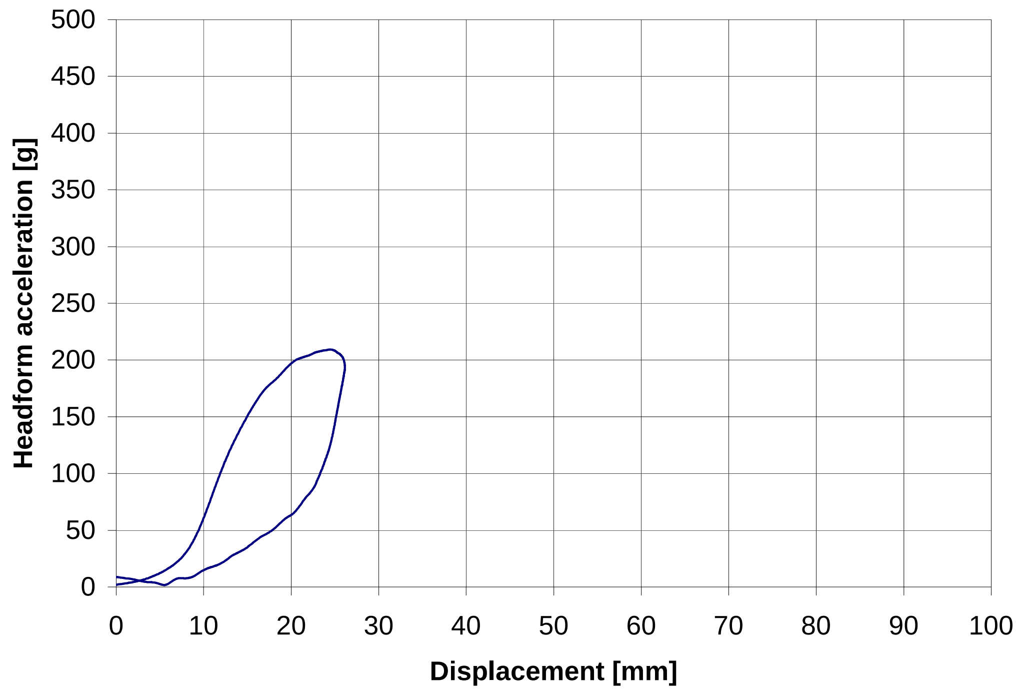
Client	DfT - S0232-VF		
Helmet	Probiker, size 57	Test reference	n04kx
Impact energy [J]	132	Peak acceleration [g]	153
Impact anvil	kerb	HIC	848
Impact site	low side	Displacement [mm]	32





Client	DfT - S0232-VF		
Helmet	Probiker, size 57	Test reference	o04kx
Impact energy [J]	132	Peak acceleration [g]	209
Impact anvil	flat	HIC	2375
Impact site	rear	Displacement [mm]	26





S0232 - VF - ECE reg 22 linear tests (off site)

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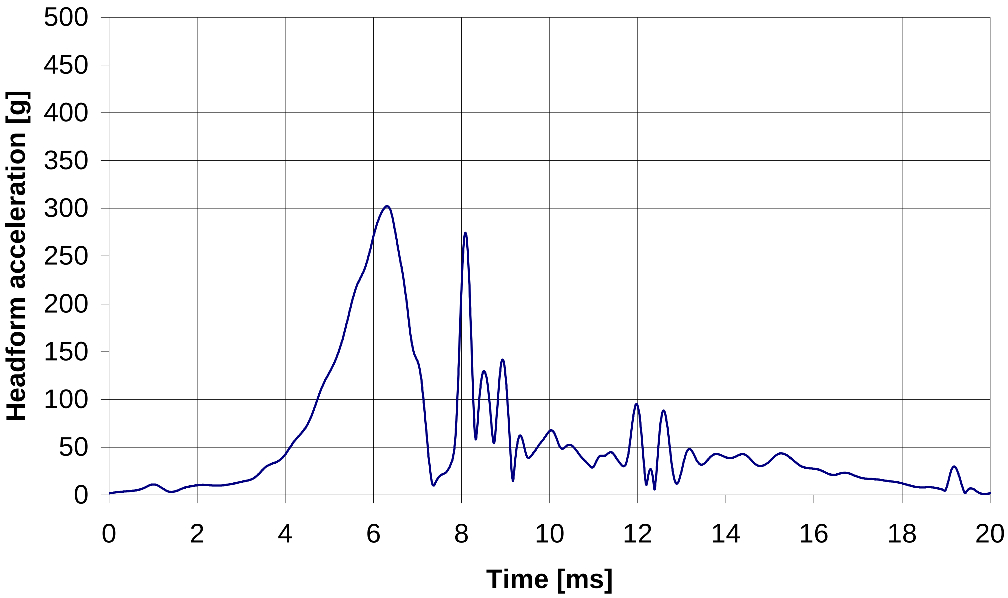
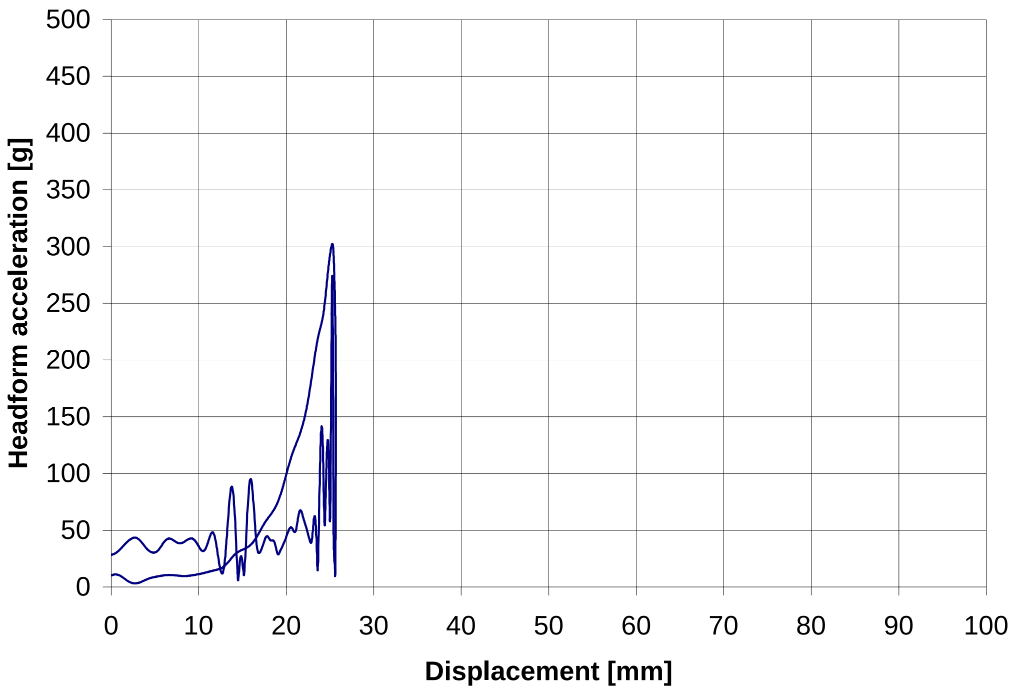
Client	DfT - S0232-VF		
Helmet	Probiker, size 57	Test reference	d23cy
Impact energy [J]	132	Peak acceleration [g]	302
Impact anvil	Flat	HIC	1458
Impact site	Chinguard	Displacement [mm]	26





S0232 - VF - ECE reg 22 linear tests (off site) www.trl.co.uk

Appendix C. Helmet optimisation using Bimass model

SYSTEMES BIOMECANIQUES - TRANSPORT ET SECURITE

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Collaborative research between TRL Limited and the Université Louis Pasteur (ULP), Strasbourg, France

Helmet optimisation using Advanced Test Tools.

Date : October 5th, 2005

Authors : C. Deck, R. Willinger

Helmet optimisation using Advanced Test Tools.

TABLE OF CONTENTS

1 INTRODUCTION

Following COST 327 project, ULP continued research on experimental and numerical head modelling as well as protective system investigation (2000-2004) with following main results:

- Numerical replication of 64 real world accidents with the ULP Human Head FE model
- Deriving of new head tolerance limits to specific injury mechanism (Willinger et al. 2004)
- Coupling of a motorcyclist helmet to the head FE model
- Optimisation of the helmet against HIC value
- Optimisation of the helmet against Human head FE model response.

It was interesting to observe that the helmet optimisation was model dependent i.e. that the “best” helmet is a function of the human head model used. The existing work concerns the rigid Hybrid III head and the ULP head FE model.

The objective of the present study is to illustrate How Bimass head form could contribute to helmet improvement. The proposed approach consists in evaluating numerically the protective aspect of about 16 helmets against Bimass response. For that purpose a similar helmet optimisation procedure as the one used with Hybrid III model will be conduced but using Bimass FE model and obviously Bimass outputs.

2 HELMET AND BIMASS MODELS

The helmet used in this study was a full face helmet with a non-reinforced polycarbonate thermoplastic shell and an expanded polystyrene foam liner, certified to BS6658A [BRI.85]. The geometry was determined by digitising the external shell surface and the helmet shell was meshed with shell elements. Brick elements, obtained by “extrusion" of the shell surface, were used to model the foam as illustrated in figures 1, 2 and 3.

Concerning material properties summarize in table 1, characteristics for the protective foam liner were obtained from dynamic compression tests on foam samples by Willinger and al.(2000). In order to determinate shell Young’s modulus, and to validate the shell global dynamic behaviour, an experimental and numerical analysis of the shell was performed (Willinger and al. (2000)).

Willinger, R., Baumgartner, D., Chinn, B., Neale, M., Head tolerance limits derived from numerical replication of real world accidents, *Proceed. of IRCOBI Conf.*, pp. 209-221, 2000.
Willinger, R., Baumgartner, D., Guimberteau, T., Dynamic characterization of motorcycle helmets : modelling and coupling with the human head. *Journal of Sound and Vibration*, vol. 235, pp. 611-625, 2000.

Figure 1. External surface of the Helmet.

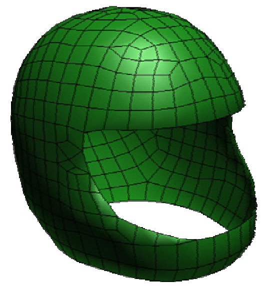

Figure 2. Outer Shell (524 shell elements) Thickness 4mm.

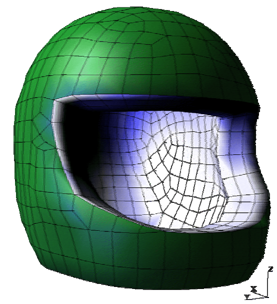

Figure 3. Foam Thickness 40mm.

The B150 headform consists of the following seven components; (1) viscoelastic skin layer, (2) aluminium skull shell, (3) Hybrid III dummy headform mounting, (4) steel sleeve, (5) polyamide contact plug, (6) brain mass and (7) cylindrical cushion. Details of how these components fit together are provided in figure 4. The skull shell, which is covered by the viscoelastic skin layer, is rigidly fixed to the Hybrid III dummy headform mounting. Secured to the top of the Hybrid III mounting is a steel sleeve, which fits around and secures the lower end of a flexible polyamide contact plug. Fitted around the upper end of the contact plug is a steel block representing the brain mass. The flexible contact plug allows the motion of the brain mass to de-couple from the motion of the skull during impacts to or high accelerations of the outer skull shell, so representing the expected response of the real skull and brain. In between the steel sleeve and the brain mass a cylindrical cushion is fitted in order to damp the relative motion between the brain and skull. Accelerometers are fitted to both the brain and skull in order that the independent motions of these structures can be measured. Further details concerning the structure and development of the B150 headform are detailed in Willinger *et al.* 2001. The helmet model was finally coupled with the B150 Headform model as shown in figure 5.

Willinger, R., Baumgartner, D., Chinn, B., and Schuller, E. *New dummy head prototype: development, validation and injury criteria*. International Journal of Crashworthiness, 6, 2001, pp281-293.

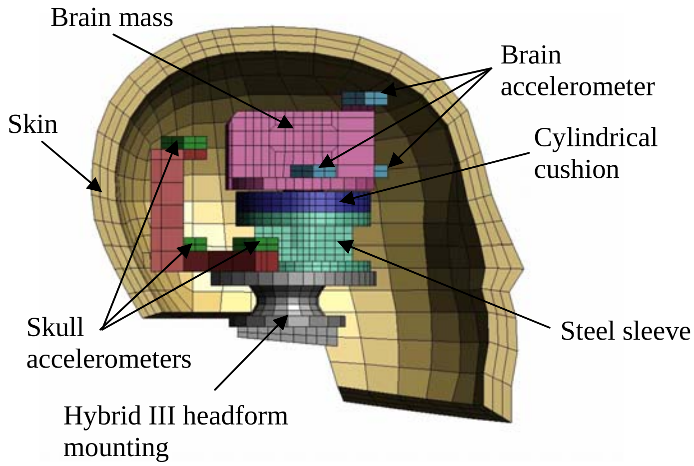

Figure 4. B150 Headform Model

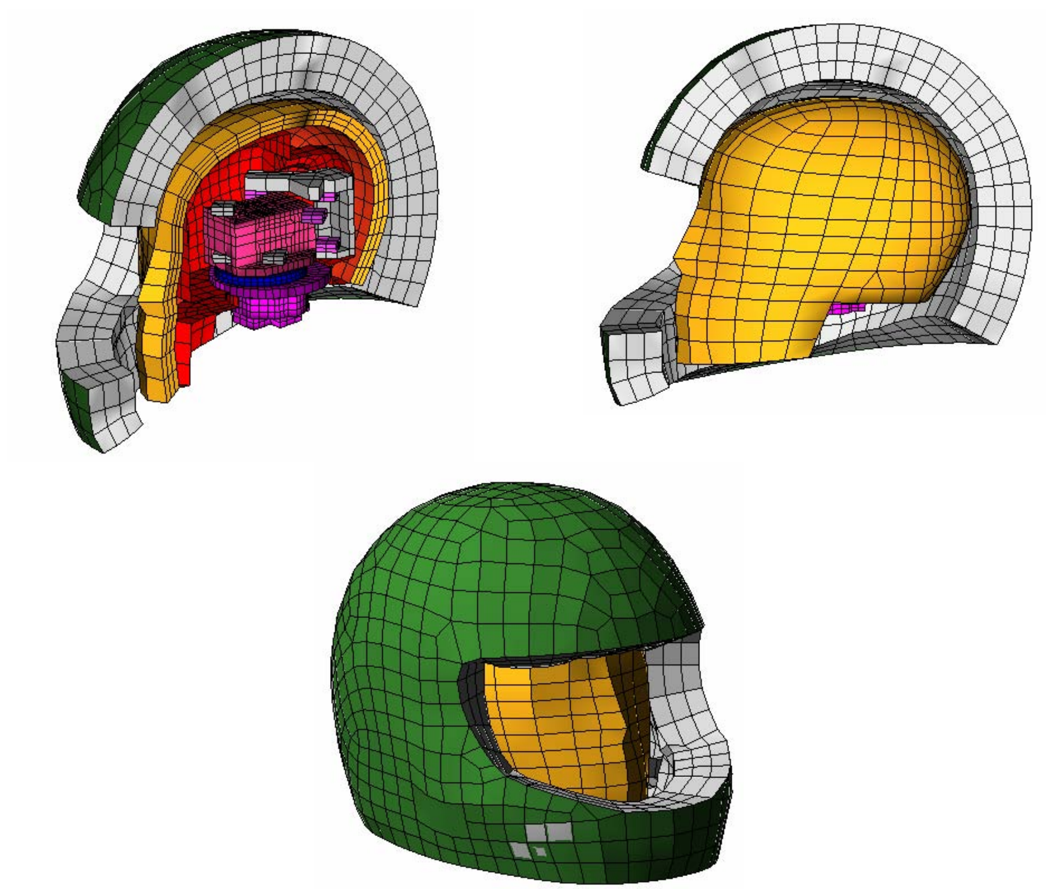

Figure 5. Helmet coupling with the B150 Head Model.

Table1 : Material and modelling data for the full - face helmet model (these values correspond to the reference helmet properties).

Component	Material	Model	E [Gpa]	ν	ρ [kg/m³]	Comment
Outer shell	thermo-plastic	linear-elastic	1.5	0.35	1055	Thickness 4mm
Protective padding	expanded polystyrene	elasto-plastic	$1.5e^{-3}$	0.05	25	Thickness 40mm yield stress = 0.35 MPa

3 HELMET OPTIMISATION PROCEDURE

Four mechanical parameters of the helmet have been varied: the foam elastic limit (D) and Young modulus (A), the thickness of the shell (B) and its Young modulus (C). Each parameter has been set on three different values: the reference value used in the model validation, a high (+30%) and a low (-30%) value (Table 2).

The total number of possibilities therefore is 81. However the factorial method permits it to analyse the influence of a given parameter with a reduced number of combination. The factorial analysis is an effective method to determine the influence of a parameter on the response of a model and if required to detect the effects of interaction between two parameters. In the case of an analysis on two levels, each parameter has two values. Then, the analysis requires 2^n simulations, where n is the number of parameters studied. In the present case,(with n=4) this leads us to a total of 16 virtual helmets.

This conduces to 16 virtual helmets for which the protective capability will be evaluated both against Hybrid III and Bimass headform outputs under normative impact condition (Table 3).

The tests used for the parametric study remain the drop test on a flat anvil in three impact situations (frontal, rear and lateral impact as illustrated in figure 6) at 7.5 m/s initial velocity.

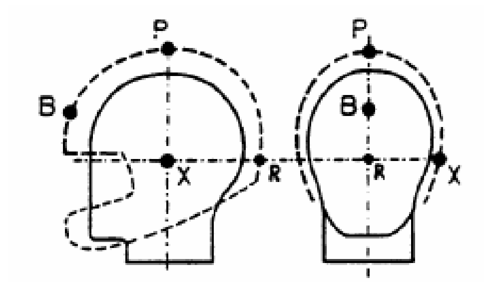

Figure 6. Localisation of the four impacts stipulated by the European norm ECE-R022

Table 2. Helmet parameters using for parametric study.

Facteurs	Niveaux		
	-	Baseline	+
A Young modulus of the foam	1.05 MPa	1.5 Mpa	1.95 MPa
B Shell thickness	2.8 mm	4 mm	5.2 mm
C Young modulus of the shell	1.05 GPa	1.5 Gpa	1.95 GPa
D Foam elastic limit	0.21 MPa	0.35 Mpa	0.455 MPa

Table 3 : Simulation protocol indicating for each of the 16 simulations, the helmet characteristics retained: +/- stand +30% or –30% of the reference helmet properties.

Simulations	A (Ep)	B (eq)	C (Eq)	D (σep)
S1	-	-	-	-
S2	+	-	-	-
S3	-	+	-	-
S4	+	+	-	-
S5	-	-	+	-
S6	+	-	+	-
S7	-	+	+	-
S8	+	+	+	-
S9	-	-	-	+
S10	+	-	-	+
S11	-	+	-	+
S12	+	+	-	+
S13	-	-	+	+
S14	+	-	+	+
S15	-	+	+	+
S16	+	+	+	+

Computed results will be arranged under the form of histograms which present for each injury parameter the maximum value calculated for each virtual helmet. It will therefore be possible to extract the “best” helmet relatively to each injury parameter and to compare the optimal solution with the ones obtained with the HybridIII and the ULP FE head model.

Concerning the calculated B150 mechanical parameters, we will focus on three outputs well correlated with injury mechanisms as follows:

1. The maximum force computed at the interface between the skull (wrapped by the scalp) and the helmet. This mechanical parameter seems to be well correlated with skull fractures

2. The maximum angular acceleration undergone by the brain relative to the skull. This mechanical parameter is correlated with the subdural and subarachnoidal Haematoma.
3. The linear acceleration of the brain which is correlated with neurological injuries.

4 TYPICAL RESPONSES UNDER NORMATIVE IMPACT

4.1 Headforms responses

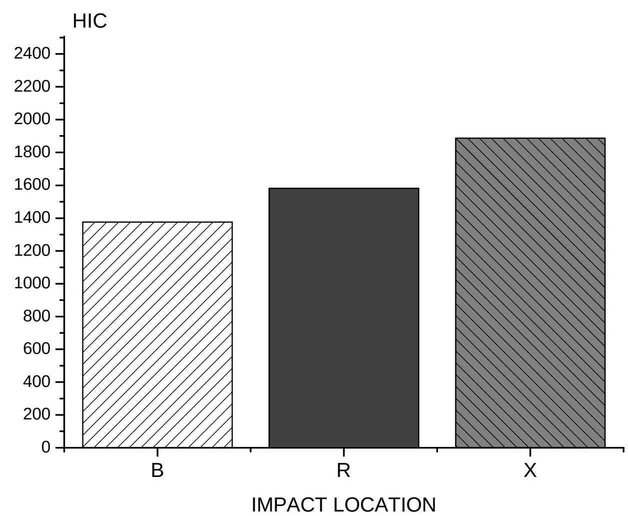

Figure 7. HIC calculation for the three impact location stipulated by the ECE-R022 norm with the reference helmet properties.

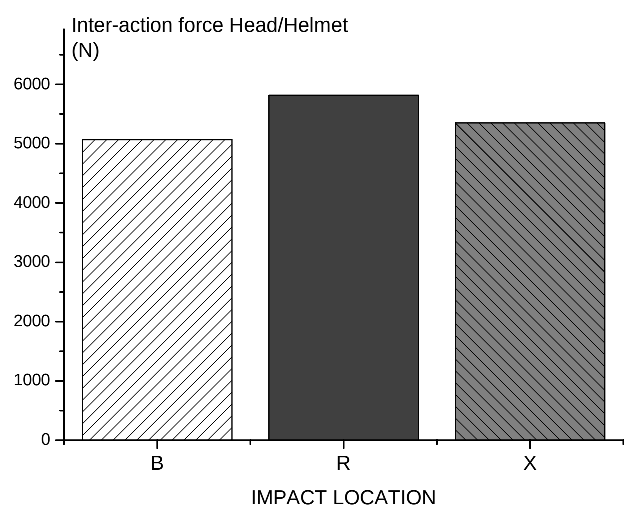

Figure 8. Inter-action force calculated between the helmet and the B150 head Model for the three impact locations with the reference helmet properties.

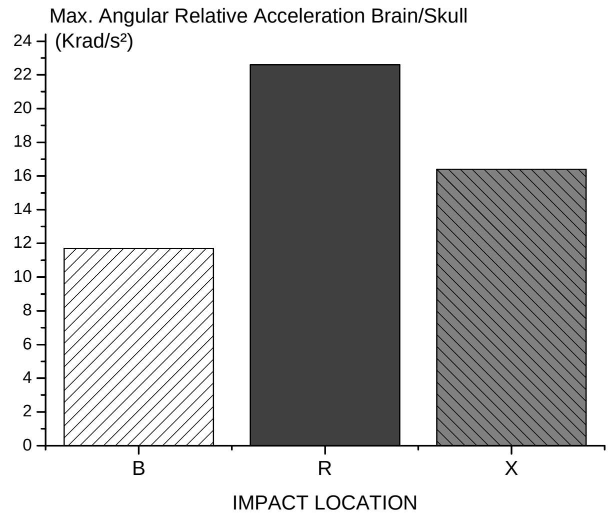

Figure 9. Maximum of angular relative acceleration between the brain and the skull for the three impact locations with the reference helmet properties.

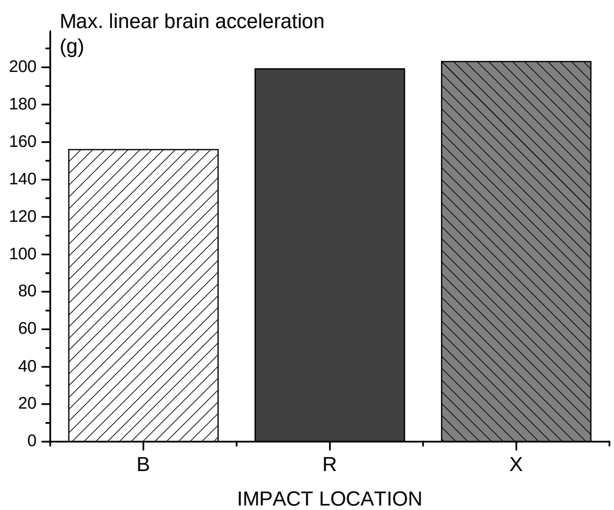

Figure 10. Maximum of linear brain acceleration calculated for the three impact locations with the reference helmet properties.

4.2 Comments

The frontal impact corresponds to a low injury risks comparing to the results obtained in the rear and lateral directions. This observation is true regarding the four mechanical parameters calculated (HIC (figure 7), Inter-action force between the head and the helmet (figure 8), Maximum angular relative acceleration between the brain and the skull (figure 9), Maximum linear brain acceleration (figure 10)).

4.3 Typical curves obtained for a frontal impact with the reference helmet

In this section we show the typical curves obtained for a frontal impact with an initial velocity at 7.5 m/s.

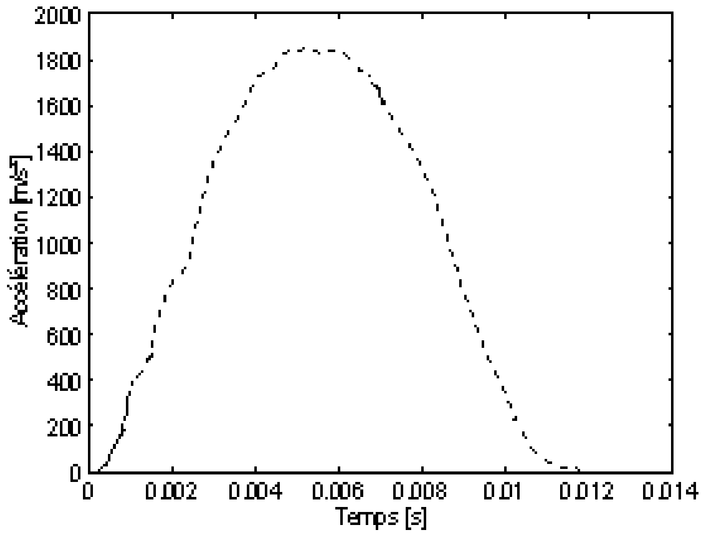

Figure 11. Linear acceleration of the centre of gravity of a helmeted headform for a frontal impact with an initial velocity at 7.5 m/s. The helmet used here corresponds to the helmet with the reference mechanical properties (Table 1).

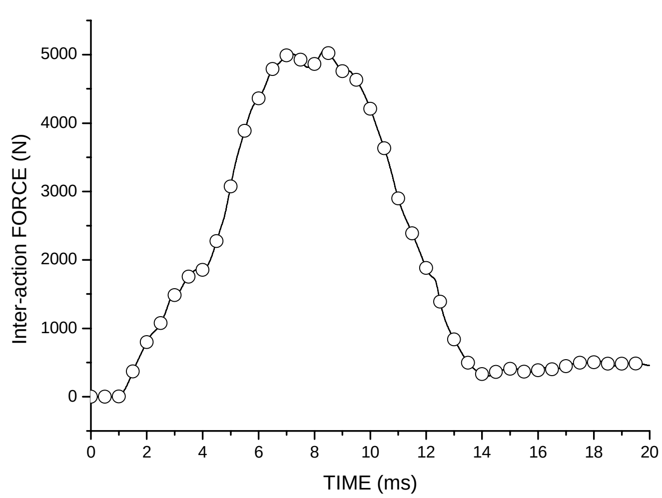

Figure 12. Inter-action force curve obtained for the frontal impact with an initial velocity at 7.5 m/s. The helmet used here corresponds to the helmet with the reference mechanical properties (Table 1).

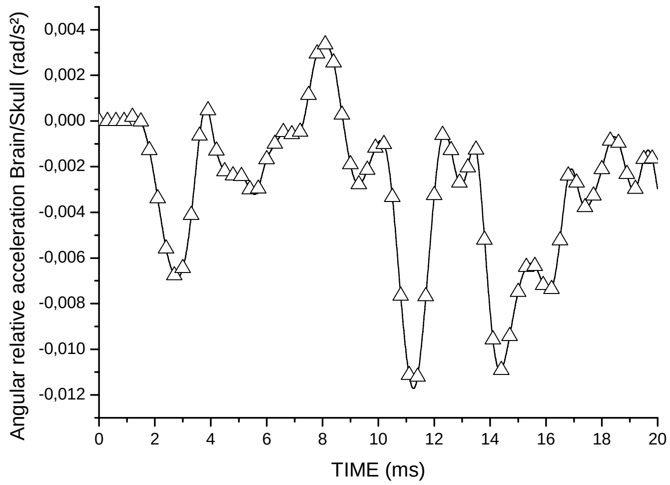

Figure 13. Angular relative acceleration in rd/s^2, curve between the brain and the skull for the frontal impact with an initial velocity at 7.5 m/s. The helmet used here corresponds to the helmet with the reference mechanical properties (Table 1).

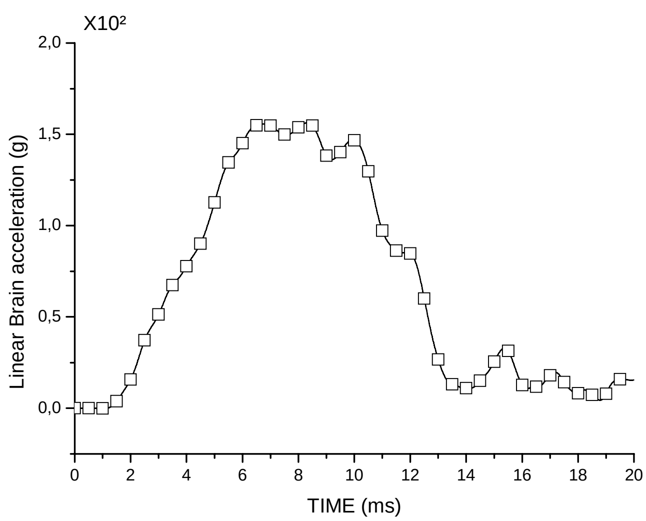

Figure 14. Linear Brain acceleration curve for the frontal impact with an initial velocity at 7.5 m/s. The helmet used here corresponds to the helmet with the reference mechanical properties (Table 1).

5 RESULTS CONCERNING THE HELMET OPTIMISATION AT 7.5 m/s

5.1 B-IMPACT (frontal impact)

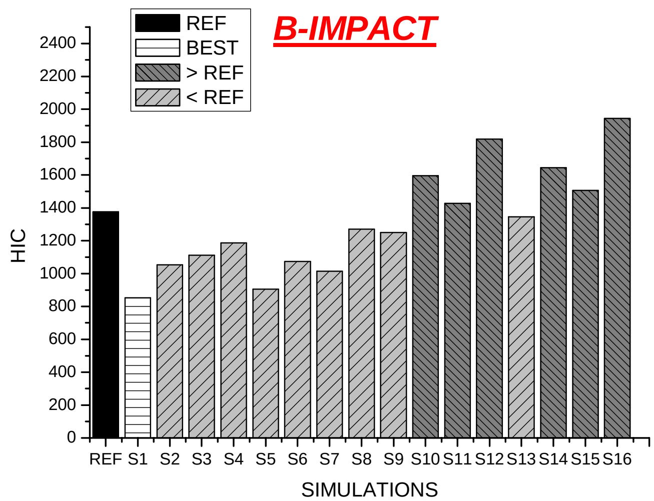

Figure 15. HIC calculation for the 16 virtual helmets and the reference helmet for a frontal impact with an initial velocity at 7.5 m/s.

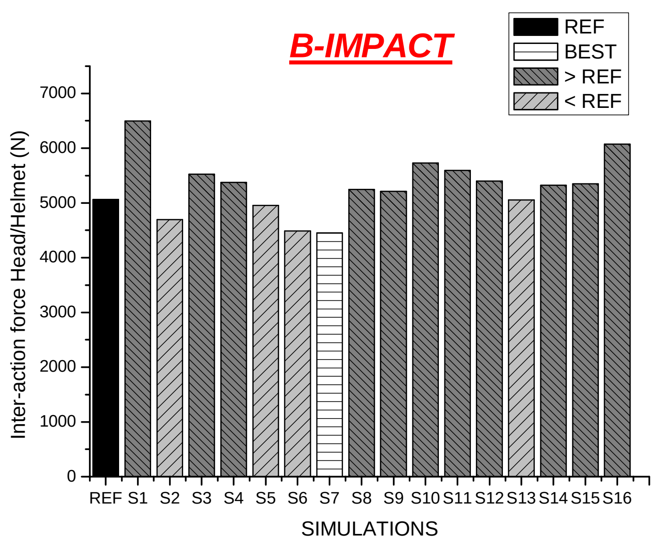

Figure 16. Inter-action force calculated between the helmet and the B150 head Model for the 16 virtual helmets and the reference helmet for a frontal impact with an initial velocity at 7.5 m/s

Appendix D. Light reactive visors - draft performance requirements

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HEALTH & SAFETY LABORATORY

Anticipating the development of light-reactive visors for motorcyclists: Draft performance requirements

PE/04/03

Project Leader: **N Vaughan**
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Science Group: **Human Factors Group**

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EXECUTIVE SUMMARY

It is anticipated that new forms of light-reactive motorcycle visor will be developed to address the problem of glare. This report describes a draft standard giving performance requirements for this new class of motorcycle visor, in anticipation of them being manufactured and placed on the market.

The draft standard is based on existing requirements drawn from British and European eye protection standards, modified where necessary for this application.

The draft standard should be submitted to BSI PH/2/5 for proposal as a new work item, either within BSI or in CEN.

Anticipating the development of light-reactive visors for motorcycle helmets: Draft performance requirements

INTRODUCTION

This report describes work carried out under contract to Transport Research Laboratory.

Low angle sun and sunglare have been identified as significant problems for riders of motorcycles, leading to discomfort, distraction and accidents resulting from loss if clear vision. It is anticipated that the industry will develop novel means of combating this glare, by incorporating light-reactive visors into motorcycle helmets. Such products will have to be properly assessed for performance and safety before being released onto the market. This report contains a draft performance standard developed for this purpose.

BASIS OF STANDARD

European standards already contain requirements and test methods for various forms of light-reactive eye protectors, notably:

- EN 1836 – Personal eye protection – Sunglasses, sunglare filters for general use and filters for direct observation of the sun.
- EN 379 – Personal eye protection – Automatic welding filters.

In combination with existing requirements for motorcycle visors taken from:

- BS 4110 – Specification for visors for vehicle users.

New forms of equipment have been anticipated and catered for.

The specific operating principles for light-reactive visors considered in this process were:

- Electro-optical filters, based on liquid crystal technology. These require a source of power (normally form batteries or photoelectric cells) to operate, and adjust their luminous transmittance in response to the intensity of incident light. Filters of this type are used in automatic filters for eye protection during welding, and have reached and advanced level of sophistication. However, there are currently technical barriers in forming them into curved filters.
- Electro-mechanical devices, where a dark fixed shade visor flips into the field of view at high levels of incident illumination under the control of an electrically driven servo system. Again, battery or photoelectric power may be used.
- Photochromic filters. Requiring no power input, these are made from lens materials doped with light-sensitive dyes, which darken in response to the intensity of incident illumination (usually predominantly in the UV wavelength range). This technology is currently used in "reactolite" spectacle lenses, but the speed with which these lenses typically change shade is too slow for the envisaged visor applications. The technology exists to speed this process up significantly.

While the draft standard has been written with these technologies in mind, it also avoids design restriction as far as possible. Other, as yet unknown, technologies should also be able to satisfy the requirements.

There is no available information on whether any current technologies can satisfy the requirements included in this draft. The requirements are simply an extrapolation from currently existing standards to this new application, based on the needs of safety and practicality.

COMMENTARY ON THE DRAFT STANDARD

This section of the report works through the draft standard, which is given in full in Annex 1. For each section where comment is necessary, reasoning for the form and requirements of that section is given.

1 Scope

Only those aspects of visor performance relating to light-reaction are included in this draft standard. For all other aspects of visor performance, BS 4110 is deferred to. This in turn calls up various European eye protection standards, which could be referred to instead, but the single reference to BS 4110 approach is simpler.

2 Normative references

Usual wording and format used.

3 Terms and definitions

Virtually all the terminology needed in this standard appears in the existing referenced standards. Only two new terms need definition; these are required later in the text.

4 Classification

Two basic forms of filter are described; active and passive filters. Active is taken to mean any form of filter system requiring electrical or mechanical sub-systems to operate. Passive is specifically intended to cover photochromic-type technology.

5 Designation of filters

This section appears in some relevant standards, but does seem to be somewhat redundant, as the contents are covered elsewhere in the standard. It has been included here for completeness, but may be deleted later if considered superfluous.

6 Design and manufacturing requirements

BS 4110 applies for these aspects.

7.1.1 Basic general requirements

BS 4110 again deferred to except for spectral and luminous transmittance requirements.

7.1.2 Residual eye/face protection

In an emergency, some forms of darkened visor may need to be removed from the field of view. This clause addresses the continuing need for vision and impact protection in these circumstances.

7.1.3 Resistance to water
Particularly addressed to Active filter systems, this addresses continued reliable operation of the sensing and switching functions when wet.

7.1.4 Angular dependence of means of actuation
Direct lighting from any position visible to the wearer must cause appropriate darkening of the filter. The requirement does not forbid darkening caused by illumination from outside this region, but this function is not mandatory.

7.2.1 Transmittance
Requirements in this section are largely drawn from EN 1836. The lower temperature limit at which performance is tested has been reduced from $5^{o}C$ to reflect the likely operating temperatures. EN 379 tests electro-optical welding filters down to $-5^{o}C$, but this was considered excessive.

The note beneath Table 1 recognises that darker filter shades may be considered illegal for drivers of motorcycles on the road in some countries. These shades would, however, still be suitable for use by pillion passengers who preferred them. However, one of the main reasons for outlawing dark shade visors is their potential for use when driving in low-light conditions. This problem would not arise for a light-reactive visor, which would not achieve such dark levels under these environmental conditions. National legislation may need to change to recognise this advance in technology.

7.2.2 Reaction time
This draws on the definition at 3.1, and the requirements of EN 379, modified for this application. Transmission characteristics of existing light-reactive devices tend to change non-linearly between light and dark states, hence the need to measure only the time to approach the end condition, and not the time to the end condition itself. The time limit of 5 seconds is somewhat arbitrary and could be shortened, but this represents a value which is relatively easy to assess, is considerably faster than current typical photochromic lenses, and provides reasonably rapid protection to the visor wearer. Too rapid switching of filter transmission is undesirable – riding through dappled shade could induce strobe-like interference with vision.

7.2.3 Recognition of signal lights and spectral transmittance
The Q values (0.8) quoted in BS 4110 have been used here. However, EN 1836 allows different Q values for the various colours of signal from 0.4 to 0.8. These could be adopted instead.

7.2.4.1 Power off
In the event of power failure, the visor must revert to a light (although not necessarily the lightest) shade to ensure vision is maintained. This differs from the equivalent requirement for automatic welding filters where power-off must revert to a dark shade, to ensure continued protection from welding glare.

7.2.4.2 Manual control
Over-ride of the shade setting mechanism to revert to high transmission must be provided. Various means are envisaged, all of which must "latch" in the over-ride

condition until cancelled. For one-handed operation, requiring this to be the left hand was considered, but rejected on the grounds of design restriction.

7.2.5 Special requirements for passive filters
As for 7.2.4.2.

7.3 Angle dependence of luminous transmittance
This is a problem which currently affects electro-optical LCD filters, and must be assessed to ensure consistency of glare reduction. How a curved LCD filter would perform in this assessment is unknown.

7.4 Visibility of LCD displays
This is a problem which may affect any filter incorporating polarising elements. These may interfere with the polarisers built into LCD displays (which are becoming increasingly common as vehicle instrument displays) to render them unreadable. Typically, LCD displays are polarised at 45^o, and eye protectors at 90^o, so while there may be a reduction in clarity of displays, they should remain readable.

8.3 As worn position
The intention here is to ensure that testing is carried out with the visor in the position and orientation that it would have in use. While the spirit of this requirement is obvious, semantically the definition given here is not very rigorous. It could be made more explicit if considered necessary.

8.4 Uncertainty of measurement
This topic is assuming greater importance in certification. The wording here is adapted from recent standards. The $\pm$5% value is consistent with the specific requirements for measurement of luminous transmittance in EN 1836 for the shades of filter within the scope of this draft standard.

8.5 Resistance to water
This is intended to be a simple simulation of exposure to rain, to assess any qualitative malfunctions of the filter actuating system. Higher levels of specification and rigour are probably unnecessary.

8.6 Reaction time
This is a simplified and less sensitive adaptation of the method used in EN 379 to assess automatic welding filters.

8.7 Angle dependence of luminous transmittance
The method called up in EN 379 is used, but carried out on the optical axes of both eyes to assess any differences introduced by curvature of the filter. The standard interpupilary distance of 64 mm is used as the default value for these measurement positions, but the manufacturer can specify something different if they choose.

9 Marking
Most of the marking requirements of BS 4110 are carried over to this draft by reference. Additional marking is required to describe the Classification and filter performance. The markings for these aspects have been chosen to avoid confusion with other markings required by BS 4110.

"E" denotes an Active filter (E notionally standing for "electronic"). "A" cannot be used because of potential confusion with "ZA" for impact resistance.
"P" denotes a Passive filter.
Markings for minimum and maximum filter category are based on those for automatic welding filters. Distinction between discrete and continuous shade filters is achieved by the use of a different separator (" / " or " – " respectively) between the maximum and minimum category numbers.

10 Information provided by the manufacturer
Again, this is mostly carried over from BS 4110, except for a few bullet points which are disapplied. Some of the existing bullet points will now cover additional information generated by this standard (e.g. "the meaning of any markings" will now need to include explanation of the filter class and category). Additional bullets are proposed where required.

RECOMMENDATIONS
The draft standard included in this report is at the first stage of development. It should be regarded as no more than a basis for the further development of performance requirements against which to assess the adequacy and safety of products within its scope.

This work cannot be done in isolation. All stakeholders (manufacturers, users, test and certification bodies, regulators) in the field should be consulted and involved. The usual forum for this activity is in the National, European and International Standards bodies. As the next step in the process of development of a standard, this draft should be submitted to the relevant BSI committee (PH/2/5 – Eye protection for vehicle users) with a request to generate a new work item, either within BSI or for them to propose the work item to the equivalent European Standards committee CEN TC/85 WG/5.

PH/2/5 is currently dormant, having no appointed chairman, and no work items. On receipt of the suggestion for this new work item, the committee secretary (contact details below) will have to circulate members of PH/2 for views and nominations for convenorship of the working group. This process is unlikely to take less than a few months. The next meeting of PH/2 is not yet scheduled.

Contact details for the secretary of BSI committee PH/2:

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Secretary PH/2
British Standards Institution
389 Chiswick High Road
London W4 4AL

Tel: 0208 996 7175
Fax: 0208 996 7249
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Annex 1

Draft standard:
Light-reactive visors for motorcycle helmets

1 Scope

This standard specifies the luminous transmittance and related performance requirements for motorcycle visors reacting to solar radiation to protect against transmitted glare and to improve the visual comfort of the user. Other requirements for these visors are given in BS 4110:1999.

2 Normative references

This standard incorporates by dated and undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed below. For dated references, subsequent amendments to or revisions of any of these publications apply to this standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies.

EN 165:1995 Personal eye protection - vocabulary
EN 167:2001 Personal eye protection – Optical test methods
EN 1836:1997 Personal eye protection – Sunglasses, sunglare filters for general use and filters for direct observation of the sun
EN 61747-1:2000 Liquid crystal and solid-state display devices; Part 1: Generic specification
IEC 50 (845):1987 International Electrotechnical Vocabulary: Chapter 845 - Lighting
ISO/CIE 10526:1991 CIE standard colourimetric illuminants
BS 4110:1999 Specification for visors for vehicle users

3 Terms and definitions

For the purposes of this standard, the definitions of EN 165:1995, EN 1836: 1997 and of IEC 50 (845):1987 apply, together with the following:

3.1 Reaction time

The time taken for filter to approach within 5% of the final luminous transmittance value resulting from a step change in the intensity of incident illumination. This applies both to increases and decreases in luminous transmittance.

3.2 Reactive filter

Filter which automatically and reversibly alters its luminous transmittance in response to incident illumination. This can be achieved by any suitable process, including photochromic reaction, electro-optical automatic shade setting, or mechanical means.

4 Classification

4.1 Active filter

Filters relying on an auxiliary powered system to detect incident illumination and to adjust their luminous transmittance in a pre-determined way (e.g. electro-optical filters).

4.2 Passive filter

Filters which respond to incident illumination by altering their luminous transmittance in a predetermined way, without any auxiliary powered systems (e.g. photochromic filters).

5 Designation of filters

Filters shall be described according to their classification (see clause 4) and their maximum and minimum luminous transmittance. Marking on the filters shall distinguish between filters alternating between fixed levels, and those which vary continuously between the minimum and maximum values, as described in clause 9.3.

6 Design and manufacturing requirements

The requirements of BS 4110:1999 clause 4 shall apply.

7 Requirements

7.1 Basic requirements

7.1.1 Basic general requirements

The visor shall meet the requirements of BS 4110 for field of vision, impact strength, resistance to fogging, abrasion and corrosion, and for optical properties (refractive powers, variations in luminous transmittance, quality of material and surface, resistance to UV, diffusion of light), except spectral and luminous transmittance.

7.1.2 Residual eye / face protection

Where the filtering visor has to be removed from the field of view to achieve the requirements of 7.2.3.2 or 7.2.4, an additional, non-filtering, visor meeting the full requirements of BS 4110 shall remain in the wearer's field of view.

7.1.3 Resistance to water

The light-reactive performance of the visor and any auxiliary system, attached to a helmet as directed by the visor manufacturer, shall be unaffected during and after wetting. Test in accordance with 8.5.

7.1.4 Angular dependence of means of activation

Darkening of the visor shall be initiated by incident radiation from any angle within the field of vision of the helmet / visor, as determined in clause 5.1 of BS 4110:1999.

7.2 Spectral and luminous transmittance

7.2.1 Transmittance

Filtering visors shall be classified according to the filter categories in Table 1. When describing the transmittance properties of reactive filters, two filter categories shall be used, corresponding to the lightest and darkest states of the filter. Filter category 0 shall apply to reactive filters in their lightest state. The luminous transmittance in the lightest state shall be $\geq$ 1.25 the luminous transmittance in the darkest state.

Test in accordance with clause 6.1 of EN 1836:1997, substituting $(0\pm1)^{o}$C for the minimum test temperature in Table 7 of that standard.

7.2.2 Reaction time

The luminous transmittance of the visor shall take less than 5 seconds to approach within 5% of its final value in response to a change in incident illumination. This requirement shall apply to both darkening and lightening of the filter, and shall be met at ambient temperatures of $(0\pm1)^{o}$C and $(35\pm1)^{o}$C.

Test in accordance with 8.6.

Table 1 – Transmittance requirements for reactive visors

<table>
<tr><th rowspan="4">Filter category</th><th colspan="6">Requirements</th></tr>
<tr><th colspan="3">Ultraviolet spectral range</th><th colspan="2">Visible spectral range</th><th>Enhanced infra red absorption[1]</th></tr>
<tr><th colspan="2">Maximum value of spectral transmittance $\tau_{\Phi}(\lambda)$</th><th>Maximum value of solar UVA transmittance τ_{SUVA}</th><th colspan="2">Range of luminous transmittance τ_{ω}</th><th rowspan="2">Maximum value of solar infra red transmittance $\tau_{\Sigma IP}$</th></tr>
<tr><th>280 nm to 315 nm</th><th>Over 315 nm to 350 nm</th><th>315 nm to 380 nm</th><th>From over %</th><th>To %</th></tr>
<tr><td>0</td><td rowspan="4">$0.1\tau_v$</td><td rowspan="3">τ_v</td><td rowspan="3">τ_v</td><td>80</td><td>100</td><td rowspan="4">τ_v</td></tr>
<tr><td>1</td><td>43</td><td>80</td></tr>
<tr><td>2[2]</td><td>18</td><td>43</td></tr>
<tr><td>3[2]</td><td>$0.5\tau_v$</td><td>$0.5\tau_v$</td><td>8</td><td>18</td></tr>
<tr><td colspan="7">[1] Only applicable to filters recommended by the manufacturer as protection against IR radiation.
[2] National regulations may limit the use of these filter shades for driving motorcycles on the road.</td></tr>
</table>

7.2.3 Recognition of signal lights and spectral transmittance

For filters in their lightest and darkest state, and any intermediate state, the relative visual attenuation quotient Q for red, yellow, green and blue signal lights shall not be less than 0.8. Test in accordance with clause 4.1.2.2.2 of EN 1836:1997.

For wavelengths between 500 nm and 650 nm, the spectral transmittance of filters in their lightest and darkest states, and any intermediate state, shall not be less than $0.2\tau_v$.

7.2.4 Special requirements for active filters

7.2.4.1 Power off – in the power-off condition, the luminous transmittance of the filter shall not be less than 80% when measured in accordance with clause 6 of EN 167:2001 using CIE Standard Illuminant D65 (ISO/CIE 10526:1991).

7.2.4.2 Manual control – In any condition of luminous transmittance, it shall be possible to manually over-ride the shade setting system to provide a luminous transmittance of greater than 80%, which shall remain in this condition until the over-riding mechanism is deactivated. This action shall not require continuous actuation of a switch, and shall be possible to accomplish within 2 seconds using one hand.

7.2.5 Special requirements for passive filters

It shall be possible to remove the filtering visor from the wearer's field of view, and for the filtering visor to remain in this position. This action shall be possible to accomplish within 2 seconds using one hand.

7.3 Angle dependence of luminous transmittance

The luminous transmittance of the visor shall be measured on the visual axis of each eye for the darkest shade achievable. The measurement shall be repeated at angles of up to $\pm 15^{o}$ (both vertically and horizontally) about this axis to establish the maximum and minimum transmittances. The maximum and minimum values shall not differ by more than 10% of the minimum luminous transmittance measured on the visual axis.

Test in accordance with 8.7.

7.4 Visibility of LCD displays

With the filter in its darkest state, a wearer with normal eyesight shall be able to read the details of a liquid crystal display conforming to EN 61747-1:2000. The display shall not have back-lighting, and shall be viewed in the correct orientation from within its defined horizontal and vertical viewing angles.

8 Testing

8.1 Conditioning

Unless otherwise specified below, visors shall be stored at $(23 \pm 5)\,^{o}C$ and $(50 \pm 20)\%$ relative humidity for at least 24 hours before testing.

8.2 Test environment

Unless otherwise specified below, visors shall be tested at $(23 \pm 5)\,^{o}C$.

8.3 As-worn position

Unless otherwise specified below, visors shall be tested in the as-worn position. This may be achieved either by attaching the visor to a helmet as directed by the visor manufacturer, or reproducing this position on a suitable test fixture.

8.4 Uncertainty of measurement

Unless otherwise specified, values given in this standard, except for limits, are subject to an uncertainty of measurement of ±5%.

8.5 Resistance to water

Two samples shall be tested after conditioning according to 8.1.

Assemble the helmet, visor and any auxiliary system as directed by the visor manufacturer. Arrange incident illumination which causes the filter to achieve its darkest state, and confirm that the visor reverts to a lighter state when this illumination is removed, with the complete assembly in a dry condition.

Using a watering can fitted with a coarse rose, pour 10 litres of distilled water over the helmet / visor from a vertical height of 1m, thoroughly wetting the entire outside surface of the assembly, over a continuous period in excess of 90 seconds. Half way through the application, switch on the illumination for 10 seconds and observe for the darkening of the filter, and lightening of the filter when the illumination is turned off. Immediately after the application of water has finished, repeat the illumination / observation process.

Report any malfunctions in the filter activation.

8.6 Reaction time

8.6.1 Test equipment

8.6.1.1 Stimulating light source

CIE standard illuminant D 65 defined in ISO/CIE 10526:1991, capable of producing an illumination of (50000 ± 5000) lux at the surface of the visor. To allow the controlled exposure of the visor to this illumination, a shutter shall be incorporated between the source and the visor under test. The shutter shall be capable of fully obscuring the light source from the visor/helmet assembly and operating between fully closed and fully open positions within 0.1 seconds.

8.6.1.2 Light detector and recording apparatus

A detector responding quantitatively to visible wavelengths, capable of resolving ≤0.5% the source intensity, having an output connected to a means of recording with a time resolution ≤0.1 seconds. The detector is positioned in approximately the position of the eye of the visor wearer, on the opposite side of the visor to the light source.

8.6.2 Measurement

Two samples shall be tested. Maintain the test specimen at the appropriate test temperature for a minimum of 2 hours before the test, and during the period of the test.

Set up the system with the closed shutter between the light source and the visor, and the detector at the wearer's position. The helmet / visor assembly shall be in the as-worn position, with the source horizontally in front of the visor, on the visual axis. Turn on the light source and allow it to stabilise.

Start the recording system, then open the shutter. Wait for a minimum of 10 seconds, then close the shutter and wait a further minimum of 10 seconds. Stop the recording system.

From the record of detector output, determine the time taken for the reading to achieve 95% of the maximum change observed. Make this determination for the changes associated with both opening and closing the shutter. Report all the measured values.

Carry out this procedure for test temperatures of at least $(0\pm1)^{o}$C and $(35\pm1)^{o}$C.

8.7 Angle dependence of luminous transmittance

Two visors shall be tested. The test method of clause 5.5 of EN 397:2003 shall be applied to the visor in the as-worn position, using an interpupilary distance of 64 mm, unless a different value is specified by the visor manufacturer.

9 Marking

9.1 General

Markings as specified in BS 4110, substituting the number of this standard, together with the following additional details shall be permanently and legibly marked on the device:

9.2 Classification

The class of device shall be marked:
E – active light-reactive visor
P – passive light-reactive visor

9.3 Filter category

Maximum and minimum filter categories shall be marked.

For devices which switch between one fixed shade level and another, these markings shall be separated by " / ".

For devices which vary continuously between the minimum and maximum values, the marking shall be separated by " - ".

9.4 Examples of marking

a) Passive light-reactive visor, varying continuously between a light state of 0 and a darkest state of 3:

P 0-3

b) Active light-reactive visor switching between a light state of 0 and a darkest state of 2:

E 0/2

10 Information supplied by the manufacturer

The information required by BS 4110:1999, except for items f), g) and j), shall be provided. In addition, the information shall include:

a) specific instructions on over-riding / removing the filter from the field of view in an emergency;
b) specific maintenance and care instructions, including appropriate spare or replacement parts (e.g. batteries);

Appendix E. Light reactive visors - validation of ambient LUX levels

COST Motorcycle accident database ambient light conditions
Daylight
Dusk/Dawn
Night/Dark (Unlit, <7m lit, >7m lit)

Daylight 100,000 LUX Summer – Direct Sunglare

Daylight 38,000 LUX Summer


Daylight 15,000 LUX Summer

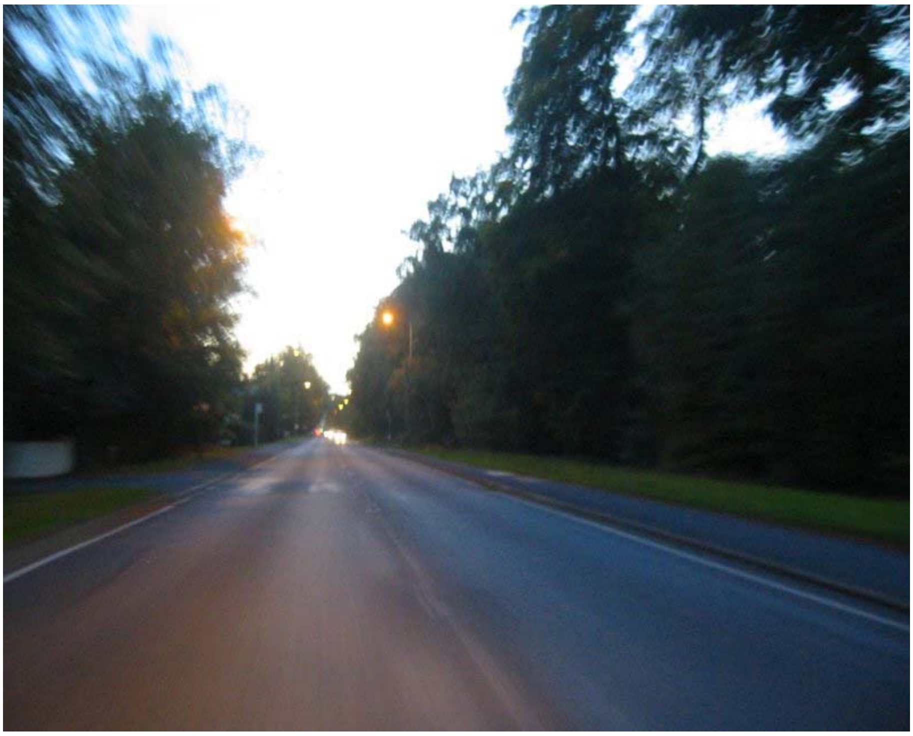

Daylight 16,000 LUX Summer

Daylight. 9,000 LUX Summer

Daylight 7,200 LUX Summer – (bright / rain)


Daylight 5,600 LUX. Summer – (trees)


Dusk/Dawn 12,000 LUX. Direct glare from setting sun

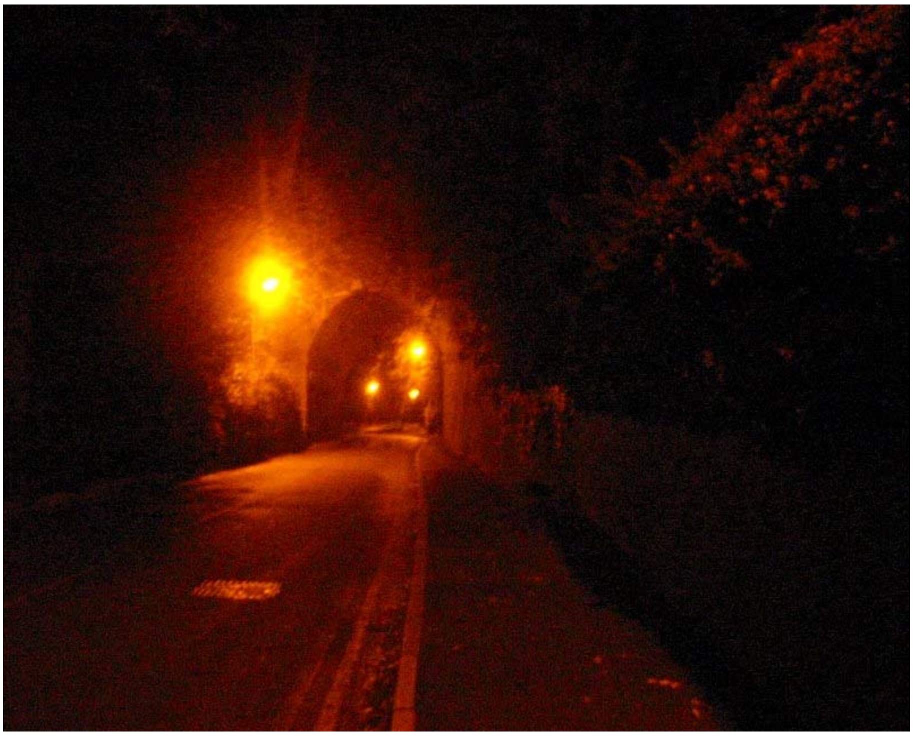


Dusk/Dawn 200 LUX. Lighting up time

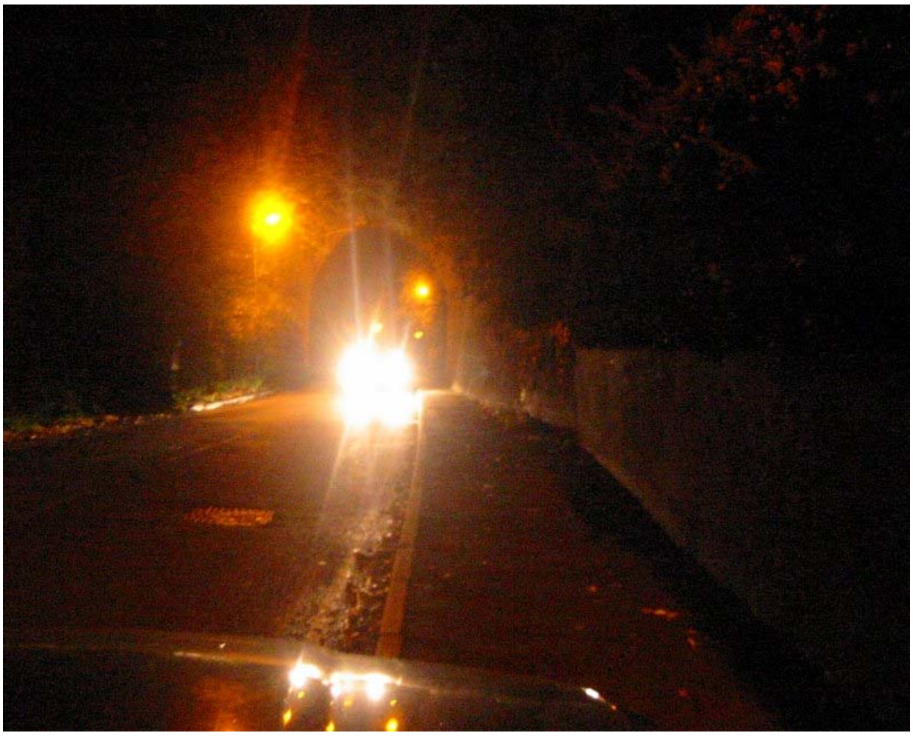
Tunnel – Lit 400LUX

Night/dark 3.70LUX Lit>7m – No headlamp glare

Night/dark 6.80LUX Lit>7m – With headlamp glare (dipped beam)



Night/dark 0.79LUX Lit<7m – No headlamp glare



Night/dark 9.4 LUX Lit<7m – With headlamp glare (dipped beam - nearside)

Night/dark 0.18LUX unlit – dipped beam

Night/dark 0.40LUX unlit – main beam


Night/dark 400 LUX unlit – with headlamp glare (main beam 20m)


Night/dark 20000 LUX unlit – with headlamp glare (main beam 1m)

PPAD 9/33/39
Quality and field of vision – A review of the needs of drivers and riders

Final report

Prepared for:

The Department for Transport, Local Governments and the Regions

Prepared by

Sharon Cook
Claire Quigley
Richard Tait

Check______________

6.2.3. Ambient Light Levels

Eight ambient lighting conditions were replicated in the model road. These are described in Table 19.

Table 19: Model road ambient lighting conditions

Lighting Condition	Max & Mean Luminance in the vicinity of the target (cd/m2)
Bright daylight	4661 442
The bright daylight condition is that under which motorcyclists wish to be granted permission to wear eye protection with luminous transmission properties as low as 18%.	
Bright daylight with target objects in shadow	1400 392
This lighting condition may be encountered in a road scenario where a driver/rider, whose eyes are adapted to bright daylight conditions, is approaching an area of road in dark shadow.	
Cloudy/Overcast day	1143 226
A lighting condition which could be encountered by a motorcyclist or driver who began a journey in bright daylight.	
Low sun (high luminance glare source in drivers'/riders' field of vision).	90600 3017
Another lighting condition where motorcyclists wish to use eye protection with low luminous transmission.	
Dawn/Dusk/Twilight	7.48 1.34
A lighting condition which is likely to be encountered by a motorcyclist or driver who began a long journey in bright daylight.	
Night time with street lights and headlamps on - dry road.	6.47 0.98
A lighting condition under which heavily tinted visors and windscreens may be misused.	
Night time with street lights and headlamps on - wet road.	3.53 0.82
A lighting condition under which heavily tinted visors and windscreens may be misused.	
Night time, unlit road, headlamps on.	0.64 0.11
A lighting condition under which heavily tinted visors and windscreens may be misused.	

6.2.4. Trial Participants

Twenty, current UK driving licence holding participants (7 male and 13 female) whose ages ranged from 18 to 75 years (mean age 44 years, SD 16.3) were recruited from ICE's database.

Appendix F. Advanced helmet concepts

(i) TRL-DFT (S100L/VF)

(ii) FIA 8860-2004

(iii) Phillips Helmets Ltd

Part (iii) of this Appendix is a reproduction of marketing information provided by Phillips Helmets relating to the Phillips Head Protection System (PHPS) helmet. By inclusion, the authors are not endorsing the product or the validity of any claims made herein.

Appendix F. Advanced helmet concepts

(i) <u>TRL-DFT (S100L/VF)</u>

(ii) FIA 8860-2004

(iii) Phillips Helmets Ltd

Improved motorcycle helmet design:

Part 4: Performance assessment, injury savings and helmet costs

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(based on work carried out for S100/L)

IMPROVED MOTORCYCLE HELMET DESIGN: PART 4. PERFORMANCE ASSESSMENT, INJURY SAVINGS AND HELMET COSTS

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EXECUTIVE SUMMARY

Each year more than 500 motorcycle riders or pillion passengers are killed on British roads, 7,000 are seriously injured and a further 20,000 suffer slight injuries. The total financial cost of these injuries is calculated to be approximately £1B (£478M fatal, £449M serious and £51M slight). Approximately 80% of the motorcyclists killed and 70% of those with serious injuries sustain head impacts. In more than half of these cases, the head injury was the most serious of those sustained.

TRL has developed a new advanced protective helmet which will provide motorcyclists with a higher level of protection than current helmet models designed to BS 6658A or ECE Regulation 22-05. This has been achieved with a lightweight carbon composite shell fitted with an high-efficiency expanded polystyrene energy absorbing liner and a low friction sacrificial shell surface. If such helmets were worn extensively by the British motorcycle riders and pillion passengers, significant reductions in injuries could be expected.

The advanced helmet is designed to reduce head injury by reducing both the linear and rotational acceleration loadings imparted to the rider's head. In order to quantify the benefits of the advanced helmet, the linear and rotational responses have been measured during a range of impact conditions, up to and exceeding those likely to cause fatal head injuries. The GAMBIT formula, which combined the linear and rotational components of the impact, was applied to these results. These values were subsequently related to AIS using correlation coefficients determined by TRL accident replication studies. The response of current helmet designs was also measured to provide a benchmark for comparison. Based on this work it was shown that the advanced helmet could provide the following injury severity reductions:

AIS 6 injuries reduced to AIS 4
AIS 5 and 4 injuries reduced to AIS 3
AIS 3, 2 and 1 injury levels maintained

The following costs and benefits are based on these figures.

There are approximately 760,000 licensed motorcycles in Britain and an estimated 152,000 new helmets are sold each year. The recommended life of a helmet is five years. If 10% of all new helmets sold conformed to the new level of performance, the sales penetration of this new helmet would be 2% in year one, 4% in year two, 6% in year three, 8% in year four and 10% in year five (a total of 76,000 units sold by year five). The price of the new helmet is estimated to be £200-cost and £300-retail, compared with an estimated average price of £50-cost and £150-retail for conventional helmets. Thus, the additional cost of 76,000 advanced helmet sales is estimated to be £11.4M (£150 per helmet).

It is assumed that every motorcycle rider, irrespective of other factors (such as rider age, motorcycle make or model and engine capacity) is equally likely to be involved in an accident. It is estimated that if 15,000 advanced helmets were sold in year one, ten motorcyclists would be involved in accidents that would have resulted in fatal injuries if conventional helmets were worn. It is estimated that at least one of these lives would be saved by the advanced helmet being worn.

The national motorcycle injury data was analysed in conjunction with data from the COST 327 study, the TRL Motorcycle Accident Replication programme and performance reference data for the advanced helmet. It was found that of the 578 fatal motorcycle riders (or pillions) killed each year, 93 lives could be saved and 434 serious injuries prevented if all riders had been wearing the advanced helmet. With the sales rate of 10% per year, over the first five years a total of 28 lives could be saved, and 130 serious injuries prevented, with nine lives being saved in year five alone.

Of the 7,000 riders who suffered serious injuries each year, more than 4,000 suffered a head injury and for 3,000 of these riders the head injury was the most severe. The AIS distribution of these 3,000 riders with head injuries was AIS 5 (13%), AIS 4 (13%), AIS 3 (17%) and AIS 2 (57%). It is estimated that with a 10% sales penetration of the advanced helmet, some 50 riders would have a reduction in head injury from AIS 5 to AIS 3 and a similar number would benefit from a reduction from AIS 4 to AIS 3. Although this is a very significant saving in terms of reduced suffering, the financial benefits are more difficult to quantify as all AIS severities within the serious-injury category are classified as having the same financial cost.

The overall cost of producing and selling 76,000 advanced helmet models in order to achieve a 10% wearing rate over five years is estimated to be £11.4M.

IMPROVED MOTORCYCLE HELMET DESIGN: PART 4. PERFORMANCE ASSESSMENT, INJURY SAVINGS AND HELMET COSTS.

1. INTRODUCTION

This is the final report to provide the Department for Transport (DFT) customer (VSE6) with a description of the experimental helmet, which was part of the project S100L/VF. Much of the preliminary work has been described in the annual progress reports and will not be repeated here. The objective of the research was to develop a prototype helmet which satisfied current requirements and which exceeded the performance of current motorcycle helmet designs. This report describes the concluding phases in which the shell materials were researched and developed and the experimental helmet was produced and tested.

Each year more than 500 motorcycle riders or pillion passengers are killed on British roads, 7,000 are seriously injured and a further 20,000 suffer slight injuries. TRL has previously estimated that it may be possible to increase the protection provided by current motorcycle helmets and improve the injury outcome for 20% of the fatally and seriously injured motorcyclists. This estimate was based on a preliminary study which assessed the principal cause of death for 10 fatally injured and 10 seriously injured motorcyclists selected from a database of 160 accident cases collected by the Southern General Hospital (SGH).

TRL has developed a new advanced protective helmet which will provide motorcyclists with a higher level of protection than current helmet models designed to BS 6658A or ECE Regulation 22-05. TRL has developed a method of assessing shell materials using flat coupons 120mm x 70mm fitted to the same size liner material. This permitted a range of materials to be tested without the need for an expensive production of full helmet shells. It was concluded from the initial research that carbon fibre would produce the optimum result.

TRL developed a strategy for the next stage of the prototype helmet development. Two potential concepts were formulated; (1) ultra stiff carbon composite helmet (2) low friction helmet, and from these, a design specification was written. This was based upon tests designed to establish the extent to which linear impact and rotational impact properties can be improved within the constraint that the mass must not exceed that of current helmets.

Carbon fibre flat coupons were obtained from CFT (Carbon Fibre Technologies) and tested. The results from these tests enabled the shell details to be specified. The principle was that the use of a specialist carbon fibre sandwich would enable a very stiff shell to be produced. This was designed such that the outcome of the linear component of an impact was independent of the target shape and thus the protection became a feature of the liner material characteristics and depth. The liner was optimised for internally induced deformation caused by the head moving into the liner. Externally induced deformation that arises, for example, by the shell of a current helmet deforming when striking a kerbstone anvil, was reduced to a negligible amount.

Forces tangential to the helmet induce rotational acceleration. TRL has been investigating ways of reducing the potential for rotations as part of the overall research. Two principal methods assessed were to coat the surface of the shell with a layer of material that has a very low friction coefficient and to apply a layer of material to the shell that readily moves relative to the shell during an impact and can be sacrificial. TRL has designed and built test apparatus to evaluate variants of both these ideas when applied to flat coupons and helmets. This report describes the results of the tests and gives conclusions as to the success of the experimental helmet.

If such helmets were worn extensively by the British motorcycle riders and pillion passengers, significant reductions in injuries could be expected. This report includes a cost benefit study which aims to assess the benefit of an improved motorcycle helmet in more detail by comparing results from laboratory and accident replication tests. These tests were performed using current helmets and then repeated using an experimental advanced helmet developed by TRL. The results were analysed in terms of head injury severity in order to quantify the improved protection provided by the experimental helmet.

2. HEAD INJURY MECHANISMS

A helmet is designed to protect the rider in the event of an accident by absorbing impact energy and reducing the loading imparted to the head. In order to maximise the protection provided by a helmet, it is important to identify the mechanisms by which a head becomes injured. The term head injury comprises various kinds of trauma to the skull and its contents. Usually, several different types of head injury occur simultaneously in a traffic accident. The anatomical location of the lesions and their severity determine the physiological consequences. Injuries may be divided into cranial injuries (skull fractures) and intracranial "soft tissue" injuries. Indeed, skull fracture can occur with or without soft tissue damage and vice versa.

Skull fracture occurs when the loading on the skull exceeds the strength of the bone and can be either open or closed. Skull fractures may be divided into facial, vault and basal. The most threatening form of skull fracture is basilar skull fracture. A characteristic of motorcycle accident victims is that fractures of the vault are rare among helmeted riders, but that basilar skull fractures are frequently encountered, both in helmeted and unhelmeted riders (Hurt et al. 1986; Thom and Hurt 1993). Soft tissue damage occurs, during an impact, due to high strains within the vascular and neurological tissues as a result of both linear and rotational loadings to the head.

The risk of both types of injury (skull fracture and soft tissue) can be reduced by improving the energy absorbing performance of the helmet. The advanced protective helmet achieves this with a liner-shell combination of appropriate stiffness to minimise linear acceleration during even high energy impacts. In addition, the outer surface of the helmet provides very low friction, so that the rotational accelerations imparted to the head are minimised.

3. TRL SPECIFICATION FOR MOTORCYCLE HELMET SHELL

The objective of the new helmet was to provide improved protection in all important areas. This was to be achieved, in part, by optimising the performance of the shell to be very stiff and able to resist excessive shell deformations and thus transmit loads more efficiently to the energy absorbing liner. It was proposed that the mass of the shell should not be greater than that of current designs and should be reduced if possible. It was accepted that the thickness may need to be increased, compared with current designs (which were typically 3mm), in order to achieve the objectives. A maximum thickness of 10mm was proposed. The materials were specified such that a helmet shaped structure with double curvature could be achieved and volume production would be practicable. In addition, it would be beneficial for the structure to possess inherent damping qualities that would minimise rebound during impacts. A technical specification, which is designed to achieve the above requirements, is provided in Appendix A.

4. ASSESSMENT OF FLAT COUPONS

4.1 GENERAL

The impact characteristics of the shell were assessed together with consideration of temperature and moisture stability, mass, thickness and scope for production. TRL developed specific test procedures to enable the evaluation of shell structures using flat samples of shell material. The cost of manufacturing and testing flat shell samples was very much lower than for helmet shaped shell structures and, therefore, a greater number of potential designs could be evaluated. The dynamic loads exerted during the flat sample tests were representative of those exerted during complete helmet tests and, therefore, it was possible to evaluate the flat shell structures for use in complete helmets.

It was also important that the results from the tests on flat samples represented the performance of complete helmets, constructed with the same materials. In order to ensure this, the test procedures were designed to represent a falling headform test, and the acceleration-history of the impactor during these flat coupon tests related to the acceleration-history of a helmeted headform during similar impact conditions. A full description of the tests is provided in Appendix B. Flat shell samples measuring 120mm by 70mm were attached to a 35mm thick ‘bed’ of energy absorbing foam. The shell and foam specimen was attached to the face of a 2.5kg mass, with the shell facing outwards, and impacted onto a 15mm radius hemi-spherical anvil. The 15mm hemi-spherical anvil was developed by TRL to simulate the loadings imparted during a helmet impact onto the ECE Regulation 22-05 kerbstone anvil.

The specification which TRL initially proposed was considerably more advanced than that of current helmet designs, and was thought to be close to the limit of what was technically achievable. However, TRL was very pleased that the specification was closely met and thus providing the opportunity to optimise performance for linear impact and resistance to rotational motion within a range of mass from what is current to a helmet that is substantially lighter.

4.2 MASS AND THICKNESS

For each variant, the average mass of four samples, each measuring 120mm by 70mm, was weighed and a Vernier gauge was used to measure the thickness of four samples hence to determine the average sample thickness. The target mass was less than 50g per sample and the target thickness was less than 10mm. The results for each variant are detailed in Table 1.

4.3 LINEAR IMPACT TESTS

4.3.1 Methodology for linear impact tests

The structural requirement for the shell structure was to transmit the impact force between the impact surface and the energy absorbing liner material, without excessive deflection or structural failure. In order to achieve this, the structure must also resist the high local contact stresses at the point of impact, without excessive local deformation.

The performance of the shell structures was evaluated by analysis of the acceleration-time history and acceleration-displacement of the impactor. Based on other work, TRL has established acceptable levels of shell deformation in order to transmit the impact forces to the energy absorbing liner. The maximum acceptable shell deformation was found to be approximately **3mm** during a 7.5m/s impact and approximately **5mm** during a 10m/s impact. TRL has also previously investigated the impact performance of an infinitely stiff shell structure which did not deflect during impact. This was achieved by impacting samples of the energy absorbing foam between parallel plates in accordance with the procedures used for shell evaluation (Appendix B).

The impact performance of the coupon structures was evaluated in accordance with the procedures described in Appendix B with tests at 7.5m/s and 10m/s. When tested at 7.5m/s the peak deformation of the impactor was **18mm** and when tested at 10m/s the peak deformation of the impactor was **27mm**. By combining these results with the target values for shell deformation, it was possible to prescribe target displacement values of 21mm at 7.5m/s (18mm+3mm) and 32mm at 10m/s (27mm + 5mm). In addition to impactor displacement, it was also possible to evaluate the results in terms of impactor acceleration. When tested at 7.5m/s, the infinitely stiff shell achieved a peak acceleration of 200g and when tested at 10m/s the peak acceleration was 300g. The acceleration results from tests on less stiff shells were, implicitly, lower than those for the infinitely stiff shell *(except for when the shell was so soft that the impactor bottomed out, hence producing a very high acceleration result)*. It was, therefore, proposed that the novel shell structures would achieve acceleration levels slightly lower than for the infinitely stiff shell tests. Based on this concept, the prescribed target values for peak impactor acceleration were as follows;

i. at least 180g during impact at 7.5m/s
ii. no more than 300g during impact at 10m/s

Although a high stiffness is a fundamental requirement of the novel shell design, it may be an advantage for the shell to deform or fail during severe impact conditions, so that the space occupied by the thickness of the shell may be fully utilised. This characteristic was also investigated during the evaluation of the novel structures.

4.3.2 Test samples for linear impact tests

The following test samples were evaluated;

1. Polycarbonate (5mm thick)
2. Polycarbonate (10mm thick)
3. Nimrod helmet shell sample (5mm thick)

4. Aluminium plate (5mm thick)
5. Carbon-sandwich composite sample CFT-MHS 01 (4.1mm)
6. Carbon-solid composite sample CFT-MHS 02 (2.9mm)
7. Carbon-experimental composite sample CFT-MHS 08 (3.0mm)

4.3.3 Results for linear impact tests

The graphical results are provided in Appendix C - figures C1 to C8 and a summary is provided in **Error! Reference source not found.** below. The target values are also included.

Table 1. Summary of test results from CFT coupon structures

Sample	Mass [g]	Thickness [mm]	Peak deformation [mm]		Peak acceleration [g]	
			7.5m/s	10m/s	7.5m/s	10m/s
Rigid flat plate			18	27	202	300
Target Value	*Not>50*	*Not>10*	*Not >21*	*Not>32*	*Not<180*	*Not>300*
5mm PC	50	5	23	35	157	364
10mm PC	100	10	18	28	195	288
5mm (Nimrod)	45	4.5	25		144	
5mm Al	117	5	18	26	204	293
CFT-MHS 01	40.6	4.8	21	30	200	298
CFT-MHS 02	36.2	3.0	20	32	210	242
CFT-MHS 08	39.7	3.0	21	34	193	293

Results in red did **not** achieve target values

The baseline polycarbonate and aluminium materials did not achieve the target performance values. These materials were found to have an insufficient strength to weight ratio such that when the mass criterion was met, the impact performance was not achieved, and when the thickness (and therefore strength) was increased to meet the impact performance, the mass criterion was exceeded.

The three CFT-MHS structures provided three different variations of composite design. All three were constructed using carbon fibre composite materials. CFT-MHS 01 was a sandwich construction with a syntactic foam core, CFT-MHS 02 was a solid laminate and CFT-MHS 08 was an experimental laminate. Both CFT-MHS 01 and CFT-MHS 02 achieved all the target values for mass, thickness, deformation and acceleration. CFT-MHS 08 met all but the deformation target during the 10m/s test, with a deformation of 34mm compared with the target of 32mm. It was found that the performance of all the carbon structures was stable after the temperature and water conditioning (Appendix C – figures C1 to C8).

In summary, CFT-MHS 01 and CFT-MHS 02 achieved all the design targets and provided significantly improved performance compared to the baseline materials. These two materials were selected for testing with full-geometry helmet constructions.

4.4 SURFACE FRICTION TESTS

4.4.1 Methodology for surface friction tests

A bespoke test method was devised to assess the potential solutions for the reduction of rotational motion by measuring the effective surface friction of the test samples. The tests samples included friction coatings and a sacrificial layer designed to peel away with very little force.

The test configuration consisted of pseudo-dynamic surface abrasion tests using flat samples of shell material. Two test methods, described below, using the same apparatus were needed depending on the intended mechanism of the sample. For samples that presented a low coefficient of friction then configuration (A) was used. For samples that presented a sliding-layer mechanism then configuration (B) was used. The results from both methods were compared directly. TRL tested three variants with three tests per variant. Figure 1 shows the apparatus used.

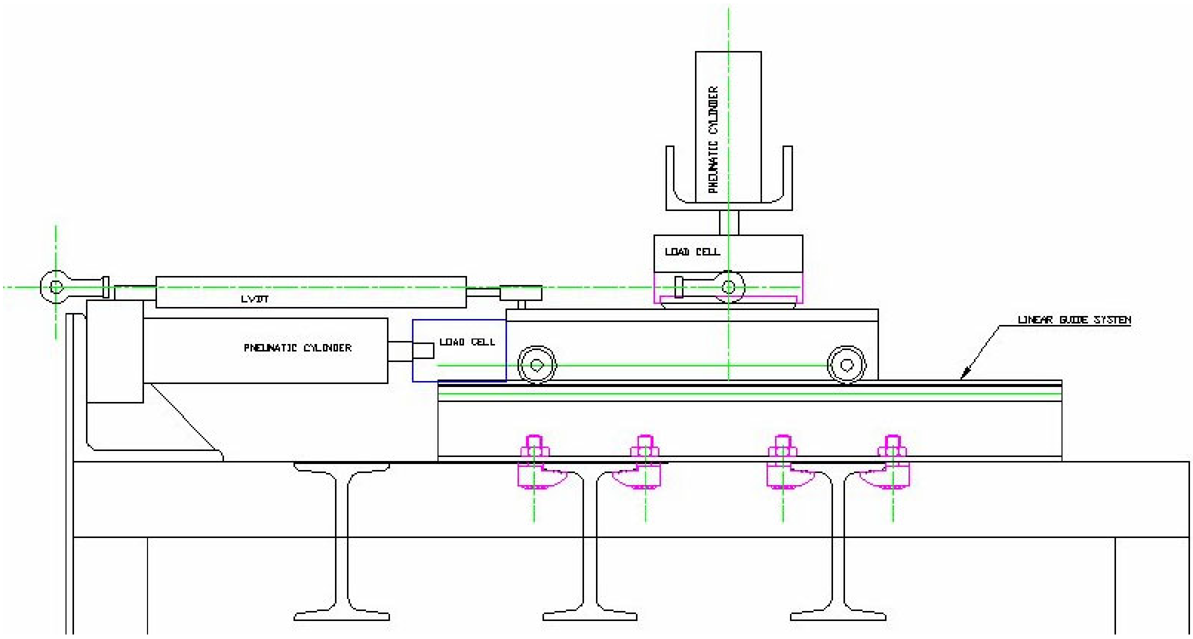

Figure 1. Low velocity, transient, surface friction test apparatus

The samples were located in a rigid housing and positioned against the flat horizontal track surface 300mm long and 150mm wide, see figure 1. A normal force was applied using a pneumatic actuator to clamp the sample against the track surface. The magnitude of this load was approximately 2,000N (to simulate the typical normal force during an oblique impact test to ECE Regulation 22-05 Method A). A tangential force was subsequently applied using a pneumatic actuator to slide the track surface relative to the test sample. The stroke of the tangential actuator was 100mm. The normal and tangential loads were measured with load-cells and the acceleration of the track surface carriage was measured with an accelerometer. The instrumentational data was recorded at a rate of 10,000 samples per second and filtered in accordance with SAE J211. A filter frequency of CFC180 was chosen after careful consideration.

For configuration (A): samples measuring 25mm x 25mm and between 2mm and 25mm thick, with a 2mm radius on one edge, were mounted in a rigid sample holder and clamped against a flat carriage fitted with 80 grit aluminium oxide paper. For configuration (B): samples measuring 120mm x 70mm and between 2mm and 25mm thick were mounted on a carriage and a 80 grit aluminium oxide tool measuring 25mm x 25mm was clamped against the surface of the sample.

For both configurations, the carriage was translated in a direction perpendicular to the clamping force over a controlled distance. By measuring the normal and tangential loads during the event, it was possible to calculate the effective dynamic coefficient of friction of the sample

4.4.2 Test samples for surface friction tests

Three coupon samples were investigated as detailed below:

1. Polycarbonate (configuration A)
2. Carbon fibre composite with toughened epoxy matrix (configuration A)
3. Sacrificial layer (configuration B)

4.4.3 Test results for surface friction tests

The graphical results are provided in Appendix C – figures C9 to C11 and a summary is provided in Table 2 below.

Table 2. Summary of test results from CFT coupon structures

Sample	Normal force [N]	Coefficient of friction	
		Peak	Sliding
Polycarbonate	1,900	0.77	0.42
Carbon fibre *CFT-MHS-01*	2,000	0.17	0.12
Sacrificial layer	1,900	0.10	0.09

The baseline polycarbonate material achieved a peak friction of µ0.77 and a sliding friction of µ0.42. The carbon fibre material achieved significantly reduced friction values of µ0.17 peak and µ0.12 sliding, a reduction of almost 80% in peak friction. The sacrificial layer achieved the lowest values of µ0.10 peak and µ0.09 sliding, a reduction of almost 90% in peak friction. Both systems were evaluated in full geometry testing as described in section 5.

5. FULL HELMET SHELL TESTS

5.1 GENERAL

Tests were conducted on full-geometry prototype helmet samples in order to develop and evaluate two parameters as defined by ECE Regulation 22-05 (1) Linear impact performance (2) Oblique impact performance.

5.2 LINEAR IMPACT DEVELOPMENT

The aim of the linear-impact development tests was to evaluate full-geometry prototype helmets with carbon shells to the laminate specification determined in section 4. The shells were fitted with energy absorbing liners of different densities (25g/l and 30g/l) in order to determine the best compatibility. The prototype helmets were full faced construction, in size 57 (medium), and conformed to the extent of protection requirements of ECE Regulation 22-05. The impact area of the shell was profiled to closely fit the energy absorbing liner. The linear impact tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg. A total of five linear impact tests were conducted on each helmet design, with tests at 7.5m/s and 10m/s onto both the flat and kerbstone anvils with temperature conditioning at –20^{o}C, 25^{o}C and +50^{o}C.

Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. The graphical results are shown in figure C14 and a summary is provided in Table 3 below. The baseline performance at 10m/s onto the kerbstone anvil (front) was 954g and onto the flat anvil (crown) was 299g. The carbon shell concept provided a significant improvement over the current motorcycle helmet design with a 10m/s kerbstone anvil (front) impact result of 235g (CFT-MHS 02) and a 10m/s flat anvil (crown) result of 230g.

The results were analysed in detail to determine the best solution in terms of (1) liner density and (2) shell construction (solid laminate or sandwich), as described below.

1. Liner Density

During tests at 10m/s the 30g/l liner achieved 235g on the front (CFT-MHS-02) and 292g on the rear (CFT-MHS-01) compared with 319g on the front and 890g on the rear for the 25g/l liner. Based on these results, the 30g/l was considered to be the best solution for the main area of the energy absorbing liner. However, it was decided that the crown area should be of a lower density to compensate for the increased volume of liner that is compressed during a crown impact test. A 25g/l was evaluated during crown impacts at 10m/s and the peak acceleration was 230g (CFT-MHS-01) and 242g (CFT-MHS-02). A 25/30g/l dual density liner was, therefore, chosen as the best solution for the performance evaluation of the advanced helmet.

2. Shell construction

The results for the two carbon shell concepts were similar as can be seen by comparing the results for side impact onto the flat and kerb anvil: 185g and 173 g respectively for the solid shell and 200g and 186g respectively for the sandwich shell. However, the solid shell had two advantages over the sandwich shell;

(1) reduced thickness, thus providing space for additional liner material
(2) potentially lower production costs.

The solid shell was, therefore, chosen as the best solution for the performance evaluation of the advanced helmet.

Table 3. Results from linear impact tests

Helmet	Liner density [g/l]	Impact velocity [m/s]	Impact site	Impact anvil	Temperature [^{o}C]	Peak acceleration [g]
CFT-MHS 01 Carbon-Solid laminate	25	10	Front	Kerbstone	+50	319
	25	10	Crown	Flat	-20	230
	25	10	Rear	Kerbstone	+25	292
	30	7.5	Side R	Flat	+25	185
	30	7.5	Side L	Kerbstone	+25	173
CFT-MHS 02 Carbon-Sandwich	30	10	Front	Kerbstone	+50	235
	25	10	Crown	Flat	-20	242
	25	10	Rear	Kerbstone	+25	890
	30	7.5	Side R	Flat	+25	200
	30	7.5	Side L	Kerbstone	+25	186
Baseline current		10	Front	Kerbstone	+25	954
		10	Crown	Flat	+25	299

5.3 SURFACE FRICTION DEVELOPMENT

The aim of the surface friction development tests was to develop a low friction surface coating or system to reduce the tangential forces during an oblique impact. The two systems identified in section 3 were evaluated together with an additional hardened metallic surface as detailed below.

1. Carbon composite with toughened epoxy system
2. Sacrificial layer
3. Tungsten carbide (hardened metallic surface)

The surface friction tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg impacting onto the 15^{o} abrasive anvil at 8.5m/s. Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. A summary of the results is provided in Table 4 below. It was found that the carbon composite shell and tungsten carbide surface significantly improved performance during the oblique impact tests, with frictional values of µ0.42 and µ0.39 respectively, compared to the baseline value of µ0.69. However, the sacrificial layer provided the greatest improvement with a friction of µ0.16, which represented a 77% percent improvement over the baseline result. The sacrificial layer was, therefore, chosen as the best solution for the performance evaluation of the advanced helmet.

Table 4. Results from surface friction tests

Helmet	Impact velocity [m/s]	Impact anvil	Peak force [N] Normal	Peak force [N] Tangential	Friction
CFT-MHS 01 Carbon shell with toughened epoxy matrix	8.5	15^o abrasive	2640	1118	0.42
CFT-MHS 02 Carbon shell with sacrificial layer	8.5	15^o abrasive	2066	323	0.16
CFT-MHS 01 Carbon shell with Tungsten carbide layer	8.5	15^o abrasive	3162	1250	0.39
Baseline helmet Full-faced GRP to BS6658A	8.5	15^o abrasive	2874 2709 3187 2455	1890 2000 2060 1806	0.66 0.74 0.65 0.74
(average)			(2806)	(1998)	(0.69)

ECE Regulation 22-05 limit for tangential force is 3,500N

6. PERFORMANCE EVALUATION OF ADVANCED HELMET

The protection provided by the advanced helmet was assessed by comparing the impact performance of the advanced helmet with that of current motorcycle helmet designs conforming to ECE Regulation 22-05. This was achieved by performing both linear and oblique impacts with the helmets fitted with an Hybrid II headform instrumented with a nine-accelerometer array to measure linear and rotational accelerations. The linear impact tests were conducted onto the kerb and flat anvils as prescribed by ECE Regulation 22-05 with impact velocities up to 10m/s. The results from the linear tests were used to characterise the relationship between impact velocity and peak linear acceleration. The oblique impact tests were conducted onto the abrasive anvil as prescribed by ECE Regulation 22-05 (Method A) and additional tests were conducted using a variety of impact conditions established by the COST 327 replication programme to simulate real accidents.

The results from these tests were analysed, as described below, to determine the response of both helmet designs in terms of AIS injury severity for a given impact severity. Because an impact to the head induces both linear and rotational motions, it was necessary to develop a method of assessing the performance and protection provided by the helmet with regard to both mechanisms. The GAMBIT assessment criterion was chosen for this study because it considers both linear and rotational motions. Although the COST 327 report found that the relationship between GAMBIT and AIS was low ($r^2 = 0.0751$), the replication data was analysed including the results from motorsport accident replication tests and a correlation coefficient of 0.57 was found ($r^2 = 0.3214$) as shown in Figure 2. It should be noted that the fatal cases were not included in this study. The following section describes the methodology for comparing the performance of the current and advanced helmets in terms of AIS injury outcome.

Tests onto the rigid anvil were used to establish the relationship between impact velocity and peak linear acceleration as shown in Figure 3. The advanced helmet was designed to provide protection during normal impacts up to 10m/s onto the rigid test anvils compared with 7.5m/s for current helmets. The results show that the advanced helmet provides similar protection to the current helmet up to approximately 7m/s (normal impact velocity). At higher velocities the protection provided by the advanced helmet it considerably increased.

The advanced helmet was designed to provide improved protection during oblique impacts by having a very low friction outer surface. Figure 4 shows the relationship between linear and rotational accelerations for both current and advanced helmets based on the results from the ECE Regulation 22 (Method A) tests and the accident replication tests. It can be seen that the advanced helmet achieves considerably lower rotational accelerations for a given linear acceleration. The results from Figure 3 and Figure 4 were combined to provide a relationship between equivalent normal impact velocity and peak rotational acceleration (Figure 5). It can be seen that the advanced helmet provides slightly improved protection up to approximately 7m/s and significant improved protection for higher impact speeds. The accident replication results, for the current helmet, were further analysed by plotting the normal impact velocity component against the peak rotational acceleration. The equation of the line of best fit was found to be $y = 1230.9x^{1.362}$. This line, as presented in Figure 5, was found to very closely agree with the rotational acceleration response curve for the current helmet and, therefore, was considered to support the validation of this methodology.

The relationship between impact velocity and GAMBIT results was determined by combining the results from Figure 3 (linear acceleration) and Figure 5 (rotational acceleration) using the equation below (see Figure 6).

$$GAMBIT = \sqrt{(g/250)^2 + (rad/s^2/10{,}000)^2}$$

The relationship between impact velocity and AIS (Figure 7) was determined using the results in Figure 6 and the equation established in Figure 2 (as shown below).

$$AIS = 2.0273Ln(GAMBIT) + 2.0933$$

The results in Figure 7 can be used to compare the performance of the current and advanced helmets in terms of AIS injury outcome. Based on this study, it was possible to estimate the injury reduction benefits of the advanced helmet for those accident types where it was considered that an improved helmet could reduce the level of head injury. The following AIS injury reductions were used for the next part of this study.

- AIS 6 injuries reduced to AIS 4
- AIS 5 and 4 injuries reduced to AIS 3
- AIS 3 remain AIS 3 *
- AIS 2 remain AIS 2 *
- AIS 1 remain AIS 1 *

** although the AIS 1, 2 and 3 levels are shown to be reduced with the advanced helmet (Figure 7), the reductions were less than one whole AIS level. And, therefore, for the purpose of this study it was considered that the advanced helmet would provide the same injury outcome for these accidents.*

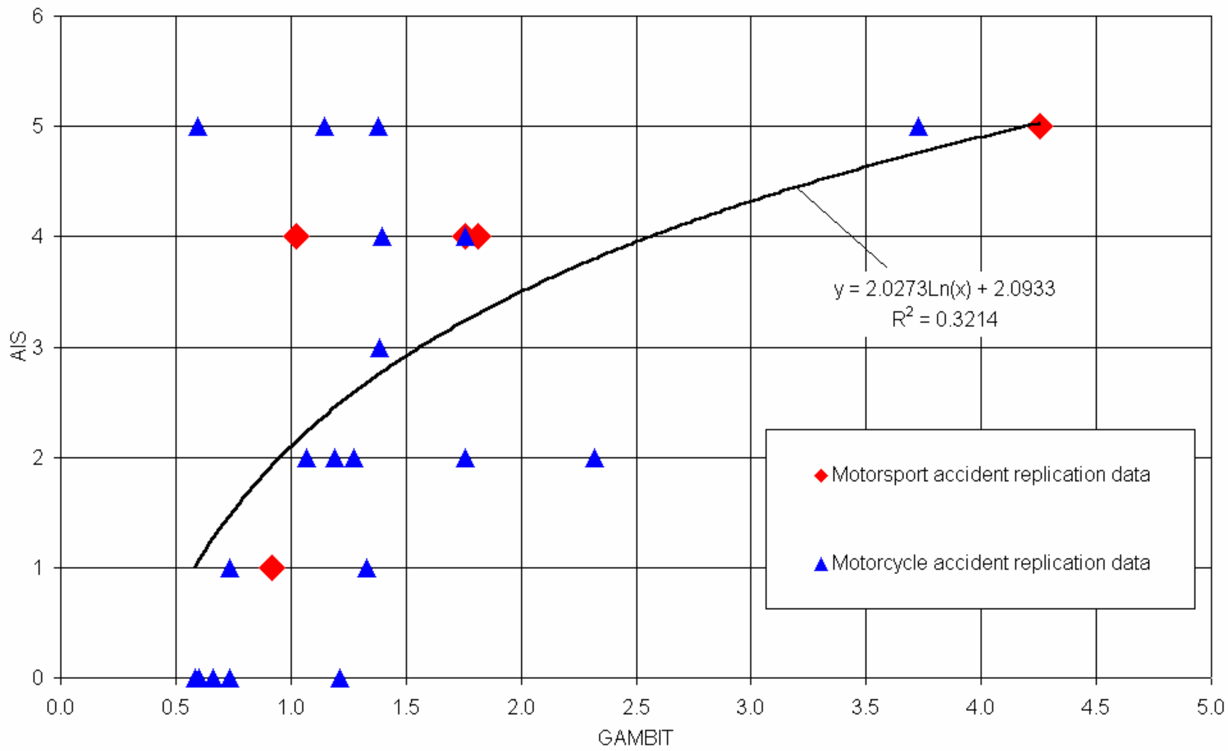

Figure 2. Relationship between GAMBIT and AIS injury level based on accident replication data

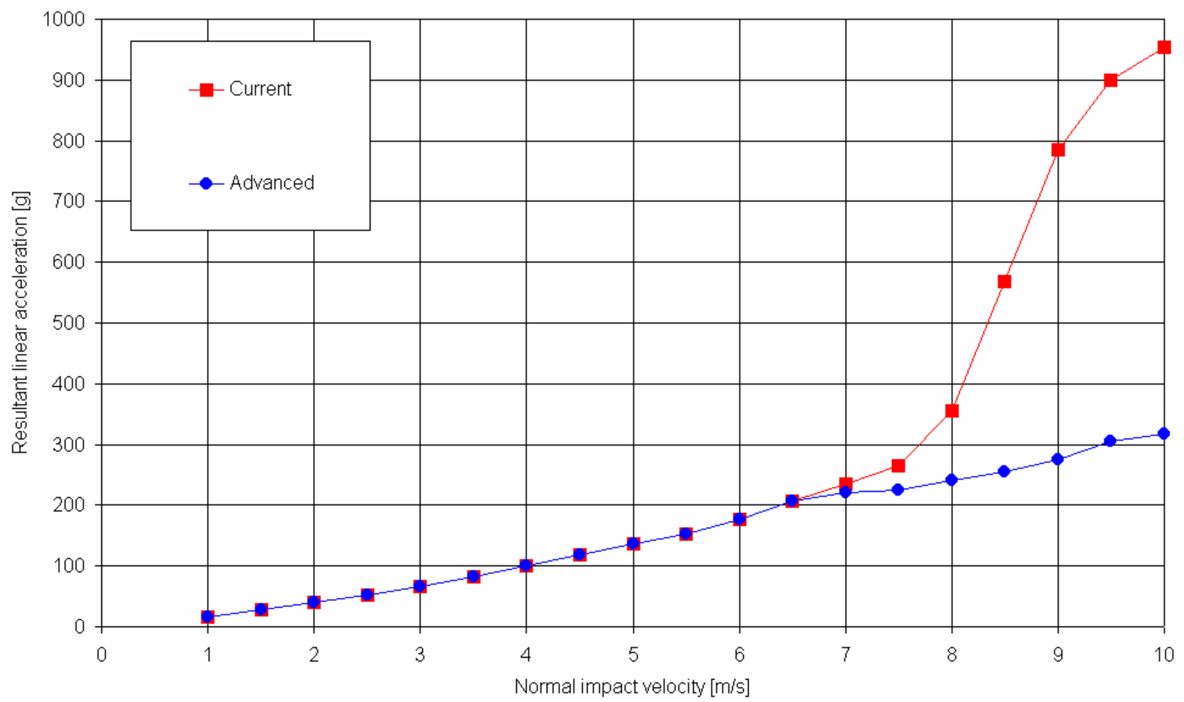

Figure 3. Relationship between impact velocity and linear acceleration for current and advanced helmets

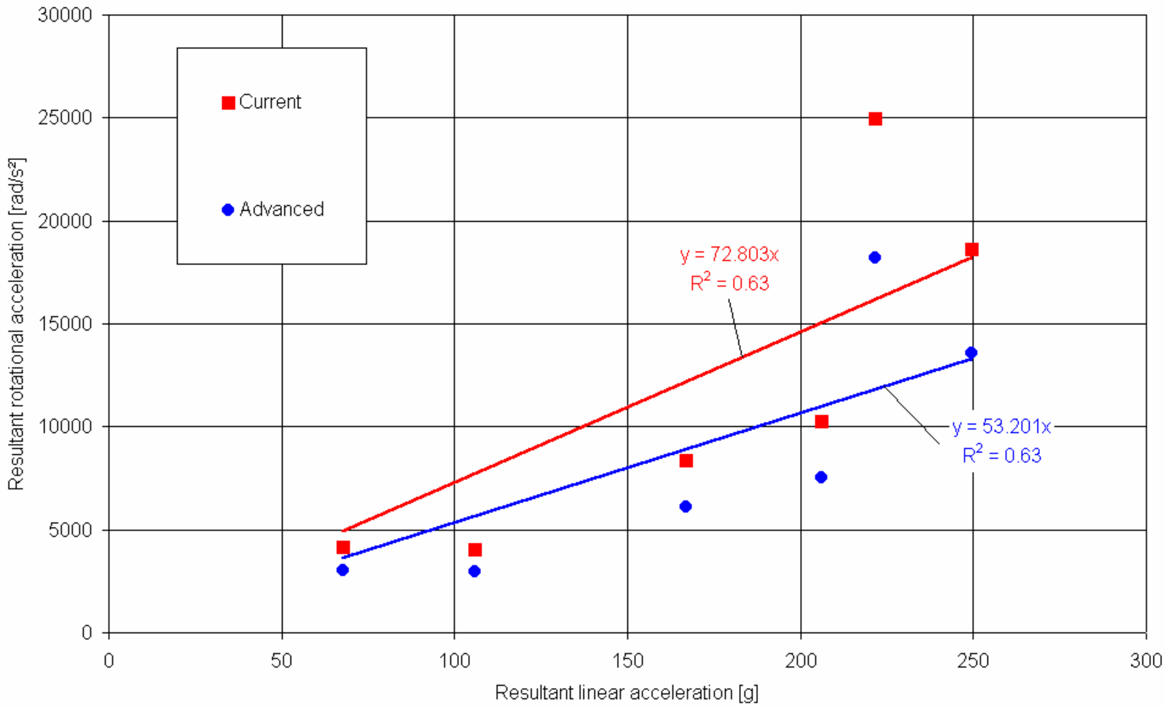

Figure 4. Relationship between linear acceleration and rotational acceleration current and advanced helmets

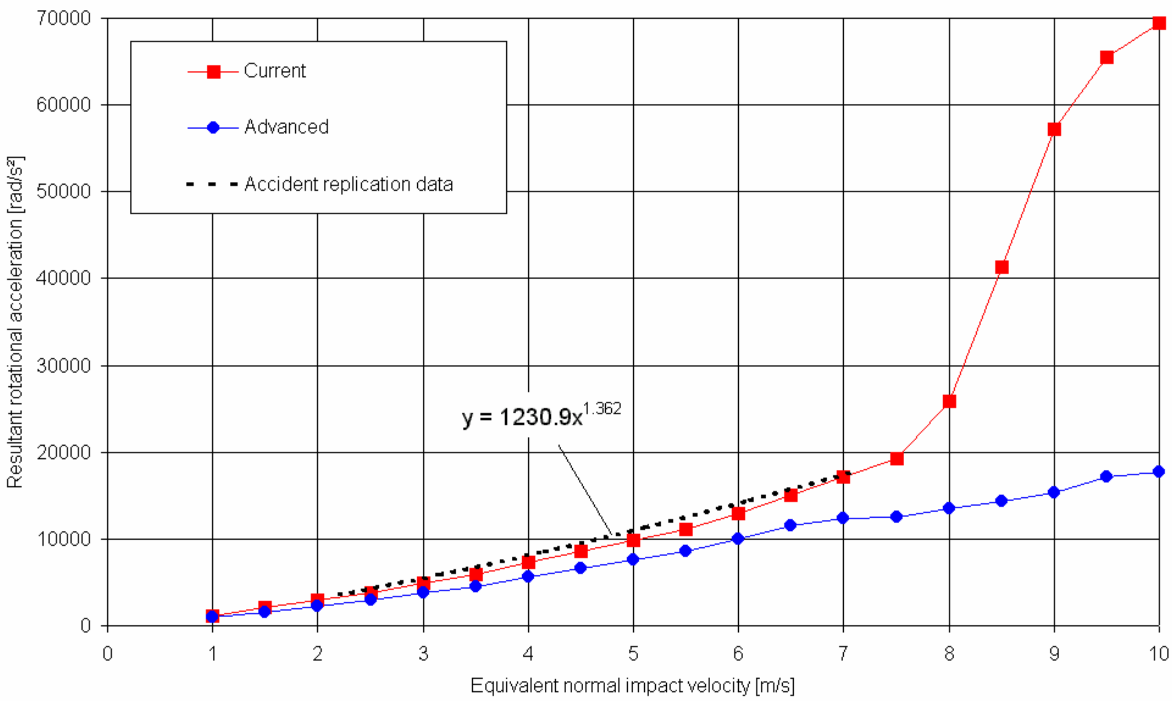

Figure 5. Relationship between impact velocity and rotational acceleration for current and advanced helmets

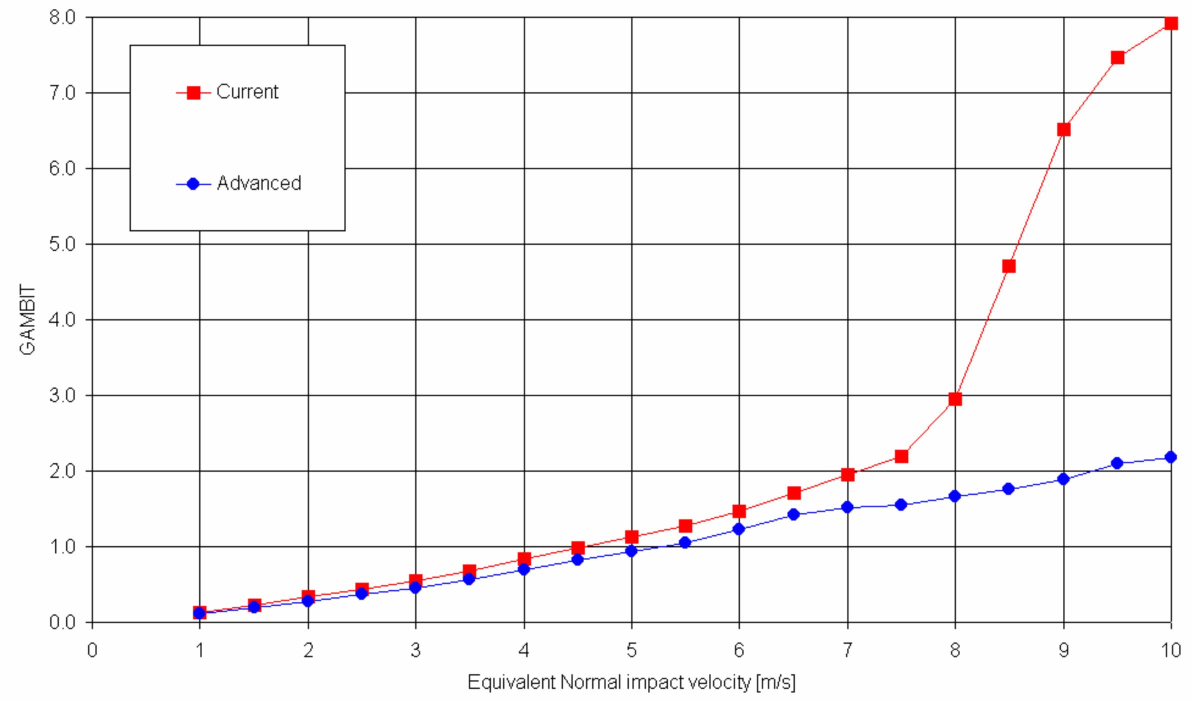

Figure 6. Relationship between impact velocity and GAMBIT for current and advanced helmets

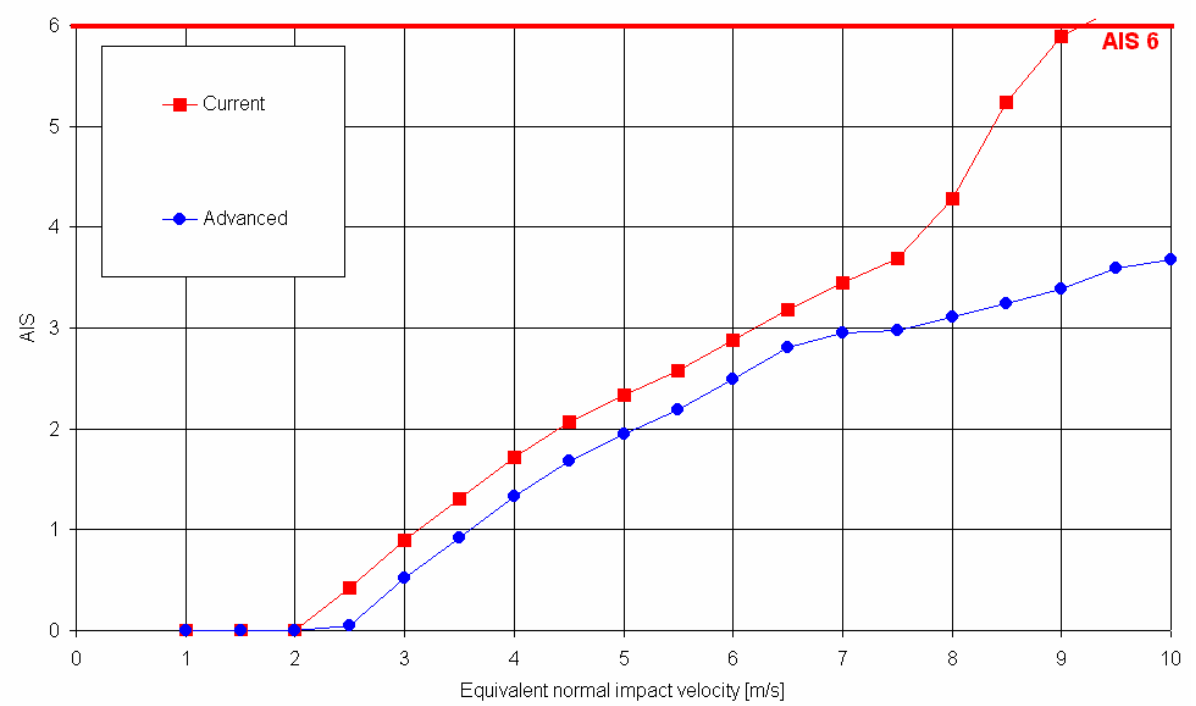

Figure 7. Relationship between impact velocity and AIS injury severity for current and advanced helmets

7. ASSESSMENT OF INJURY SAVINGS AND HELMET COSTS

7.1 INJURY SAVINGS

7.1.1 Number of casualties who may benefit from an improved helmet

In order to evaluate the number of motorcyclists that may potentially benefit from an advanced helmet it was necessary to examine the national accident data. Table 5 indicates the number of Two-Wheeled Motor Vehicle (TWMV) casualties, by casualty severity, for the years 1999 to 2001 (RAGB, 2002).

Table 5. Motorcycle casualties (1999-2001; RABG 2002)

Casualty severity	1999	2000	2001	1999-2001 (mean)
Fatal	547	605	583	578
Serious	6,361	6,769	6,722	6,617
Slight	19,284	20,838	21,505	20,542

For the purposes of the cost benefit analysis the mean values (1999-2001) were used. Previous accident data analysis has shown that 81.3% fatal, 67.9% serious, and 37.7% slight injured riders sustained head impacts (COST 327 final report, page 43) which corresponded to 470 fatal, 4,493 serious and 7,744 slight.

It was important to consider specifically the cases for which head was the most severely injured body region as these cases would benefit most from an improved helmet design. Based on data presented by Chinn (1993), the head was the most severely injured body region in 80% of fatal and 70% of serious cases where a head impact was sustained, which corresponded to 376 fatal and 3,145 serious cases. It was estimated that the proportion of slight injuries where the head was the most severely injured body region was 60% corresponding to 4,647 cases. A summary of these results is provided in Table 6.

Table 6. Annual number of motorcycle accidents where riders or pillions suffered head injuries

Casualty severity	(A) All casualties (1999-2001)	(B) Casualties with head injury	(C) Casualties with head injury *and head most severely injured region*
Fatal	578	470 (81.3% of A)	376 (80% of B)
Serious	6,617	4,493 (67.9% of A)	3,145 (70% of B)
Slight	20,542	7,744 (37.7% of A)	4,647 (60% of B)

7.1.2 AIS distribution of casualties who may benefit from an improved helmet

The AIS (AAAM, 1998) distribution of those casualties whose head was the most severely injured body region was estimated by reviewing 158 cases from the COST 327 accident replication project for which detailed accident and injury data has been analysed. The AIS injury distribution is presented in Table 7, below.

Table 7. AIS injury distribution for fatal, serious and slight motorcycle casualties

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	All
Fatal*	33.3%	33.3%	22.2%	11.1%	0%	0%	100%
Serious*	0%	13.0%	13.0%	17.4%	56.5%	0%	100%
Slight†	0%	0%	0%	0%	12%	88%	100%

* based on analysis of 158 cases from COST 327

† based on COST 327 final report

The AIS distribution (Table 7) was combined with the estimated number of casualties whose head was the most severely injured body region (Table 6) to derive the data presented in Table 8 below. The numbers of slight casualties in Table 8 were distributed according to data contained within the COST 327 final report which indicated that 88% of slight injures are AIS 1 in severity; the remainder of injuries were assumed to be AIS 2 injuries.

Table 8. AIS injury distribution for casualties with head most severely injured body region

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	All
Fatal	125	125	84	42	0	0	376
Serious	0	409	409	547	1,777	0	3,145
Slight	0	0	0	0	558	4,089	4,647
Total	**125**	**534**	**492**	**589**	**2,335**	**4,089**	**8,167**

Further analysis of the Cost 327 cases was made to determine whether or not the advanced helmet design would have provided improved protection to the wearer. The impact kinematics, impact type and impact mechanisms were considered, including an assessment of the linear and rotational injury potential. It was important to consider both the type and the severity of the impacts to determine which cases exceeded the protective capability of even the advanced protective helmet. Other cases involved impacts with aggressive structures or impacts through the visor that would not be protected by the advanced helmet. Table 9 presents a summary of this analysis with an estimate of the proportion of cases of each AIS severity that may have benefited from the advanced protective helmet.

Table 9. Proportion of cases† for which an advanced helmet may provide additional protection.

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1
Fatal	16.7%	66.7%	100%	100%		
Serious		100%	100%	75%	92%	
Slight					92%	40%

† *cases with head injury and head most severely injured region*

The values in Table 9 were combined with the values in Table 8 to provide an estimate of the number of casualties that may have had an improved injury outcome with the advanced helmet. This calculation assumes that every motorcycle rider, irrespective of factors (such as rider age, motorcycle make or model and engine capacity) is equally likely to be involved in an accident. These results are presented in Table 10.

Table 10. Number of casualties where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	**Total**
Fatal	21	84	84	42			**230**
Serious		409	409	410	1,635		**2,863**
Slight					513	1,636	**2,149**
Total	**21**	**492**	**492**	**452**	**2,148**	**1,636**	**5,241**

Thus, if all motorcycle riders wore helmets to the performance specification of the advanced helmet, there is potential to improve injury outcome for 230 fatal, 2,863 serious and 4,647 slight per annum (see Table 10). The next part of the analysis was to quantify the *magnitude* of benefit that would be afforded by the advanced helmet. Details of this analysis are provided in section 4 and a summary is provided in Table 11 below.

Table 11. Comparison of AIS injury outcome for current and advanced helmet designs

AIS current helmet	AIS advanced helmet†
6	4
5	3
4	3
3	3
2	2
1	1

† AIS injury severity for those accidents where it was considered that the improved helmet may improve the injury outcome

7.1.3 Assessing the injury distribution for the advanced helmet

Using the AIS injury reduction levels presented in Figure 7 (summary in Table 11) it was possible to consider those accidents where an advanced helmet would have benefited the rider (Table 10) and determine the overall level of injury reduction. Table 12 shows the AIS distribution for both current and advanced helmets, assuming the advanced helmet had been worn for all the cases presented in Table 10. Table 13 shows the injury severity in terms of fatal, serious or slight, based on the values AIS values in Table 12. This analysis was conducted within the spreadsheet model and assumes that the distribution of injury severity (fatal, serious, slight) remains constant within each AIS classification for both current and advanced helmets.

The difference between the results in Table 12 and those in Table 10 represents the overall annual injury reduction that may be achieved with the advanced helmet, as shown in Table 14. The advanced helmet was found to have the potential of saving 94 lives and 434 serious injuries each year.

Table 12. AIS severity distribution for current and advanced helmets†

AIS distribution	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	Total
Current helmet	21	492	492	452	2,148	1,636	5,242
Advanced helmet	0	0	260	992	1,725	2,265	5,242

† for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Table 13. Injury severity distribution assuming the advanced helmet had been worn†

Casualty severity	AIS 6	AIS 5	AIS 4	AIS 3	AIS 2	AIS 1	Total
Fatal	0	0	44	92	0	0	136
Serious	0	0	216	901	1313	0	2,429
Slight	0	0	0	0	412	2265	2,677
All severities	0	0	260	992	1,725	2,265	5,242

† for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Table 14. Estimated annual injuries for current and advanced helmet design

	Current	Advanced	Reduction
Fatal	230	136	94
Serious	2,863	2,429	434
Slight	2,149	2,677	-528
All	5,242	5,242	0

7.2 HELMET COSTS

According to DfT figures there were 760,000 licensed Two-Wheel Motor Vehicles (TWMVs) in Great Britain in 1999 (DfT, 1999). It was assumed that the average rider purchases a new helmet every five years, giving estimated annual helmet sales of 152,000 units. This is consistent with the number of new registrations for TWMV; 168,000 in 1999 (DfT, 1999) since a proportion of TWMV riders may purchase a new vehicle but already own a helmet.

Table 18. Estimated costs for advanced and standard helmets

	Standard helmet	Advanced helmet
Cost of manufacture	£50	£200
Retail price	£150	£300

Table 11 gives details of the costs of standard and advanced motorcycle helmets. The price of the advanced helmet is estimated to be £200-cost and £300-retail, compared with an estimated average price of £50-cost and £150-retail for conventional helmets. If 10% of all new helmets sold conformed to the new level of performance, the market share of this new helmet would be 2% in year one, 4% in year two, 6% in year three, 8% in year four and 10% in year five (a total of 76,000 units sold by year five). Therefore, the additional cost of 76,000 advanced helmet sales is estimated to be £11.4M (£150 per helmet).

8. CONCLUSIONS

- An advanced prototype helmet has been developed by TRL to offer improved protection from both linear and rotational loadings to the head.

- This was achieved with a lightweight carbon composite shell fitted with an high-efficiency expanded polystyrene energy absorbing liner and a low friction sacrificial shell surface.

- The advanced helmet has the potential to achieve significant safety benefits over a conventional motorcycle helmet. It was estimated that the advanced helmet has the capability to reduce AIS 6 injuries to AIS 4 and AIS 5 and 4 injuries to AIS 3.

- National accident data was analysed in conjunction with the data from the COST 327 study, the TRL motorcycle accident replication programme and the performance reference data for the advanced helmet. It was found that of the 578 fatal motorcycle riders (or pillions) killed each year, 93 lives could be saved and 434 serious injuries prevented if all riders had been wearing the advanced helmet.

- It was estimated that the advanced helmet may cost £150 more than a standard helmet. If 10% of all new helmets sold conformed to the new level of performance, the market penetration of this new helmet would be 2% in year one, 4% in year two, 6% in year three, 8% in year four and 10% in year five (a total of 76,000 units sold by year five). This equates to an increase in cost of an estimated £11.4M over conventional helmets.

- It was estimated that with a 10% sales penetration of the advanced helmet, some 50 riders would have a reduction in head injury from AIS 5 to AIS 3 and a similar number would benefit from a reduction from AIS 4 to AIS 3. Although this is a very significant saving in terms of reduced suffering, the financial benefits are more difficult to quantify as all AIS severities within the serious-injury category are classified as having the same financial cost.

- The overall cost of producing and selling 76,000 advanced helmet models in order to achieve a 10% wearing rate over five years was estimated to be £11.4M.

REFERENCES

AAAM (1998) Abbreviated Injury Scale 1990. USA: Association for the Advancement of Automotive Medicine, 1998.

DfT (2000) Road accidents Great Britain 1999. National Statistics, 1999.

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Hurt et al. (1986). Epidemiology of head and neck injuries in motorcycle fatalities. In: Mechanisms of head and spine trauma by Sances, Thomas, Ewing, Larson and Unterharmscheidt. Aloray

Thom, D R and Hurt, H H (1993). Basilar skull fractures in fatal motorcycle crashes. 37th Annual Conference of the AAAM.

APPENDIX A. TRL SPECIFICATION OF FLAT SHELL STRUCTURES

1. Size	120mm * 70mm
2. Thickness	Maximum of 10mm
3. Mass	Maximum of 50g
4. In-plane tensile strength	Peak tensile stress will occur at the *inner surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
5. In-plane compressive strength	Peak compressive stress will occur at the *outer surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
6. In-plane bending stiffness	10 times as stiff as 3mm GRP (or 5mm unreinforced polycarbonate).
5. Through-thickness compression strength*	Management of compressive forces without excessive dimpling to the outer skins. Peak compressive stresses approximately 30N/mm² at 1.5mm shell deformation.
6. Operating conditions	-20^{o}C to +50^{o}C with extremes of moisture

TRL proposes that in order to achieve these objectives, a sandwich construction is required. The sandwich will comprise of relatively thin (<2mm) composite outer and inner skins, separated by a thicker (3mm to 6mm) core.

* During a linear impact onto a kerbstone anvil, the shell must transmit forces up to 15,000N. It is calculated that the through-thickness compressive stress during such an impact will be in the region of 30N/mm² (assuming 1.5mm shell deformation). If the structure is a sandwich, with the core material less stiff than the skins, the structure must be able to resist these loads without excessive deformation. If the core material compresses significantly, the effective thickness of the web is reduced and the bending stiffness is greatly decreased.

APPENDIX B. TEST PROCEDURES TO EVALUATE IMPACT PERFORMANCE

B1. Linear impact tests

Flat shell samples measuring 120mm x 70mm were attached to a ‘bed’ of foam measuring 120mm x 70mm x 35mm with double sided adhesive tape. The foam/shell specimen was attached to the base of a 2.5kg mass, with the shell facing outwards, and impacted onto a steel hemi-spherical anvil with a 25mm radius. The anvil was designed to simulate the shell-stresses developed during a helmet impact onto the ECE Regulation 22 kerbstone anvil. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 5m/s, 7.5m/s and 10m/s.

B2. Temperature and moisture tests

The samples were pre-conditioned at -20^{o}C, +25^{o}C, +50^{o}C and with moisture conditioning by means of a water soak. The samples were placed on a rigid anvil, with the shell facing upwards, and impacted with a 2.5kg mass fitted with the steel hemi-spherical impact surface as above. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 7.5m/s.

B3. Analysis and results

For each test the acceleration history of the impactor was recorded. By single integration of this result the velocity history was calculated and hence the rebound velocity was determined. By double integration of the acceleration result, the displacement history was calculated and this enabled the maximum dynamic displacement to be determined.

For each test two graphs are provided, the acceleration-time history and the acceleration-displacement history

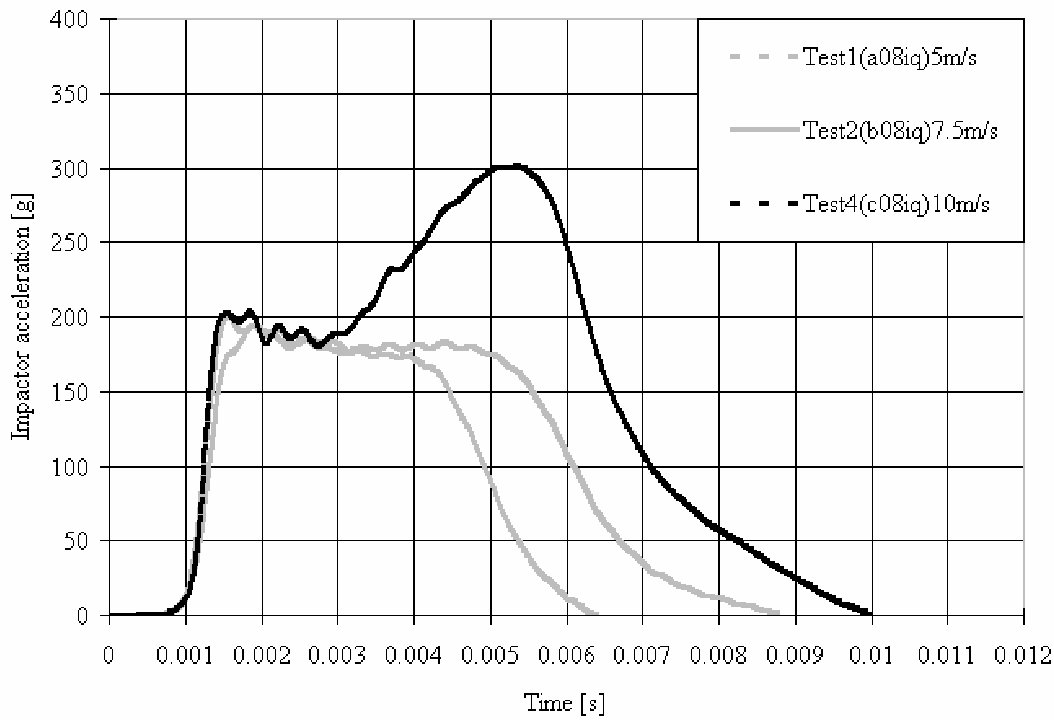
APPENDIX C. GRAPHICAL RESULTS

FIGURES C1 TO C8
FLAT SAMPLE IMPACT TESTS

FIGURES C9 TO C11
FLAT SAMPLE SURFACE FRICTION TESTS

FIGURES C12 TO C114
FULL GEOMETRY HELMET LINEAR IMPACT TESTS

FLAT SAMPLE IMPACT TESTS



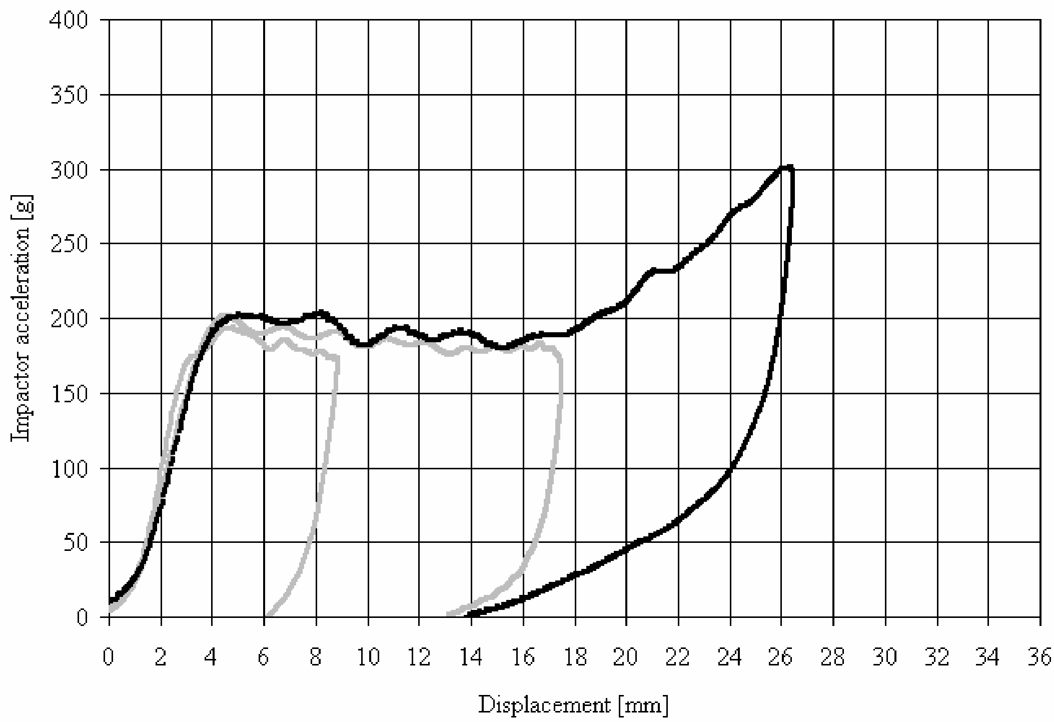
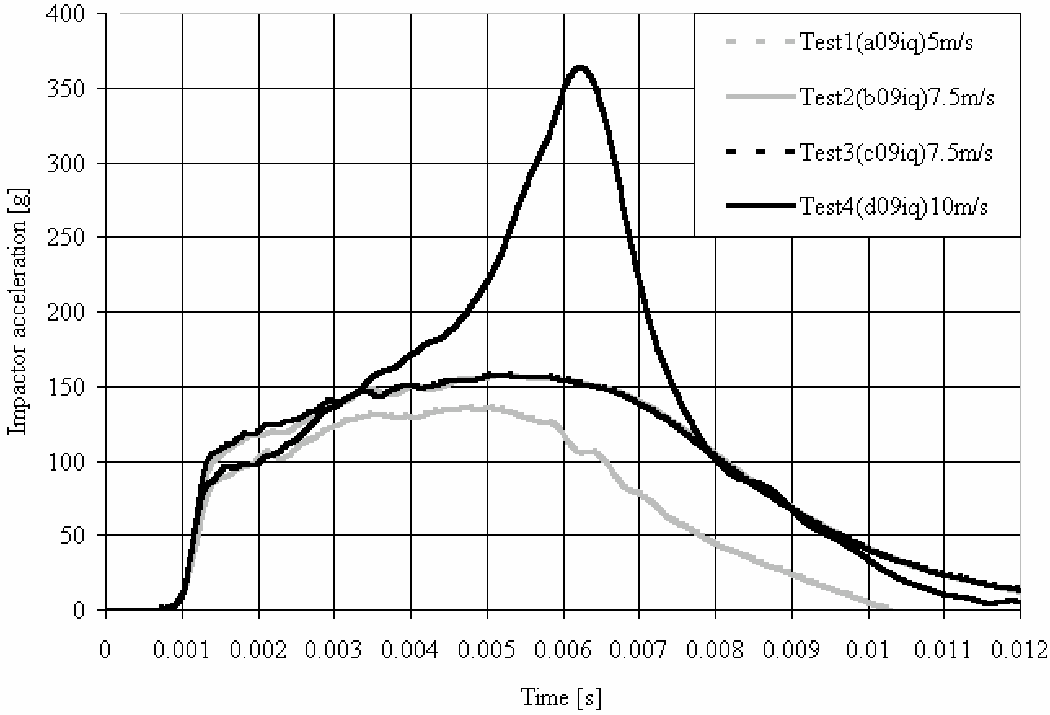


Figure C1. Impact performance of expanded polystyrene control sample (flat plates)

FLAT SAMPLE IMPACT TESTS



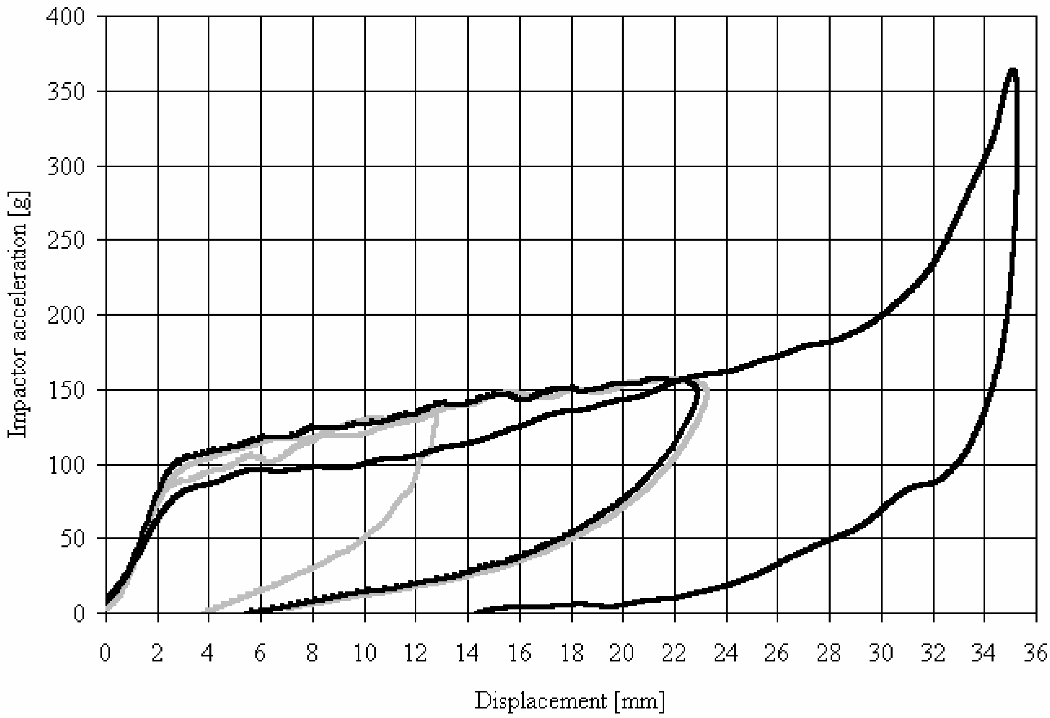
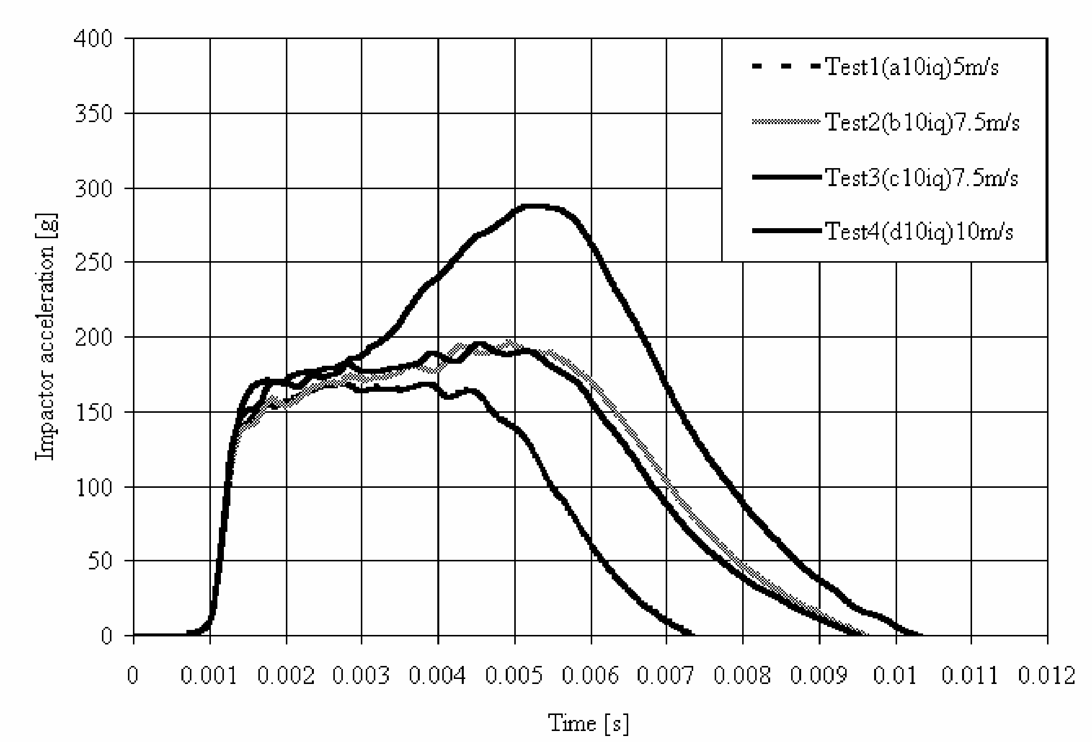


Figure C2. Impact performance of 5mm Polycarbonate shell

FLAT SAMPLE IMPACT TESTS



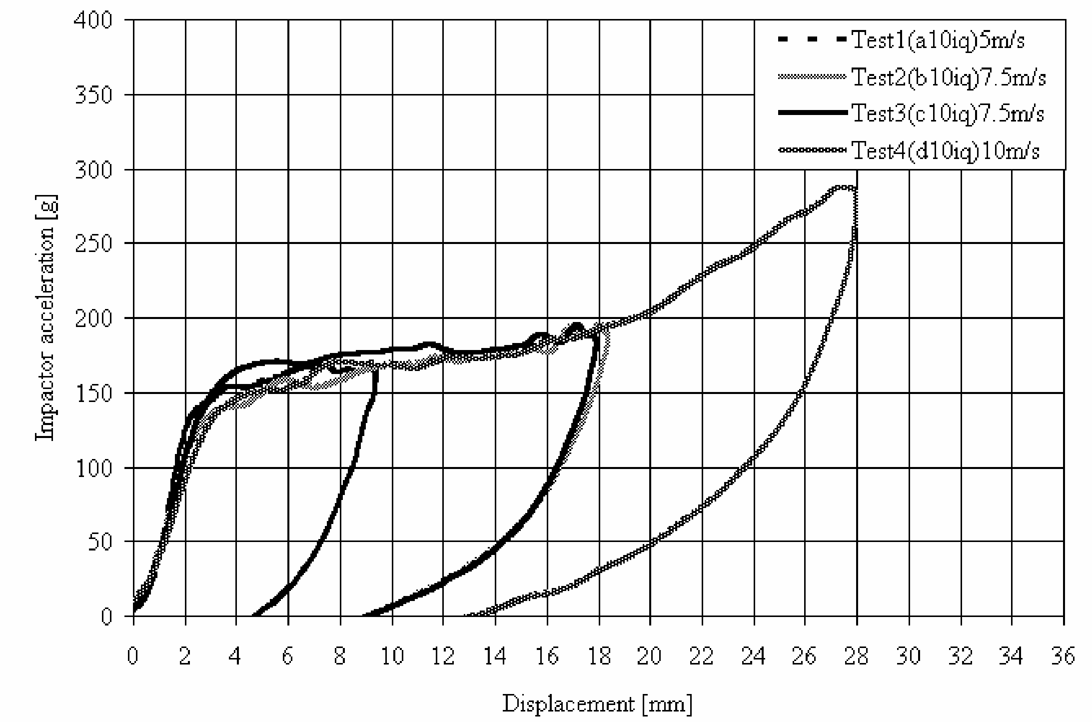
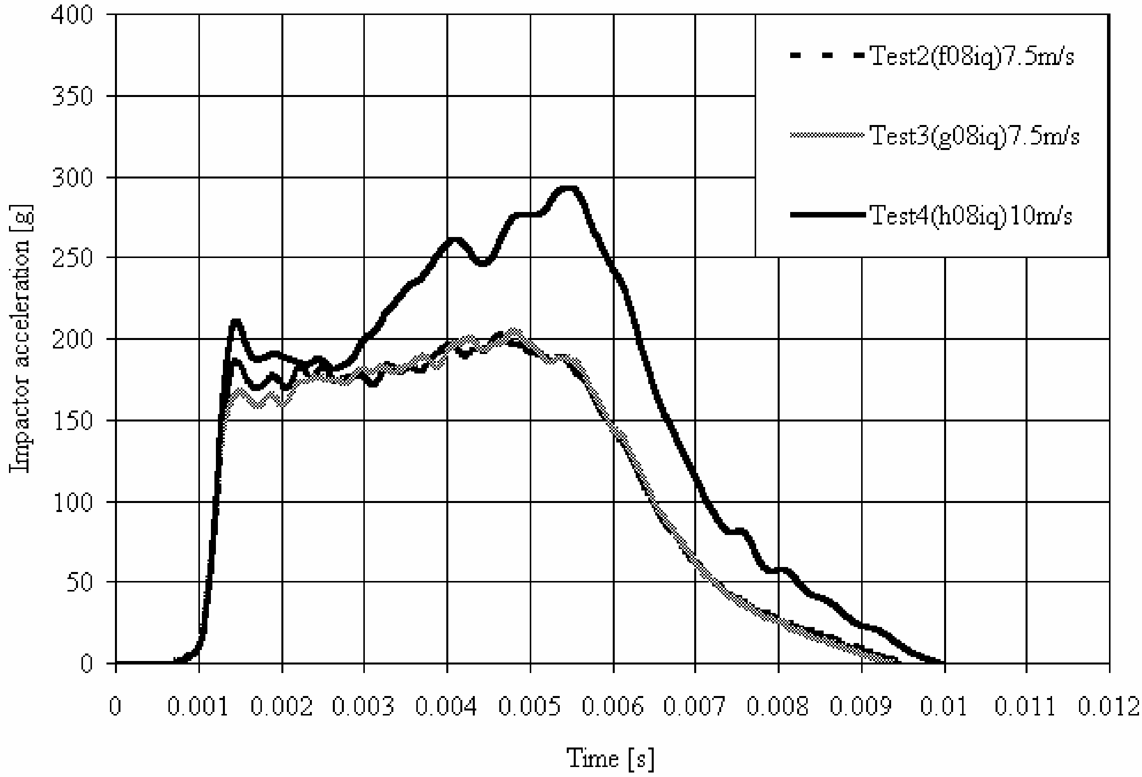


Figure C3. Impact performance of 10mm Polycarbonate shell

FLAT SAMPLE IMPACT TESTS



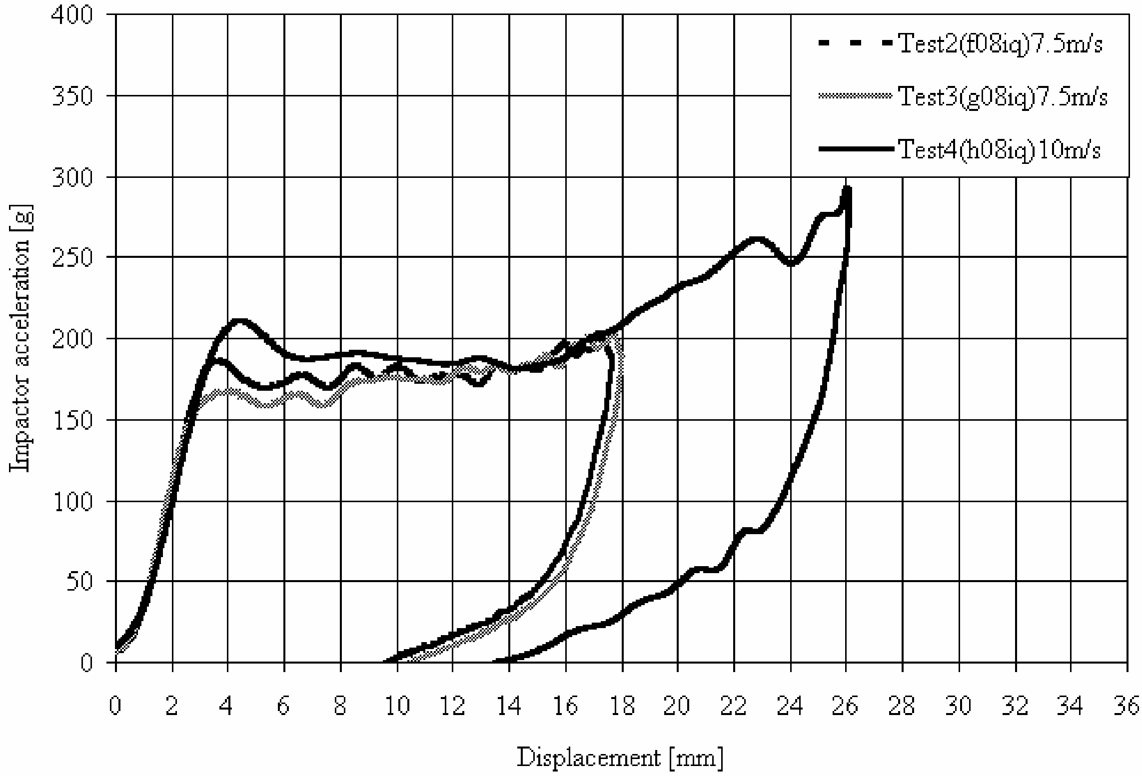
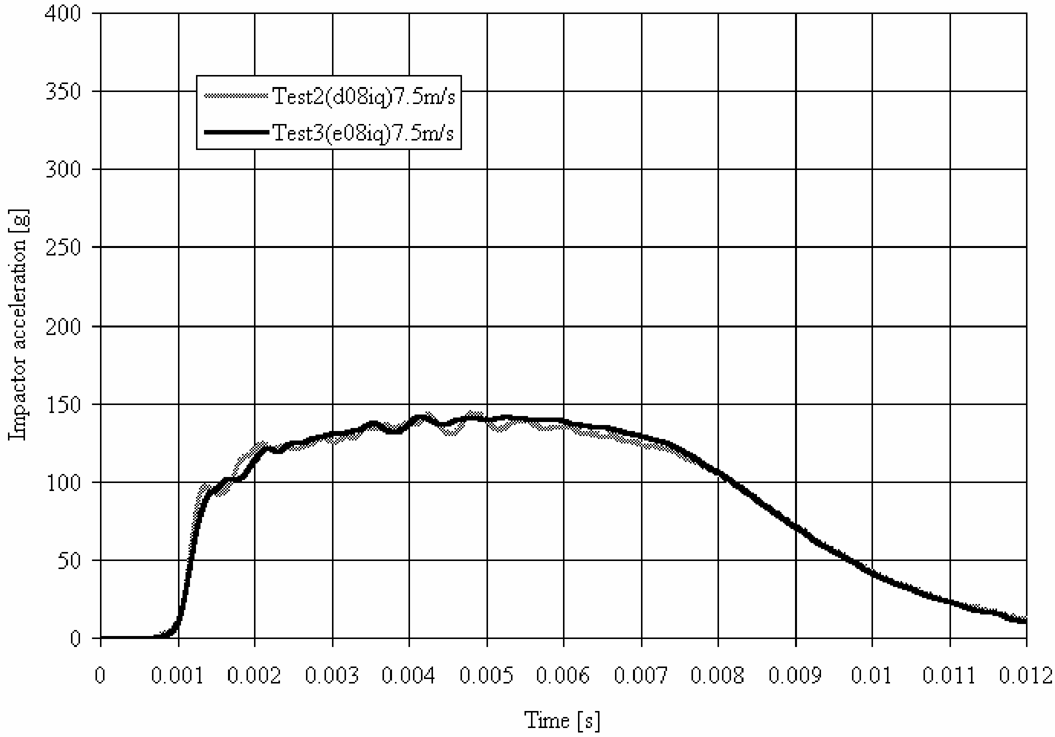


Figure C4. Impact performance of 5mm Aluminum shell

FLAT SAMPLE IMPACT TESTS



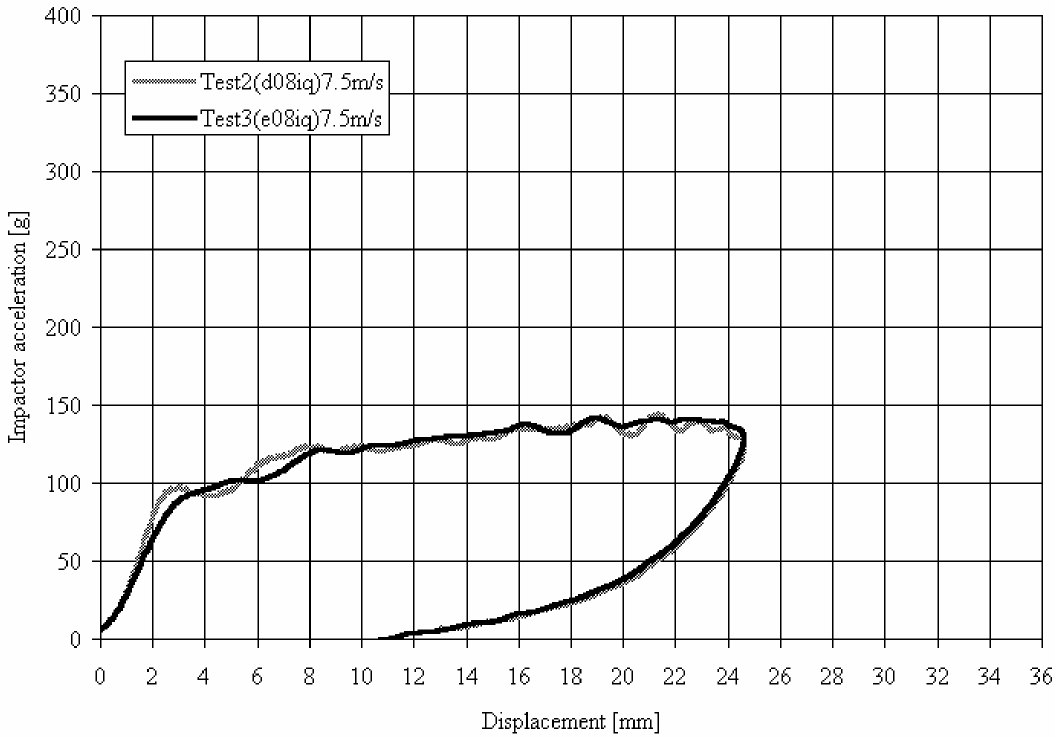
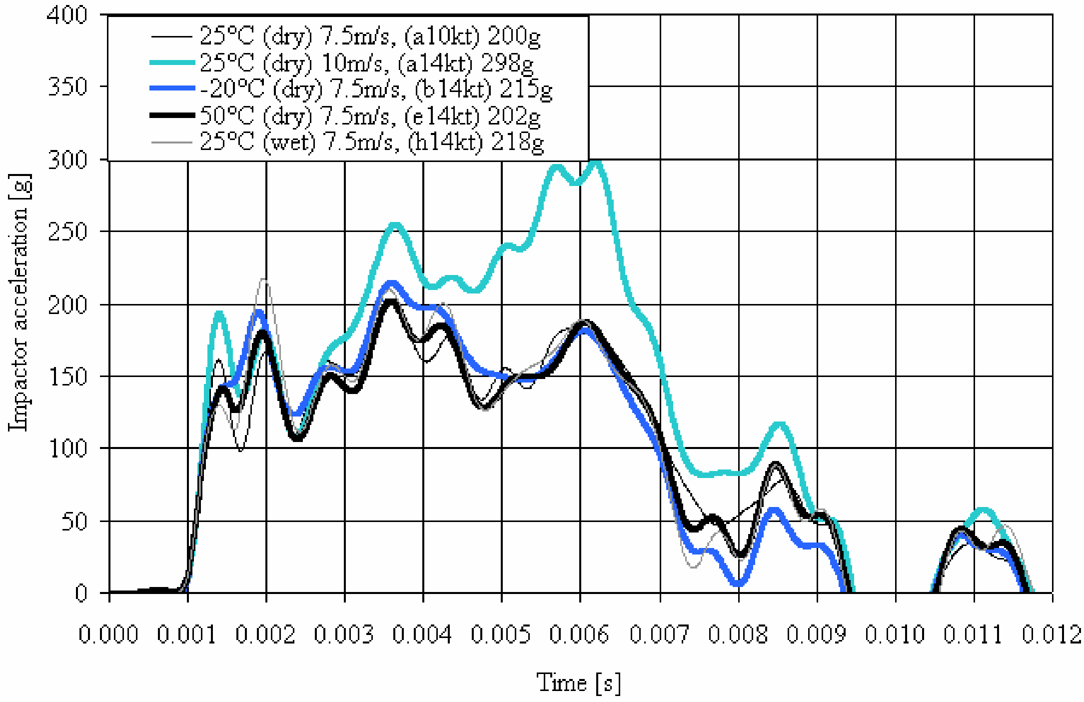


Figure C5. Impact performance of (Nimrod) PC helmet shell sample

FLAT SAMPLE IMPACT TESTS



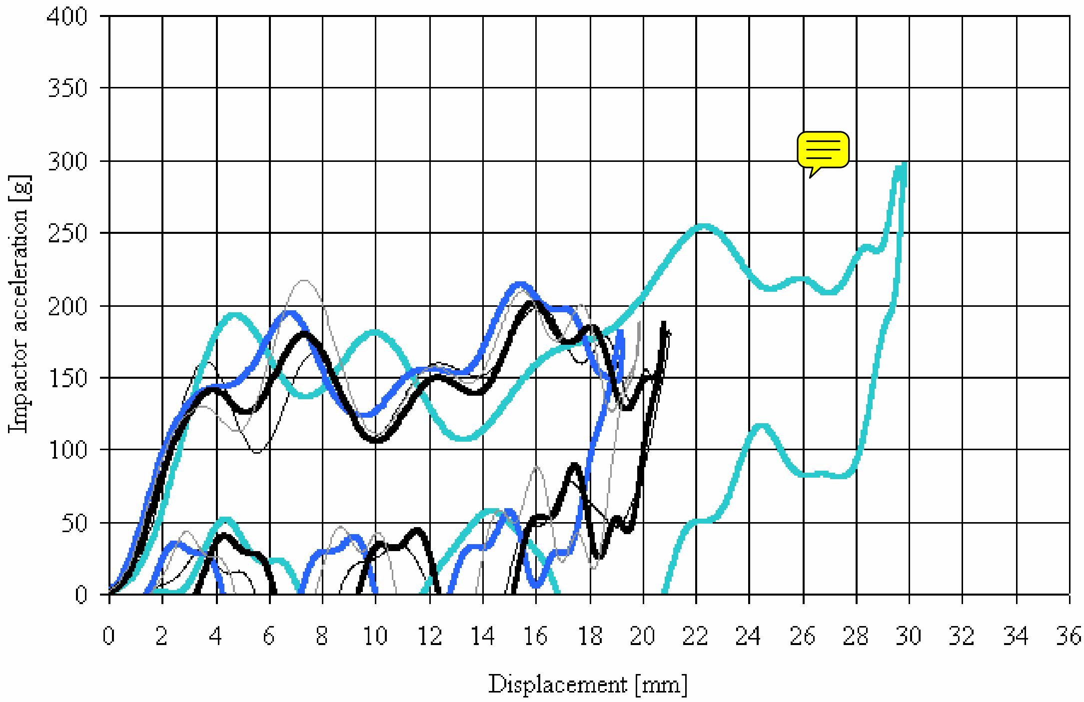
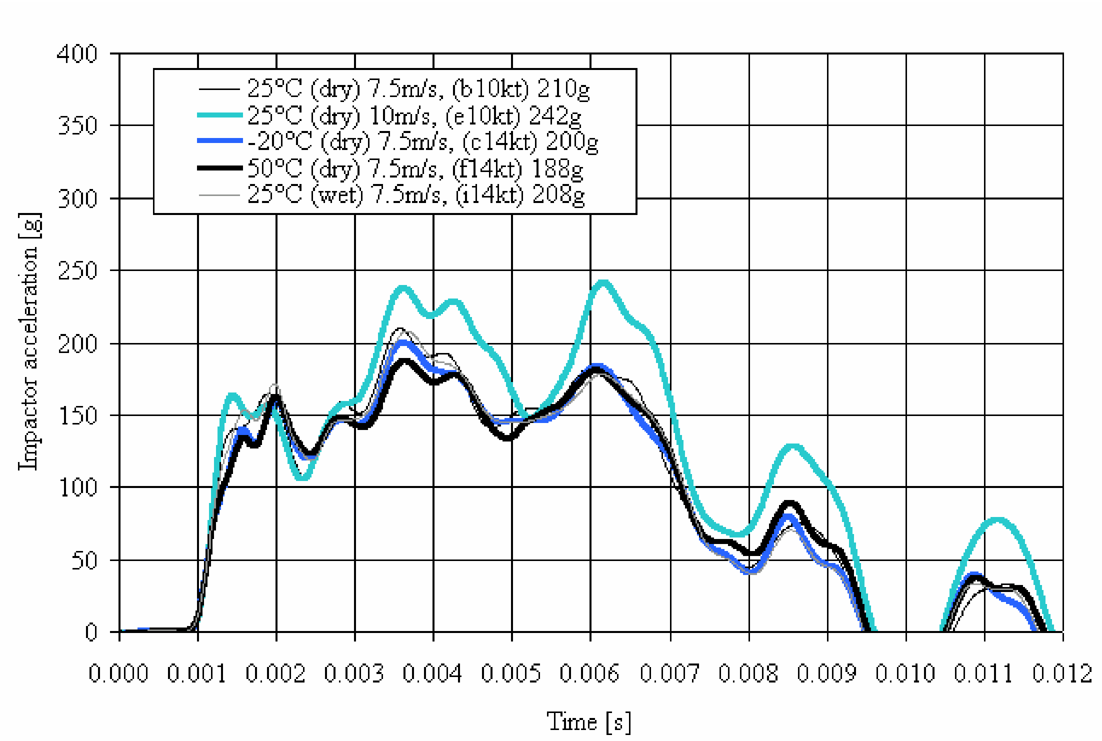


Figure C6. Impact performance of CFT-MHS-01 shell sample
5c(s2.5mm)5c

FLAT SAMPLE IMPACT TESTS



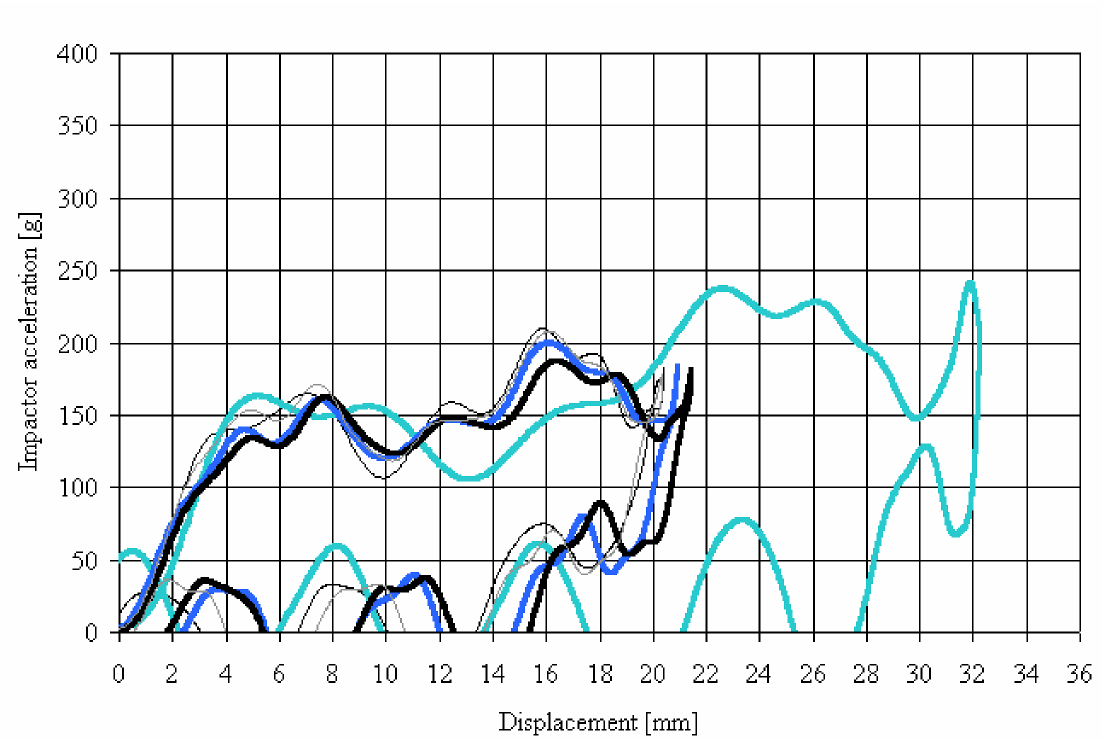


Figure C7. Impact performance of CFT-MHS-02 shell sample
13c (T800 2x2 T, 200gsm, 45% resin)

FLAT SAMPLE IMPACT TESTS

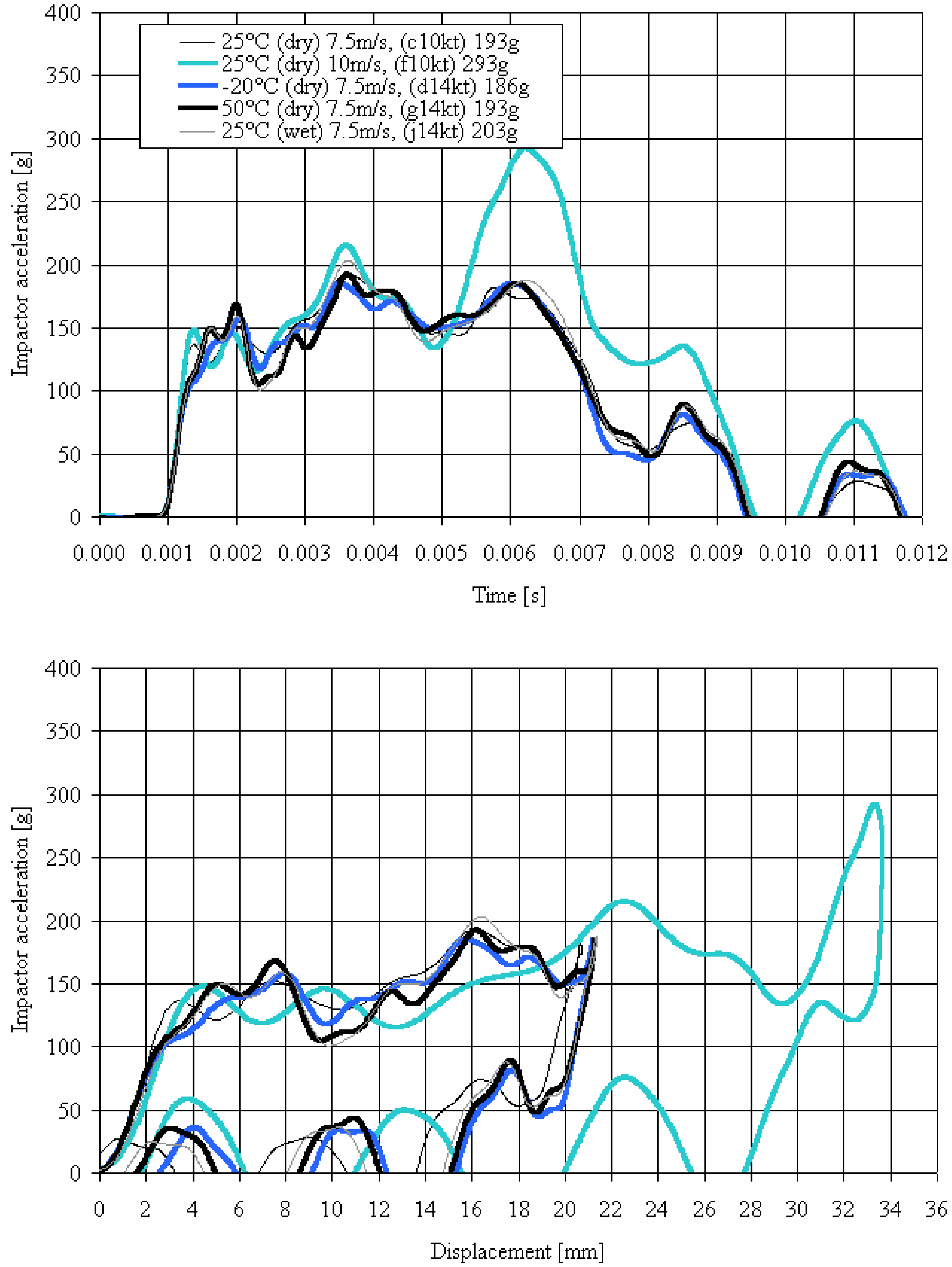


Figure C8. Impact performance of CFT-MHS-8 shell sample
CFT prototype T800 laminate

FLAT SAMPLE SURFACE FRICTION TESTS

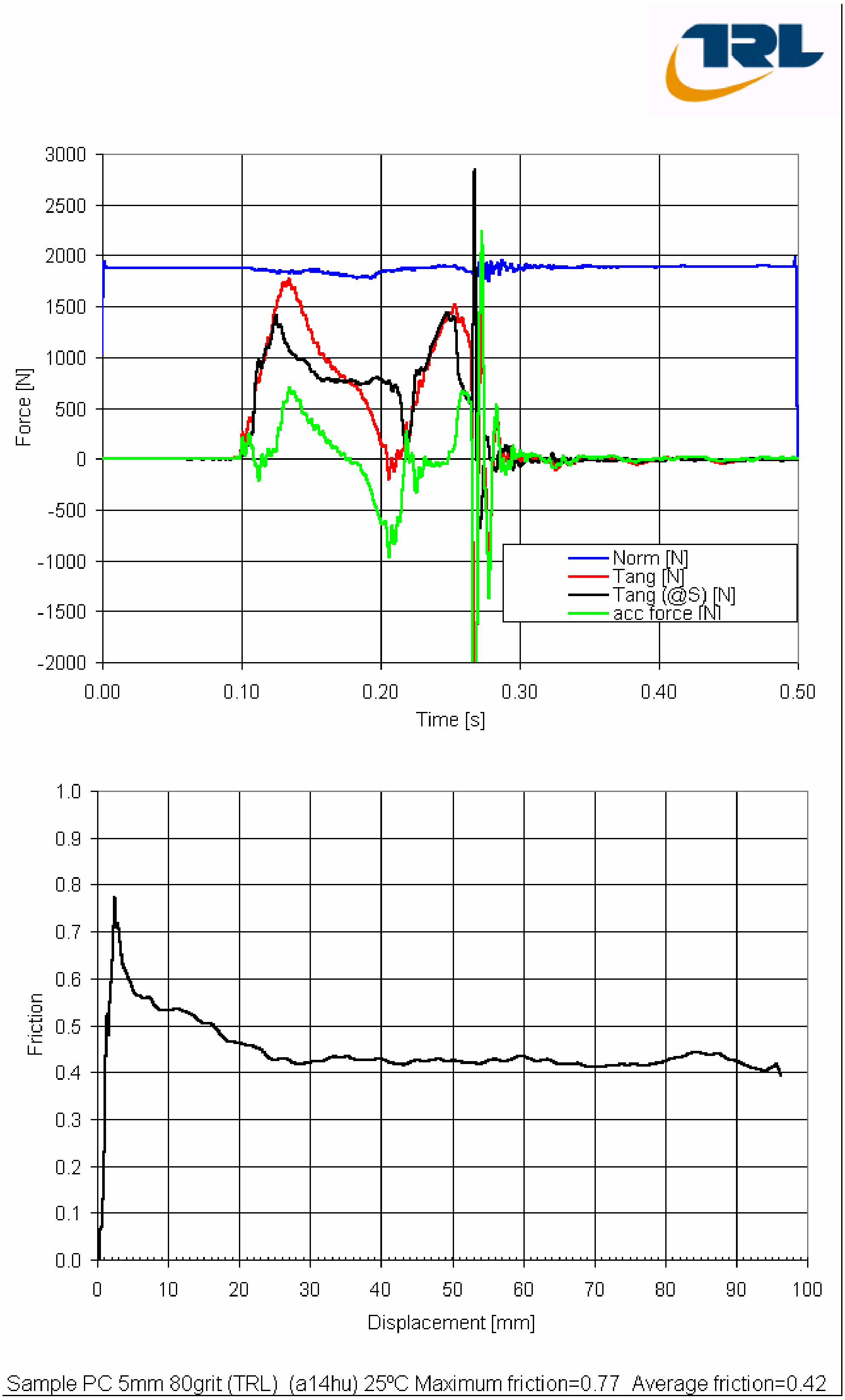


Figure C9. Surface friction test on polycarbonate sample

FLAT SAMPLE SURFACE FRICTION TESTS

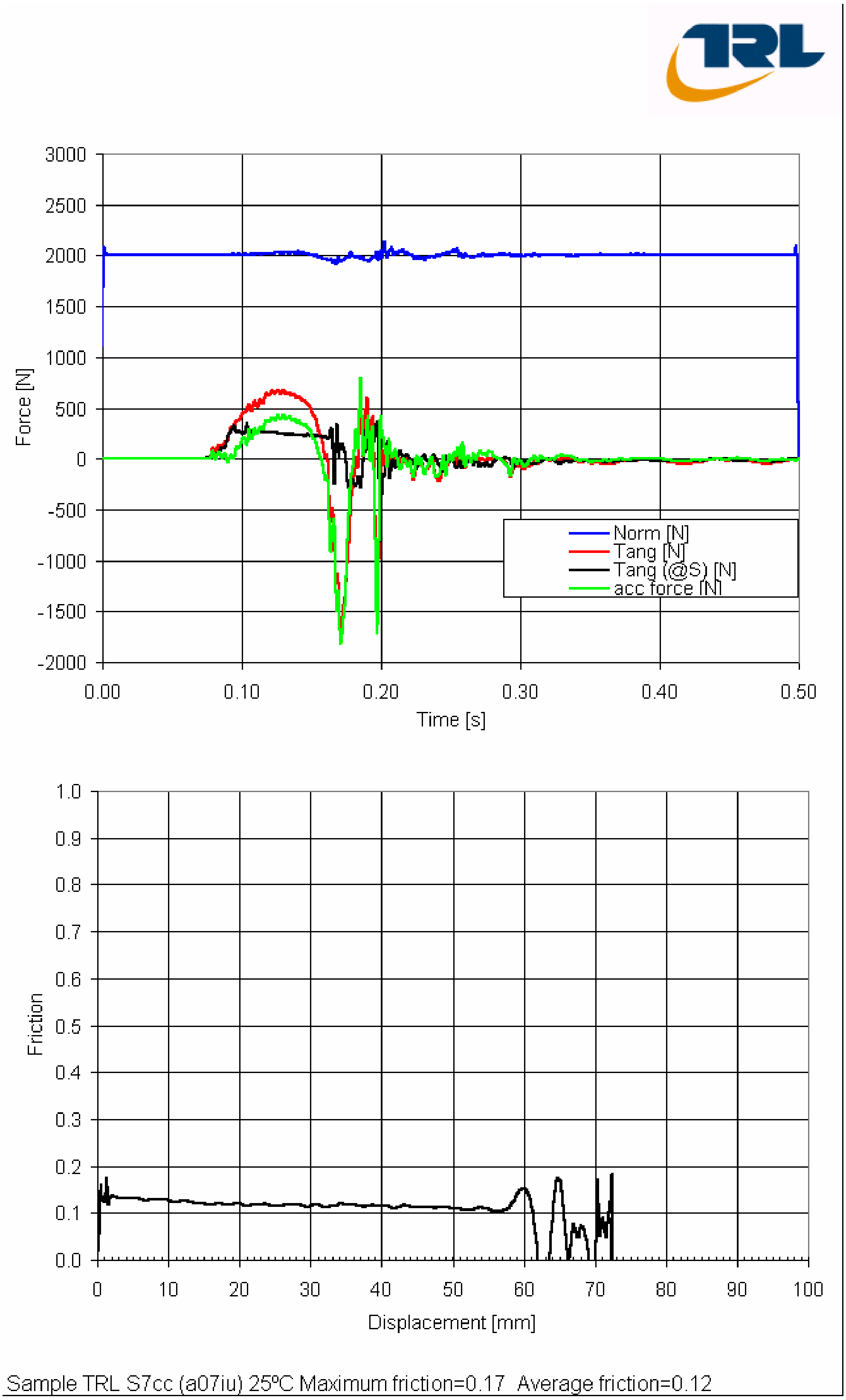
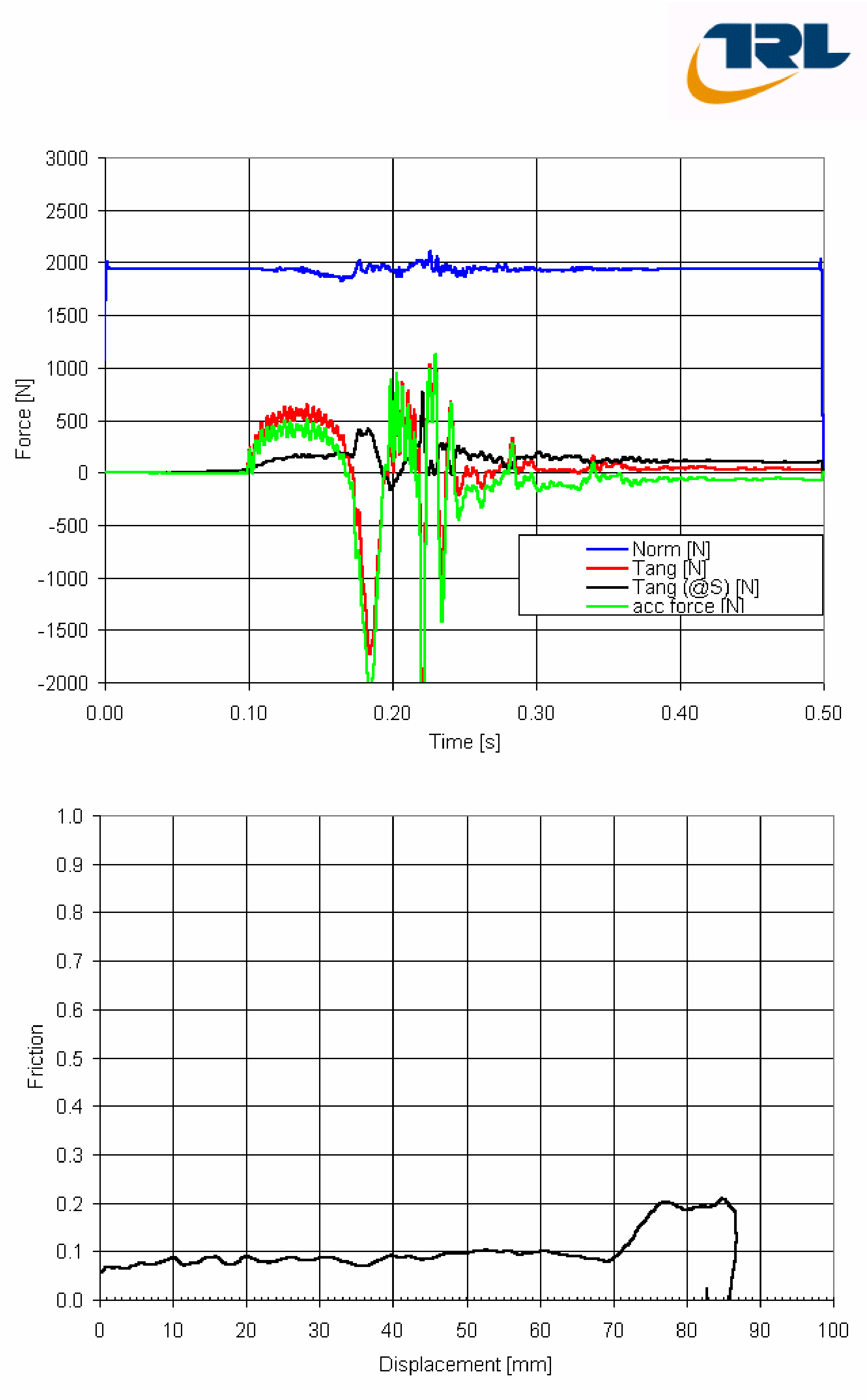


Figure C10. Surface friction test on Carbon Fibre shell sample

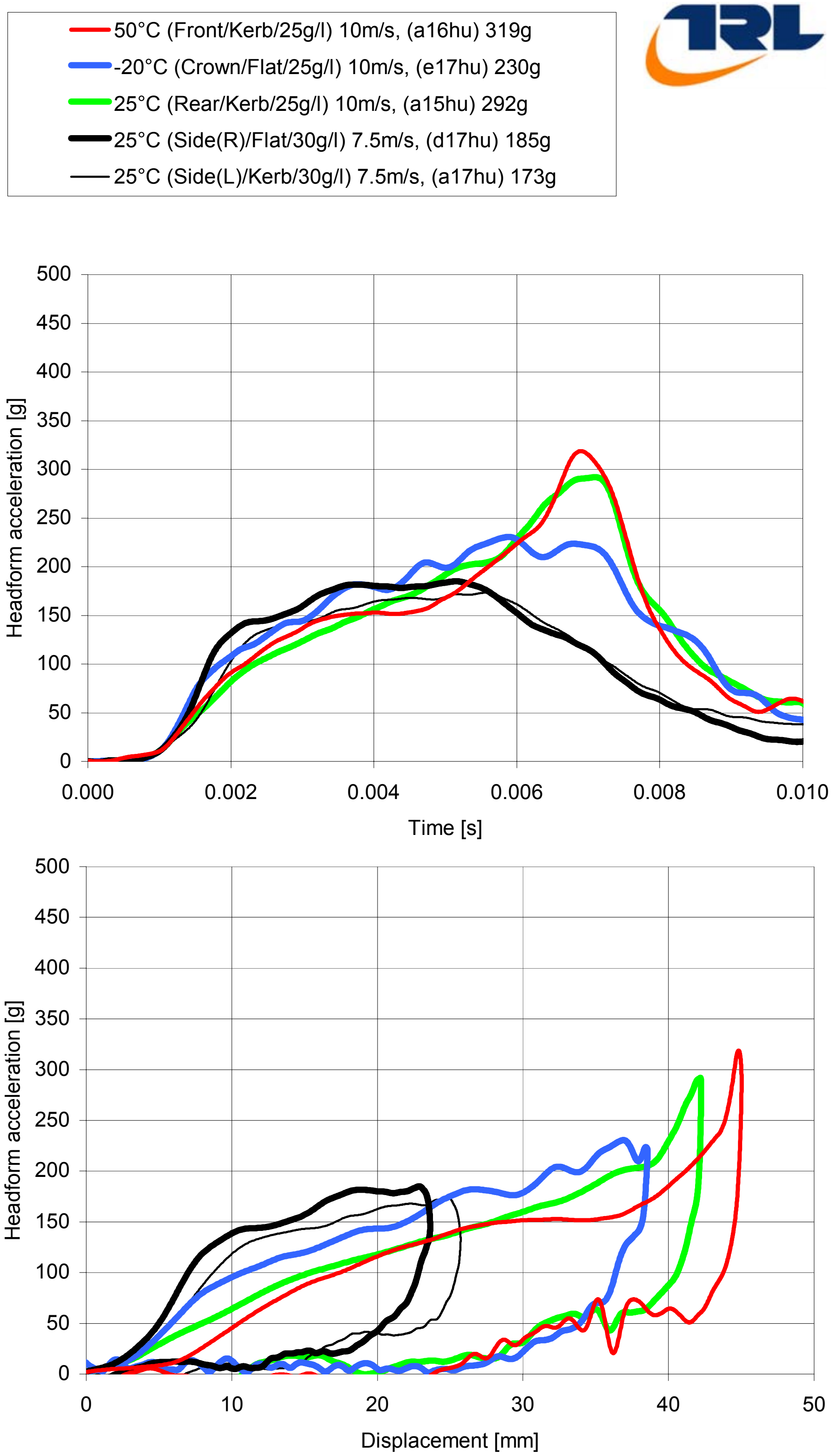
FLAT SAMPLE SURFACE FRICTION TESTS



Sample EHD (TRL) (k13hu) 25ºC Maximum friction=0.1 Average friction=0.09

Figure C11. Surface friction test on sacrificial layer shell sample

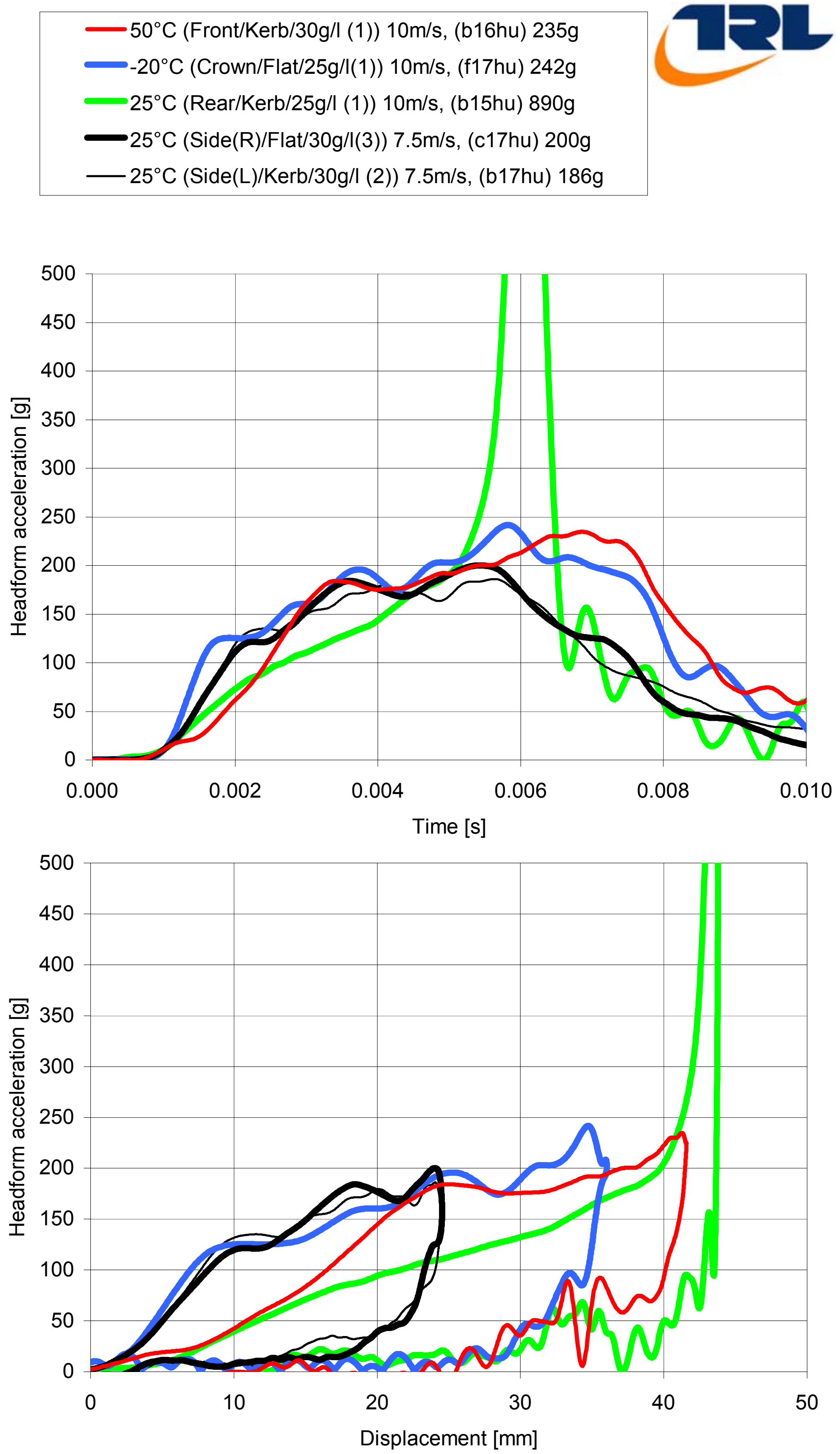
FULL GEOMETRY HELMET LINEAR IMPACT TESTS



Impact performance of CFT-MHS01 carbon solid shell (13c)

Figure C12 Impact performance of CFT-MHS-01 shell sample

FULL GEOMETRY HELMET LINEAR IMPACT TESTS



Impact performance of CFT-MHS02 carbon sandwich shell 5c(s2.7)5c

Figure C13. Impact performance of CFT-MHS-02 full-geometry helmet

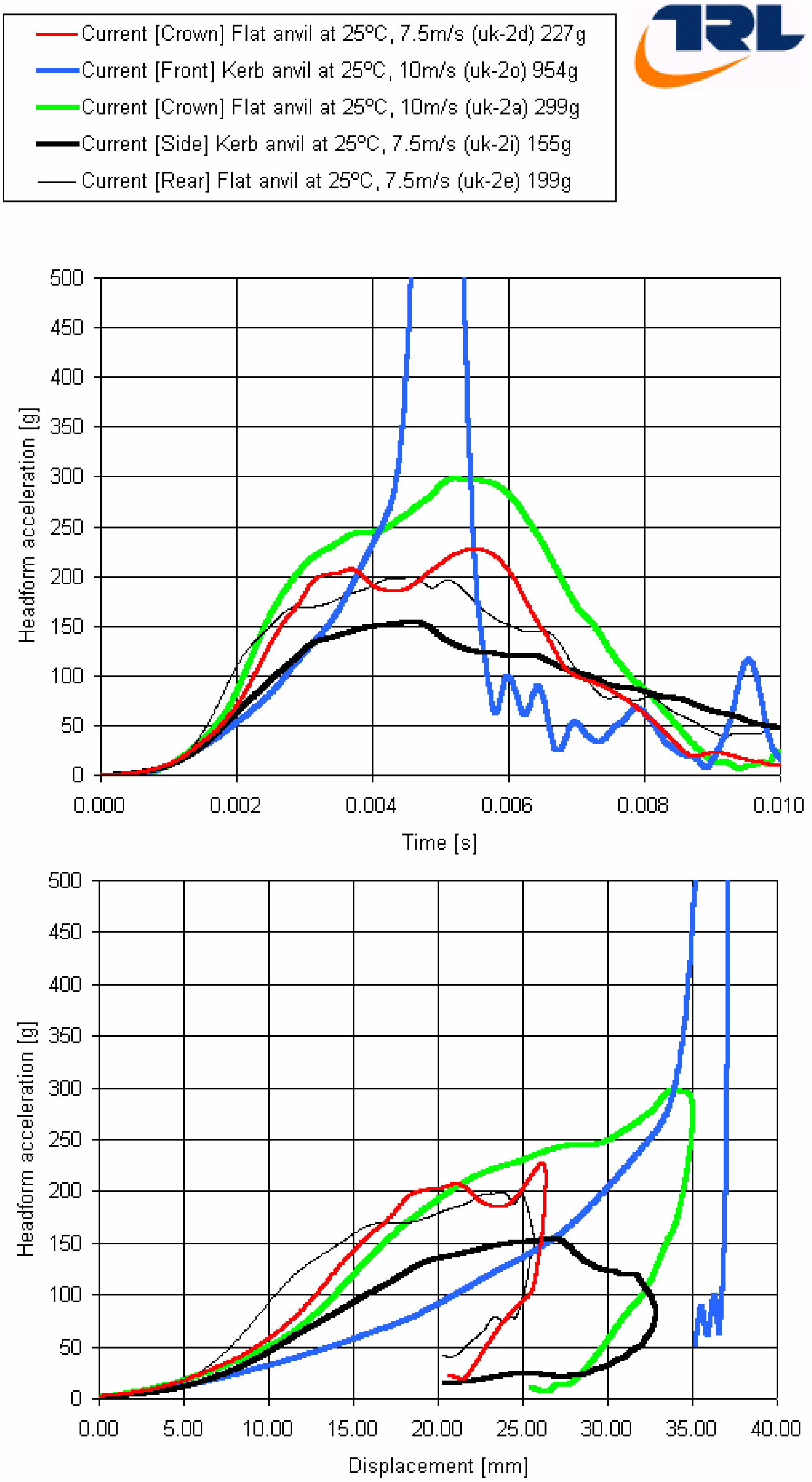


Figure C14. Impact performance of current full-geometry helmet to ECE Regulation 22-05

Appendix F. Advanced helmet concepts

(i) TRL-DFT (S100L/VF)

(ii) FIA 8860-2004

(iii) Phillips Helmets Ltd

Formula One Protective Helmet

A specification for advanced performance

A N Mellor

PR/SE/294/01

FIA - Geneva

TRL Limited

PROJECT REPORT TRL PR/SE/294/01

FORMULA ONE PROTECTIVE HELMET
A specification for advanced performance

A N Mellor

Prepared for:	**Project Record:**	**20/25A/0068**
	Client:	**FIA - Geneva**

Approvals

Project Manager

Quality Reviewed

CONTENTS

TERMS AND CONDITIONS

"This information is released to you in order that you may investigate and prepare, in collaboration with the FIA through TRL, the manufacture of helmets to satisfy a future FIA Competition Performance Requirement incorporating tests of greater severity than the standards presently approved by the FIA.

The licence to exploit TRL / FIA developed technology in the design and manufacture of such helmets will be granted without payment of royalties, on the understanding that exclusivity cannot be claimed for designs directly derived from that development work.

Any reference to an FIA Competition Performance Requirement in connection with helmets will be subject to the successful completion of an FIA homologation process. Precise details of the procedures, labelling and wording and the way in which the FIA should be referred to will be available from Mr Ian Brown at the FIA in Geneva at such time as the FIA Performance Requirement is finalised."

Although the information is released without payment, both TRL and CFT reserve the right to charge for meetings, consultancy and any other services associated with the transfer of this information. All enquiries should be directed to TRL and a copy of TRL's contact details and current fee rates are provided in Appendix E.

1. INTRODUCTION

The aim of this research programme was to improve the performance of protective helmets for Formula One. The strategy was to develop a prototype helmet, which addresses the specific requirements of the Formula One environment, and which exceeds the performance of current Formula One homologated helmet designs. A technical standard will be proposed, based on the performance of this prototype helmet. The FIA may implement this new Standard to ensure that the drivers are equipped with the state-of-the-art protective headgear. A provisional draft of the requirements of this standard is provided in Appendix D.

This research was supported by an extensive programme of work to analyse and reconstruct Formula One accidents, which occurred between 1994 and 2000, and resulted in a head impact or a head injury. This work is reported in an SAE paper 00MSV-37

At the end of the first phase of this research, TRL composed a technical specification for the design and construction of the FIA F1 helmet shell. The prototype helmet aimed to achieve improved protection from linear impact, oblique impact, crushing loads, penetration injuries and impacts to the visor and chinguard. It was also a target to reduce the overall mass of the helmet. TRL proposed that this could be achieved, in part, with a laminate sandwich helmet shell, constructed using the latest composite technology. A copy of the original specification for the shell structure is provided in Appendix A. TRL worked closely with two expert composite groups, Carbon Fibre Technologies Ltd (CFT) and the Structural Materials Centre at the Defence and Evaluation Research Agency (DERA), to produce shell structures to TRL's specification. The structures chosen were developed by Carbon Fibre Technologies Ltd and a number of full geometry protective helmets were produced which achieved the objectives of this programme. The construction specification of the best-solution FIA F1 prototype helmet is detailed in this report.

2. SPECIFICATION FOR FIA F1 PROTOTYPE HELMET SHELL

2.1 General

The linear impact performance of the helmet was improved, in part, by developing a significantly stiffer and stronger shell, that would resist excessive shell deflections during impact and thus transmit the loads more efficiently to the energy absorbing liner. The oblique impact performance was improved by reducing the dynamic coefficient of friction between the helmet surface† and the impact surface and also by reducing the normal contact force. The crush performance of the helmet was improved, in part, by a shell which was significantly stiffer, but was able to tolerate large deformations whilst absorbing increased energy levels, without transmitting injurious loads to the driver's head. The penetration performance was improved, in part, by the stiffer and stronger shell, which would absorb energy locally, and transmit loading to the energy-absorbing liner system.

† It should be noted that the addition of paint or logos to the helmet surface may alter the frictional performance

2.2 Mass and thickness

It was intended that the mass of the helmet should not be greater than current designs and the mass of the FIA F1 prototype helmet shell was 750g which corresponds to a total helmet mass of 1300g. The thickness of the shell was 3.2mm.

2.3 Structural performance

The FIA F1 prototype shell laminate achieved the structural performance of the specification defined in Appendix A. If a helmet manufacturer chooses to develop an alternative laminate configuration, TRL would advise that the structure should achieve this specification.

2.4 Laminate specification for FIA F1 prototype helmet shell

TRL/CFT developed three principal laminate configurations which achieved the structural requirements for the advanced FIA F1 helmet shell. These were:

(1) Carbon-kevlar sandwich
(2) Carbon sandwich
(3) Solid carbon laminate

However, the best solution† for this application was found to be the solid carbon laminate. A specification for a composite helmet shell, using the solid carbon laminate, is provided in Appendix D. When a helmet system was constructed using this solid carbon laminate, with an FIA F1 prototype helmet liner as defined in section 3, the requirements of the provisional FIA standard were exceeded.

† the best solution was agreed by careful consideration of four basic parameters: (1) performance (2) mass (3) thickness (4) consistency

3. SPECIFICATION FOR FIA F1 PROTOTYPE HELMET LINER

3.1 General

The impact performance of the helmet was improved by optimising the compatibility between shell and energy-absorbing liner. The prototype shell was significantly stiffer than current designs and, therefore, the liner could easily be optimised. The best solution prototype liner was a hybrid system with four sections: (1) main (2) crown (3) comfort padding (4) chinguard

3.2 Mass and Thickness

The mass of the liner was 100g and the thickness was 40mm.

3.3 Energy absorbing performance

The nominal stiffness of the three sections of helmet liner were as follows:
Section 1 (main) 0.46N/mm^2
Section 2 (crown) 0.38N/mm^2
Section 3 (comfort padding) 0.50N/mm^2 at 5m/s (visco-elastic)
Section 4 (main) 0.46N/mm^2

3.4 FIA specification for F1 prototype helmet liner

The specification for the FIA F1 prototype helmet liner is provided in Appendix C. When a helmet system was constructed using this prototype liner, with an FIA F1 prototype helmet shell as defined in section 2, the requirements of the provisional FIA standard were exceeded.

4. PERFORMANCE OF FIA F1 PROTOTYPE HELMET

The data provided in table 1 below compares the performance of the FIA F1 prototype helmet with that of leading Snell SA95/00 homologated Formula One helmets.

Table 1. Comparison of current Snell SA95/00 and FIA F1 prototype helmets

Parameter	**Snell SA95/00 helmets**	**FIA F1 prototype helmet**
Mass [kg]	1.38 (best practice)	1.30
Linear impact at 7.5m/s	270g onto flat anvil	200g onto all anvils
Linear impact at 10m/s	>500g onto hemi anvil	250g onto all anvils
Dynamic crush 14m/s (250J)	72mm	66mm (based on skull cap data)
Penetration	3m drop	+4m drop
Oblique impact at 8.5m/s	6,000rad/s^2	4,500rad/s^2

APPENDIX A

SPECIFICATION FOR FIA F1 HELMET SHELL LAMINATE

Proposed by TRL during Phase One of this programme in 1997

Thickness	Maximum of 10mm
Mass	Maximum of 930g full-shell
In-plane tensile strength	Peak tensile stress will occur at the *inner surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
In-plane compressive strength	Peak compressive stress will occur at the *outer surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
In-plane bending stiffness	15 times as stiff as 3mm thick GRP (or 5mm unreinforced polycarbonate).
Thru-thickness compression strength*	Transmission of local compressive force without causing excessive dimpling to the outer skins. Peak compressive stress in region of 40N/mm².
Operating conditions	-20°C to +50°C with extremes of moisture

TRL proposes that in order to achieve these objectives, a sandwich construction is required. The sandwich will comprise of relatively thin (<2mm) composite outer and inner skins, separated by a thicker (3mm to 6mm) core. For further information or clarification please contact TRL.

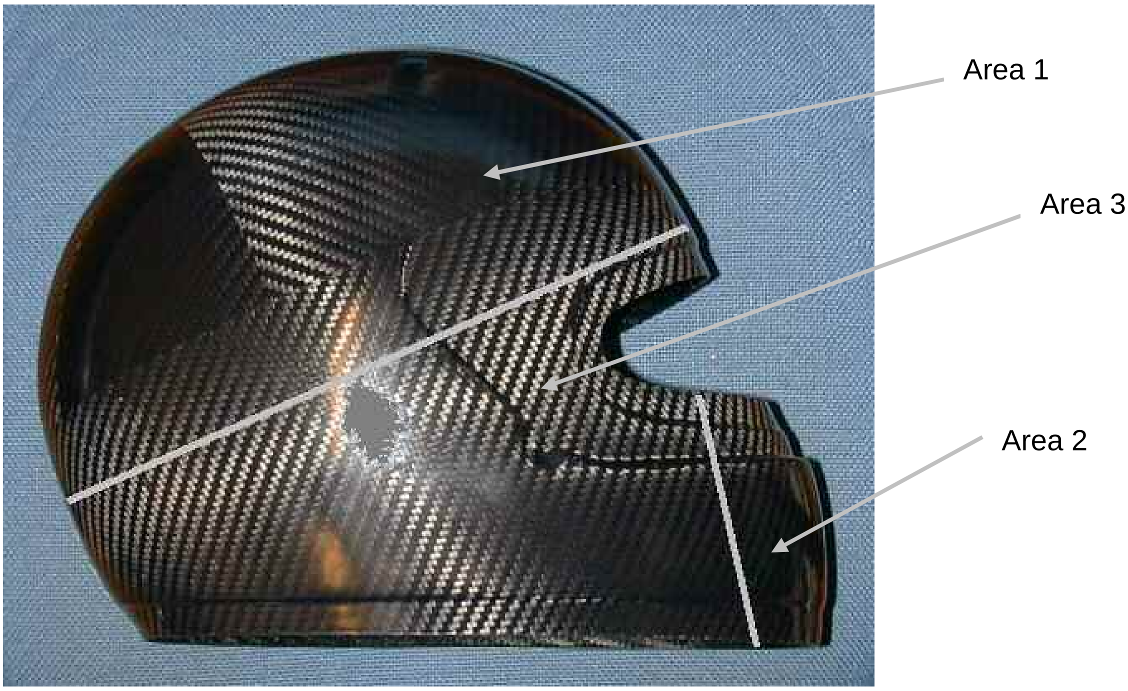
* During a linear impact onto a rigid surface, the shell may be required to transmit forces as high as 15,000N. If the surface has a profile such as the Snell SA95 edge anvil, the contact area between the outer skin of the shell and the impact surface is minimal. It is calculated that the thru-thickness compressive stress during such an impact will be in the region of 40N/mm². If the structure is a sandwich, the core material, which may be 'softer' than the skins, must be able to resist this local stress without significant deformation. If the core material were to compress significantly, the effective thickness of the web of the structural sandwich would be reduced and, therefore, the bending stiffness would be greatly decreased.

APPENDIX B

Carbon Fibre Technologies Ltd

SPECIFICATION FOR FIA F1 PROTOTYPE HELMET SHELL

(to be used in conjunction with FIA F1 prototype helmet liner-see Appendix C)



Area 1	13 plys carbon as per table B1
Area 2	As per Area 1, stagger plys out onto Area 3 over 25mm
Area 3	6 plys carbon. Ply Nos 1-3 and 11-13 inclusive, as per Table B1

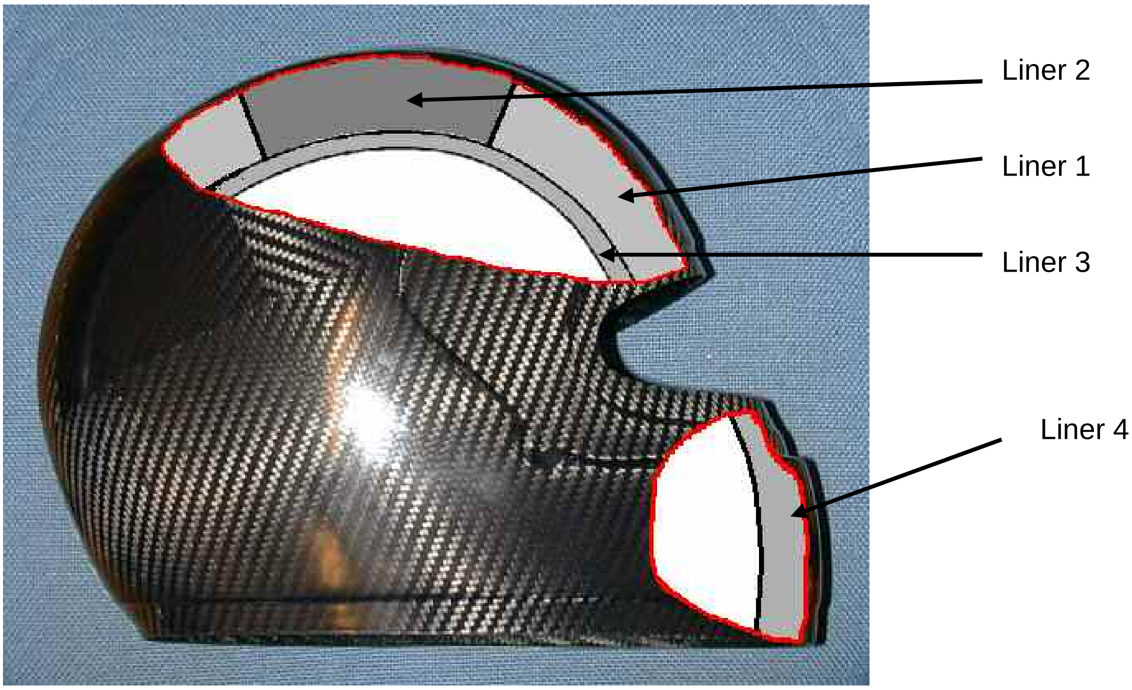
Table B1. Laminate Specification developed by Carbon Fibre Technologies Ltd

Ply No.	Material	Orientation
1	Carbon 200gsm 2x2 Twill T800 Toughened epoxy system	0/90
2	“	±45
3	“	0/90
4	“	±45
5	“	0/90
6	“	±45
7	“	0/90
8	“	±45
9	“	0/90
10	“	±45
11	“	0/90
12	“	±45
13	“	0/90

APPENDIX C

SPECIFICATION FOR FIA F1 PROTOTYPE HELMET LINER

(to be used in conjunction with FIA F1 prototype helmet shell -see Appendix B)



Liner 1.	Expanded bead polystyrene 30g/l 40mm thick
Liner 2.	Expanded bead polystyrene 25g/l 40mm thick
Liner 3.	Open cell, visco-elastic foam (under development)
Liner 4.	Expanded bead polystyrene 30g/l 20mm thick (under development)

APPENDIX D

PROVISIONAL REQUIREMENTS FOR FIA TEST SPECIFICATION FOR FORMULA ONE PROTECTIVE HELMETS

Parameter	SNELL SA2000	FIA SPECIFICATION (PROVISIONAL)
Conditioning	-10'C +50'C	-10'C +50'C
Impact surfaces	Flat/Hemi/Bar/Edge	Flat/Hemi/Bar/Edge
Impact velocity	7.7m/s (150J)	7.5m/s and 10m/s
Criteria	300g	250g (@7.5m/s) and 275g (@10m/s) Requirement for HIC
Penetration	3kg 60' Cone (3m drop)	3kg 60' Cone (4m drop)
Visor	1g pellet 500km/h	1g pellet 500km/h
Chinguard	5kg 3.5m/s	Impact at 7.5m/s
Oblique	Not included	Based on ECE Reg 22-05
Crush	Not included	Dynamic crush test (pending)

Appendix F. Advanced helmet concepts

(i) TRL-DFT (S100L/VF)

(ii) FIA 8860-2004

(iii) Phillips Helmets Ltd

The following documentation is a reproduction of marketing information provided by Phillips Helmets relating to the Phillips Head Protection System (PHPS) helmet. By inclusion, the authors are not endorsing the product or the validity of any claims made herein.

PHILLIPS HEAD PROTECTION SYSTEM

"Brain injury is unpredictable in its consequences. Brain injury affects who we are, the way we think, act, and feel. It can change everything about us in a matter of seconds."

Brain Injury Association of America, 2004

"…head injury has now become the most common cause of death among young adults in developed countries."

Head Injury Management, Marks and Lavy, 1992

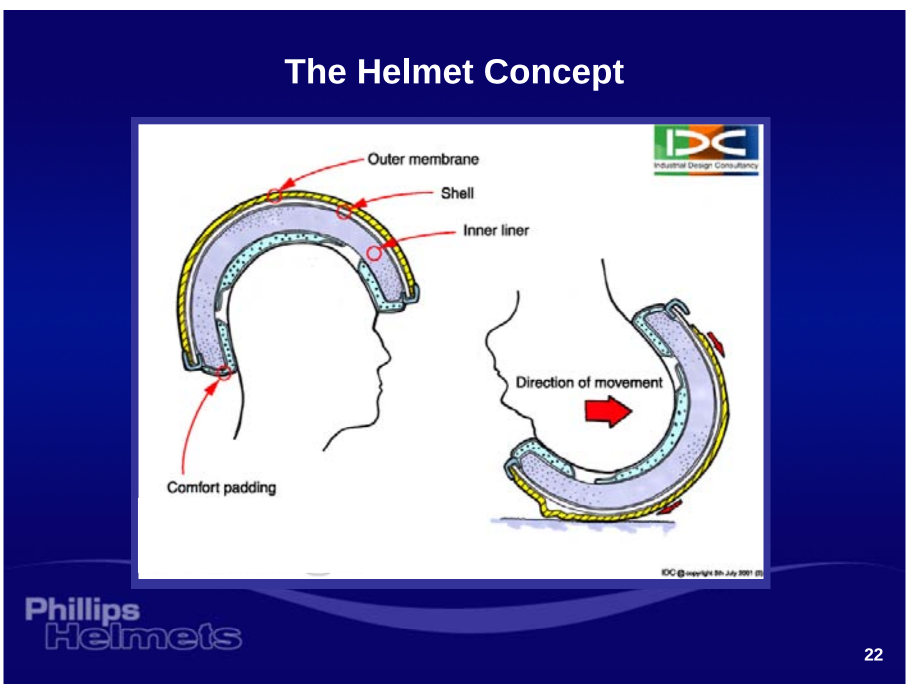
Phillips Helmets Ltd
2nd April 2006

Introduction

The Phillips Head Protection System (PHPS) was developed in response to the continuing incidence of head injury from motorcycle accidents and in recognition of the fact that conventional helmets provided no specific protection against rotational forces. Whereas linear forces acting on the brain cause local damage which is relatively easily accessible at operation, rotational forces cause stress and sheer forces throughout the brain substance resulting in microscopic haemorrhages and rupture of nerve fibres which are not accessible to any direct intervention.

Dr Ken Phillips, the inventor of this system, sought to apply the natural systems of brain protection found in the human head to the protection against rotational forces in helmet construction. He identified the scalp as being a major element of this system since, on impact, it slides over the skull and, so long as it continues this motion, no rotational forces are being imparted to the skull and its contents.

This was reproduced in the PHPS by the superimposition of a lubricated elastomeric membrane on the exterior surface of a conventional helmet shell. The concept is shown in the following diagram

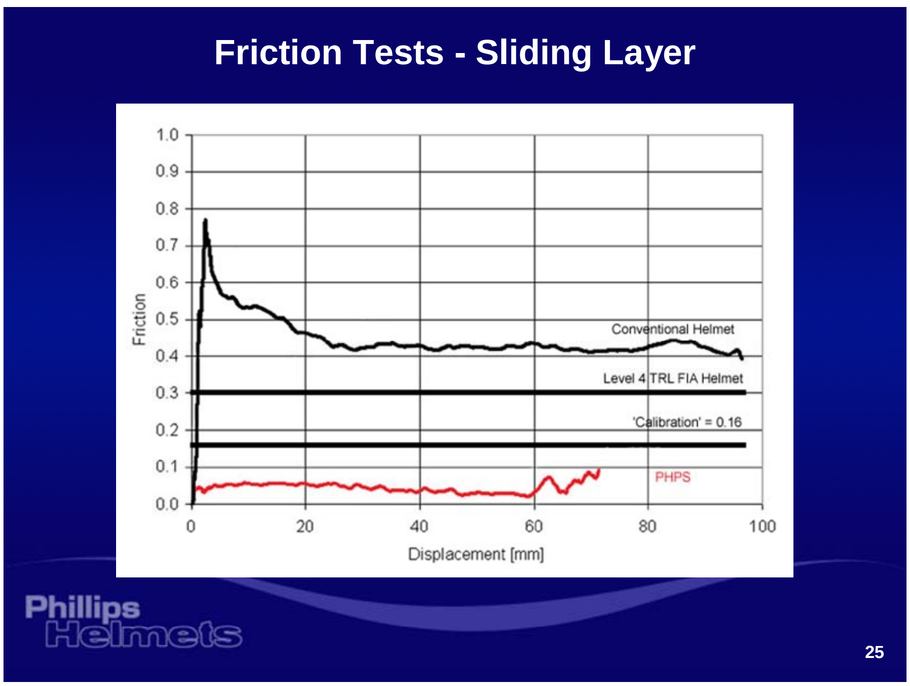


Development

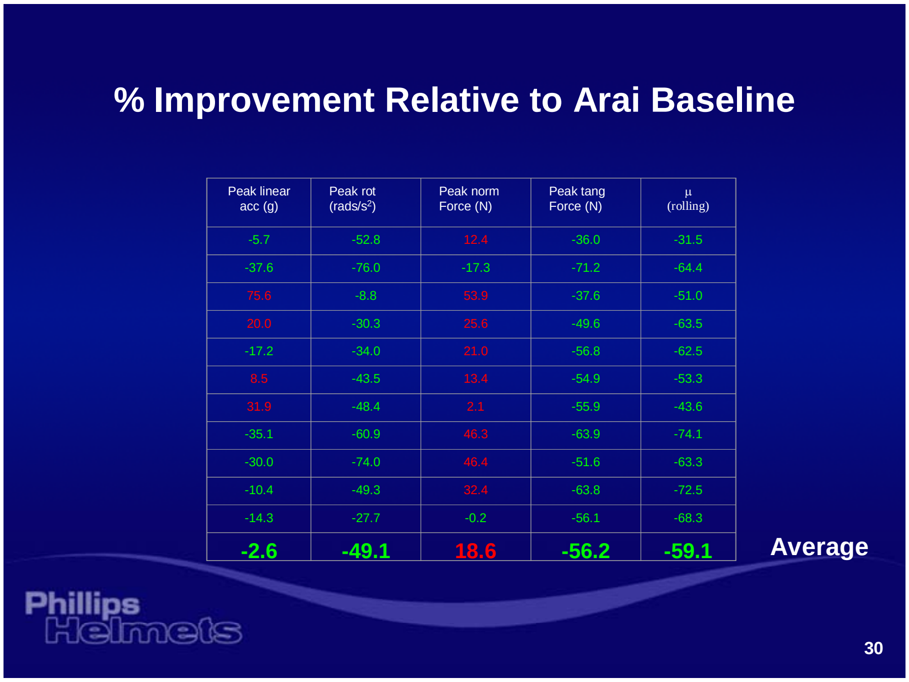
All design aspects of the PHPS were undertaken by Industrial Design Consultancy Limited and TRL was responsible for all testing and development.

Finite Element Analysis – the system was initially simulated on a head and helmet complex produced by Strasbourg University and the results indicated that, with zero friction and perfect materials reductions in rotational forces of up to 90% were possible.

Laboratory Testing – "Coupon" testing of flat substrates on a friction measuring rig produced by TRL was used for material selection of both shell and membrane material and the testing of both lubricants and fastening systems. With the objective of matching the best linear performance available from conventional helmets and adding the advantage of protection against rotation, a strong carbon Kevlar material was chosen for the shell and either one of two TPE's have been chosen for the final membrane material.
Results of these tests are shown in the following diagram



Testing of full geometry helmets by TRL showed an overall improvement of approximately 50-60% in measured rotational forces. The summary of their findings are set out in the following table.



	Peak linear acc (g)	Peak rot (rads/s²)	Peak norm Force (N)	Peak tang Force (N)	μ (rolling)
	-5.7	-52.8	12.4	-36.0	-31.5
	-37.6	-76.0	-17.3	-71.2	-64.4
	75.6	-8.8	53.9	-37.6	-51.0
	20.0	-30.3	25.6	-49.6	-63.5
	-17.2	-34.0	21.0	-56.8	-62.5
	8.5	-43.5	13.4	-54.9	-53.3
	31.9	-48.4	2.1	-55.9	-43.6
	-35.1	-60.9	46.3	-63.9	-74.1
	-30.0	-74.0	46.4	-51.6	-63.3
	-10.4	-49.3	32.4	-63.8	-72.5
	-14.3	-27.7	-0.2	-56.1	-68.3
Average	-2.6	-49.1	18.6	-56.2	-59.1

These results show an increase in protection against rotational forces of between 49 and 59% by comparison with conventional helmets

Potential Benefits

The reduction in head injuries through this added protection is speculative and subject to interpretation. In the Addendum to their report on the testing TRL are of the opinion that in the UNECE area, if all riders were to wear the PHPS, it could produce a favourable outcome in approximately 4,300 deaths annually. The significance of this finding in the UK is set out in the following table.

> Note: The following table presents the number of Two-Wheeled Motor Vehicle (TWMV) casualties in the UK, by casualty type, for 2002 (source RAGB 2003). Also shown are Department for Transport injury cost figures, based on June 2001, adjusted for inflation to June 2006.

Casualty Severity	Number (2002)	Cost per incident (adjusted for June 2006)
Fatal	609	£1.57m
Serious	6,838	£177k
Slight	22,495	£13.6k

Based on an estimate that:

- 20% of deaths would be converted to serious injuries.
- 60% of serious injuries would experience benefit – of these it is possible that 15% of these would be converted to slight injury.
- 10% of slight injuries would be avoided.

Based on these values, the potential UK savings would be approximately 120 lives and £360m in costs.

Applications

The PHPS is a system and not simply a design for a motorcycle helmet. Since rotation is significant in virtually all head impacts the PHPS is relevant to all head hazard situations ranging from industrial hard hats, through all sports where protection is worn to some military applications.

The Phillips Head Protection System can bring benefits in all head impacts with a high frictional surface.

The PHPS role in Motorsport

Because of recent introductions into safety regulations in Formula 1, particularly the introduction of the HANS system, there is probably not a role for the PHPS in this setting.

In all other types of Motorsport where high friction impact is a potential, there is probably a significant place for the PHPS. No data is available and it is the intention of Phillips Helmets Limited to undertake research in this area. A balance has to be struck between the added weight of the membrane and the protection against rotation afforded by its presence. This could be an issue of substantial importance and should be the subject of future research, particularly in juvenile participants.

Motorcycle racing – the place of the PHPS in this sport is one of its prime applications.

Other applications – the successful development of the PHPS in its motorcycle format will facilitate its application in other areas of great need such as American football, where 20% of high school participants suffer concussion in any one season. A continuing toll of head injury in the industrial field is another area where there are great potential benefits. Although the more general wearing of bicycle helmets has substantially improved the head injury situation, there is still a major need for the further improvement which the PHPS can afford.

Facilitating the development of the Phillips motorcycle helmet can bring major relief from injuries in many fields.

Current state of development

It has taken many years of intensive research to identify and develop a material with sufficient characteristics of stretch, durability and, most particularly, light weight. The final choice now lies between two particular elastomers and the final stages of evaluation of both lubricants and fixation methods are planned for the immediate future.

The PHPS role in Motorsport

Because of recent introductions into safety regulations in Formula 1, particularly the introduction of the HANS system, there is probably not a role for the PHPS in this setting.

In all other types of Motorsport where high friction impact is a potential, there is probably a significant place for the PHPS. No data is available and it is the intention of Phillips Helmets Limited to undertake research in this area. A balance has to be struck between the added weight of the membrane and the protection against rotation afforded by its presence. This could be an issue of substantial importance and should be the subject of future research, particularly in juvenile participants.

Motorcycle racing – the place of the PHPS in this sport is one of its prime applications.

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Facilitating the development of the Phillips motorcycle helmet can bring major relief from injuries in many fields.

Current state of development

It has taken many years of intensive research to identify and develop a material with sufficient characteristics of stretch, durability and, most particularly, light weight. The final choice now lies between polyurethane and Santoprene and the final stages of evaluation of both lubricants and fixation methods are planned for the near future.

Whilst funding is necessary for these activities, Santoprene can only be produced by injection moulding and if this becomes a necessity heavy expenditure will be necessary for one tool to produce development membranes and a further one for a production prototype.

Appendix G. Consumer Information Scheme

(i) Test Protocols

(ii) Assessment Protocols

(iii) Results Presentation

Appendix G. Consumer Information Scheme

(i) <u>Test Protocols</u>

(ii) Assessment Protocols

(iii) Results Presentation

TRL Limited
2005

TEST PROCEDURES FOR THE ASSESSMENT OF

MOTORCYCLE HELMET SAFETY PERFORMANCE

Final Draft. Issue 1.2

9 March 2006

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TRL Limited

TEST PROCEDURES FOR THE ASSESSMENT OF

MOTORCYCLE HELMET SAFETY PERFORMANCE

A N Mellor

Prepared for: **Project Record:** **S0232VF**

Approvals

Project Manager

Quality Reviewed

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CONTENTS

FOREWORD

These test procedures are based on the test specification that was agreed during the workshop on future helmets and visors held in London on 21st November 2003. The test procedures take account of the recommendations reported by the European Co-operation in the Field of Scientific and Technical Research (COST 327) during 2001, together with the performance of an advanced helmet developed by TRL on behalf of the UK Department Transport within project S100L and the FIA 8860-2004 helmet specification.

The new test procedures will permit objective evaluation and comparison of the protection provided by a wide selection of motorcycle helmet models. The results may be published to provide consumers and end-users with an independent and objective assessment of the safety performance. Furthermore, it is intended that the new procedures will encourage significant improvements to the protection afforded by future helmet designs.

1. SCOPE

This document defines the test procedures for assessment of motorcycle helmet safety performance. The assessment protocols are presented in the document “Assessment Protocol for the Assessment of Motorcycle Helmet Safety Performance”.

The aim of the test procedures are to provide appropriate methodologies for the assessment of all Motorcycle helmet designs that are currently available in Europe. The procedures also aim to be appropriate for assessing advanced designs such as low friction and sliding membrane helmets.

2. MHAP TEST SCHEDULE

2.1 General

Each helmet model and size will be subjected to fifteen (15) tests as described below. The test results will be processed to determine a performance rating for each helmet model and size.

2.2 Helmet Sizes

Five sizes of each helmet model shall be tested, with the exception of surface friction and projection strength. These shall be size A (500mm), size E (540mm), size J (570mm), size M (600mm) and size O (620mm). Four helmet samples will be required in each size. Thus a total of twenty helmets are required for each helmet model.

2.3 Procurement of Test Samples

The helmets must be procured from an outlet or store which is chosen to ensure that the manufacture cannot influence the selection of test samples.

3. HELMET RECEIPT PROCESS

The helmet receipt process shall include the following tasks for each helmet model and size.

- digital photograph
- mass
- recording of all available manufacturer's data on test sample labels (serial number, batch number, date of manufacture, certification levels)
- tagging of helmet samples (both overtly and covertly) with a unique identification number

4. TEST PROCEDURES

Linear impact tests shall be conducted in accordance with the impact procedures of ECE Regulation 22-05, section 7, with the following selections or modifications.

- A twin-wire guided headform system fitted with a uni-axial accelerometer shall be used
- The equipment shall enable the measurement linear acceleration in accordance with SAE J211 CFC1000.
- The total mass of the headforms including the carriage shall conform to ECE Regulation 22-5 as follows. The mass of the carriage must not be greater than 1.5kg for all headform sizes.

  Size A 500mm 3.1± 0.05kg
  Size E 540mm 4.1± 0.05kg
  Size J 570mm 4.7± 0.05kg
  Size M 600mm 5.6± 0.05kg
  Size O 620mm 6.1± 0.05kg

- The geometry of the headforms shall conform to BS6489 (EN960 or ISO DIS 6220) extending down at least to line H-H.
- The tolerance on impact velocity shall be +2% -0%.
- All impacts shall be located within Ø10mm of the test site defined by ECE R22-05.

4.1 Linear Impact Test – Low Speed
Flat Anvil - Front

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05.
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.2 Linear Impact Test – Low Speed
Flat Anvil - Side

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.3 Linear Impact Test – Low Speed
Flat Anvil – Crown

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.4 Linear Impact Test – Low Speed
Flat Anvil - Rear

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.5 Linear Impact Test – High Speed
Kerbstone Anvil - Front

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.6 Linear Impact Test – High Speed
Kerbstone Anvil - Side

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.7 Linear Impact Test – High Speed
Kerbstone Anvil - Crown

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.8 Linear Impact Test – High Speed
Kerbstone Anvil - Rear

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.9 Linear Impact Test – High Speed
Flat Anvil - Front

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.10 Linear Impact Test – High Speed

Flat Anvil - Side

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.11 Linear Impact Test – High Speed

Flat Anvil - Crown

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.12 Linear Impact Test – High Speed

Flat Anvil - Rear

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.13 Surface Friction Test

'Guided' Method A – Left Side

The surface friction test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1), with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- The impact site shall be the left side of the helmet within the test area defined by ECE Regulation 22-05
- The impact direction shall be such that the helmet is moving backwards immediately before the impact
- The equipment shall enable the measurement of both normal and tangential forces at the impact surface in accordance with SAE J211 CFC1000.

4.14 Surface Friction Test

'Guided' Method A – Right Side

The surface friction test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1), with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- The impact site shall be the right side of the helmet within the test area defined by ECE Regulation 22-05
- The impact direction shall be such that the helmet is moving forward immediately before the impact

- The equipment shall enable the measurement of both normal and tangential forces at the impact surface in accordance with SAE J211 CFC1000.

4.15 Projection Strength Test – For Motor Sport Applications Only

'Guided' Method A

The projection strength test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1) Method A, with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- As many tests as necessary shall be conducted in order to evaluate ALL notable features such as visor fittings, screws, press studs, steps in the shell surface.
- The impact direction shall be such that the helmet is moving forwards immediately before the impact if this is appropriate. If this direction is not appropriate, any appropriate direction may be chosen.

Table 1. Summary of test specification and recommended test sequence

Test number	Test sequence	Test type	Helmet number	Test site
4.1	1	6m/s Impact – Flat	1	Front
4.2	2	6m/s Impact – Flat	1	Side L
4.3	3	6m/s Impact – Flat	1	Crown
4.4	4	6m/s Impact – Flat	1	Rear
4.5	5	9.5m/s Impact – Kerbstone	2	Front
4.6	6	9.5m/s Impact – Kerbstone	2	Side L
4.7	7	9.5m/s Impact – Kerbstone	2	Crown
4.8	8	9.5m/s Impact – Kerbstone	2	Rear
4.9	9	9.5m/s Impact – Flat	3	Front
4.10	10	9.5m/s Impact – Flat	3	Side L
4.11	11	9.5m/s Impact – Flat	3	Crown
4.12	12	9.5m/s Impact – Flat	3	Rear
4.13	13	Surface friction	4	Left
4.14	14	Surface friction	4	Right
4.15	15+	Projection Strength	4	All features

5. RESULTS

5.1 The results for each helmet model and size will be presented in a colour A4 sheet, to include the following information:

1. Pre-test photograph of the helmet
2. Make, model, type, size (mm), mass (g), approval standards and approval country
3. Image (photograph of drawing) of the test apparatus
4. acceleration history (g,ms) for each of tests 1 to 12 showing peak g and HIC
5. acceleration vs displacement (g, mm) for each of tests 1 to 12
6. Force history, normal and tangential, (N,ms) for each of tests 13 to 14 showing peak normal and tangential force
7. * Force history, normal and tangential, (N,ms) for all tests in series 15 showing peak normal and tangential force

* Motor Sport applications only

5.2 The ASC data for each test, filtered at CFC1000, will be required for the analysis prescribed by the document “Assessment Protocol for the Assessment of Motorcycle Helmet Safety Performance”.

Appendix G. Consumer Information Scheme

(i) Test Protocols

(ii) Assessment Protocols

(iii) Results Presentation

TRL Limited

ASSESSMENT PROTOCOL FOR

MOTORCYCLE HELMET SAFETY PERFORMANCE

A N Mellor

Prepared for: Project Record: S0232VF

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CONTENTS

FOREWORD

The test procedures which accompany this assessment protocol are based on the test specification that was agreed during the workshop on future helmets and visors held in London on 21st November 2003. The procedures take account of the recommendations reported by the European Co-operation in the Field of Scientific and Technical Research (COST 327) during 2001, together with the performance of an advanced helmet developed by TRL on behalf of the UK Department for Transport within project S100L/VF and the FIA 8860-2004 helmet specification.

The new test procedures and assessment protocol will permit objective evaluation and comparison of the protection provided by a wide selection of motorcycle helmet models. The results may be published to provide consumers and end-users with an independent and objective assessment of the safety performance. Furthermore, it is intended that the new procedures will encourage significant improvements to the protection afforded by future helmet designs.

A safe helmet must provide good protection during both high severity and low severity impacts. The risk of injury increases rapidly with impact severity, but the exposure reduces significantly, and the vast majority of head impacts cause slight or moderate rather than serious or fatal injuries. Thus, whilst striving to improve protection during severe accidents, great care must be taken not to worsen the situation during the less severe accidents. Although the <u>risk</u> of injury during less severe accidents may be low, due to the large exposure, even a small <u>risk</u> could result in many numbers of riders being seriously or fatality injured.

For the purpose of this assessment, the injury risk function is based on COST 327 data but takes account of other relevant published data. The exposure data is based on RAGB 2001 which corresponds closely to the time of the COST 327 action.

This protocol enables the performance of a helmet to be determined with respect to a broad range of accident conditions and severities, and the Final Assessment corresponds to the number of fatalities that may occur, each year, on UK roads, if all riders and pillion passengers wore such helmets.

1. SCOPE

This document defines the assessment protocol for determining the performance ratings of helmets that have been subjected to tests as defined by the “TEST PROCEDURES FOR THE ASSESSMENT OF MOTORCYCLE HELMET SAFETY PERFORMANCE”. The protocol has been developed by the Transport Research Laboratory on behalf of the United Kingdom Department for Transport.

2. MHAP TEST SCHEDULE

2.1 General

Each helmet model and size will be subjected to fourteen (14) tests as described in the Test Procedures for Assessment of Motorcycle Helmet Safety Performance. The test results will be processed to determine a performance rating for each helmet model and size.

2.3 Procurement of Test Samples

The helmets must be procured from an outlet or store which is chosen to ensure that the manufacture cannot influence the selection of test samples.

3. ASSESSMENT

3.1 General

Each helmet model and size will be subjected to fourteen (14) tests including linear impacts at 6m/s, linear impacts at 9.5m/s and surface friction tests. The test results will be assessed, as detailed in section 4, to determine a performance rating for each given test. The overall assessment rating for each helmet model and size will be calculated as detailed in section 5.

3.2 Helmet Sizes

[Three] sizes of each helmet model (Small-540mm, Medium-570mm and Large-600mm) shall be evaluated in all of the tests with the exception of the Surface Friction tests which shall be conducted on size Medium-570mm only and the results shall be applicable to all sizes.

4. ASSESSMENT PROTOCOL

4.1 Test Results

In accordance with the Test Specification, the following tests will be conducted on each helmet model.

Table 1. Test Matrix

Test number	Test type	Test site
1	6m/s Impact – Flat	Front
2	6m/s Impact – Flat	Side L
3	6m/s Impact – Flat	Crown
4	6m/s Impact – Flat	Rear
5	9.5m/s Impact – Kerbstone	Front
6	9.5m/s Impact – Kerbstone	Side L
7	9.5m/s Impact – Kerbstone	Crown
8	9.5m/s Impact – Kerbstone	Rear
9	9.5m/s Impact – Flat	Front
10	9.5m/s Impact – Flat	Side L
11	9.5m/s Impact – Flat	Crown
12	9.5m/s Impact – Flat	Rear
13	Surface friction	Left
14	Surface friction	Right

4.2 Peak acceleration as function of impact velocity

For each linear impact test (tests 1 to 12), the acceleration history data shall be processed, by integration, with respect to displacement rather than time, to generate the peak acceleration (g) as a continual function of velocity (m/s) from 0m/s to the actual impact velocity. These results shall be presented in graphical form - an example is presented in Figure 1 and a flow chart demonstrating the methodology is provided in Figure 2.

4.3 Peak acceleration for each accident severity (Linear Impact)

Module 1 defines six accident severities in terms an equivalent test speed. The equivalent test speed represents the normal impact velocity during a laboratory test onto a rigid anvil.

With reference to 4.2, for each helmet site (front, side, crown and rear) and each impact anvil (flat and kerb), the maximum acceleration shall be determined for each accident severity as follows:

Note: for equivalent test speeds of 9.5m/s, the actual results from the 9.5m/s tests shall be used.

Table 2. Impact Anvil - Flat

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed [m/s]	3.2	5.0	6.6	7.9	8.8	9.5
Maximum acceleration – front (g)	F1	F2	F3	F4	F5	F6
Maximum acceleration – side (g)	F7	F8	F9	F10	F11	F12
Maximum acceleration – crown (g)	F13	F14	F15	F16	F17	F18
Maximum acceleration – rear (g)	F19	F20	F21	F22	F23	F24

Table 3. Impact Anvil - Kerb

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Kerb anvil equivalent test speed [m/s]	3.7	5.4	6.8	8.3	9.0	9.5
Maximum acceleration – front (g)	K1	K2	K3	K4	K5	K6
Maximum acceleration – side (g)	K7	K8	K9	K10	K11	K12
Maximum acceleration – crown (g)	K13	K14	K15	K16	K17	K18
Maximum acceleration – rear (g)	K19	K20	K21	K22	K23	K24

Table 4. Impact Anvil – Flat (data from linear impacts to be used for oblique assessment)

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed [m/s]	2.7	4.0	5.2	7.0	8.1	9.5
Maximum acceleration – front (g)	A1	A2	A3	A4	A5	A6
Maximum acceleration – side (g)	A7	A8	A9	A10	A11	A12
Maximum acceleration – crown (g)	A13	A14	A15	A16	A17	A18
Maximum acceleration – rear (g)	A19	A20	A21	A22	A23	A24

4.4 Helmet coefficient of friction during oblique impact

The results from the surface friction tests 13 and 14 shall be processed to determine the effective coefficient of friction, for each test, as follows:

(i) The peak normal force shall be determined F_normal_max

(ii) The coefficient of friction (ie the tangential force divided by the normal force) shall be calculated for all values where the normal force exceeds 0.7* F_normal_max.

(iii) The average value of the coefficient of friction shall be calculated for the cumulative period during which the normal force exceeds 0.7* F_normal_max.

The two results will be referred to as COF1 and COF2.
The average of these two results $COF_{average} = (COF1+COF2)/2$

4.5 Peak acceleration for each accident severity (Oblique Impact)

The peak resultant linear acceleration for each accident severity, during oblique impacts, shall be calculated as follows, thus giving the results in table 5. A_N represents the normal component of the impact acceleration.

$O_N = A_N x \sqrt{}(1+COF_{average}\hat{}2)$
For all values of N from 1 to 24.

ie:
$O1 = A1 \times \sqrt{}(1+COF_{average}\hat{}2)$
$O2 = A2 \times \sqrt{}(1+COF_{average}\hat{}2)$
$O3 = A3 \times \sqrt{}(1+COF_{average}\hat{}2)$ … etc

Table 5. Impact Anvil – Oblique

Accident Severity	1	2	3	4	5	6
Maximum acceleration – front (g)	O1	O2	O3	O4	O5	O6
Maximum acceleration – side (g)	O7	O8	O9	O10	O11	O12
Maximum acceleration – crown (g)	O13	O14	O15	O16	O17	O18
Maximum acceleration – rear (g)	O19	O20	O21	O22	O23	O24

4.6 Injury risk for each accident severity (Linear and Oblique Impact)

Module 2 defines the risk of head injury with respect to head linear acceleration. The risk of injury shall be calculated for each result F1 to F24, K1 to K24 and O1 to O24 as follows, thus giving the results in tables 6, 7 and 8.

R_F_N = risk associated with acceleration F_N with reference to Module 2
For all values of N from 1 to 24

R_K_N = risk associated with acceleration K_N with reference to Module 2
For all values of N from 1 to 24

R_O_N = risk associated with acceleration O_N with reference to Module 2
For all values of N from 1 to 24

Table 6. Injury Risk – Linear impact, Flat Anvil

Accident Severity	1	2	3	4	5	6
Injury risk – front %	R_F1	R_F2	R_F3	R_F4	R_F5	R_F6
Injury risk – side %	R_F7	R_F8	R_F9	R_F10	R_F11	R_F12
Injury risk – crown %	R_F13	R_F14	R_F15	R_F16	R_F17	R_F18
Injury risk – rear %	R_F19	R_F20	R_F21	R_F22	R_F23	R_F24

Table 7. Injury Risk – Linear impact, Kerb Anvil

Accident Severity	1	2	3	4	5	6

Injury risk – front %	R_K1	R_K2	R_K3	R_K4	R_K5	R_K6
Injury risk – side %	R_K7	R_K8	R_K9	R_K10	R_K11	R_K12
Injury risk – crown %	R_K13	R_K14	R_K15	R_K16	R_K17	R_K18
Injury risk – rear %	R_K19	R_K20	R_K21	R_K22	R_K23	R_K24

Table 8. Injury Risk – Oblique Impact, Flat anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury risk – front %	R_O1	R_O2	R_O3	R_O4	R_O5	R_O6
Injury risk – side %	R_O7	R_O8	R_O9	R_O10	R_O11	R_O12
Injury risk – crown %	R_O13	R_O14	R_O15	R_O16	R_O17	R_O18
Injury risk – rear %	R_O19	R_O20	R_O21	R_O22	R_O23	R_O24

4.7 Injury number for each accident severity (Linear and Oblique Impact)

Module 3 defines the exposure for each accident severity. The injury number shall be determined by multiplying the injury risk values by the exposure values as follows, thus giving the results in tables 9, 10 and 11.

$N\_F_N = R\_F_N$ x exposure
For all values of N from 1 to 24

$N\_K_N = N\_K_N$ x exposure
For all values of N from 1 to 24

$N\_O_N = R\_O_N$ x exposure
For all values of N from 1 to 24

Where exposure =	4089	for N = 1,7,13,19
	2193	for N = 2,8,14,20
	452	for N = 3,9,15,21
	493	for N = 4,10,16,22
	492	for N = 5,11,17, 23
	21	for N = 6,12,18,24

Table 9. Injury Number – Linear impact, Flat Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – front %	N_F1	N_F2	N_F3	N_F4	N_F5	N_F6
Injury number – side %	N_F7	N_F8	N_F9	N_F10	N_F11	N_F12
Injury number – crown %	N_F13	N_F14	N_F15	N_F16	N_F17	N_F18
Injury number – rear %	N_F19	N_F20	N_F21	N_F22	N_F23	N_F24

Table 10. Injury Number – Linear Impact, Kerb Anvil

Accident Severity	1	2	3	4	5	6
Injury number – front %	N_K1	N_K2	N_K3	N_K4	N_K5	N_K6
Injury number – side %	N_K7	N_K8	N_K9	N_K10	N_K11	N_K12
Injury number – crown %	N_K13	N_K14	N_K15	N_K16	N_K17	N_K18
Injury number – rear %	N_K19	N_K20	N_K21	N_K22	N_K23	N_K24

Table 11. Injury Number – Oblique Impact, Flat anvil

Accident Severity	1	2	3	4	5	6
Injury number – front %	N_O1	N_O2	N_O3	N_O4	N_O5	N_O6
Injury number – side %	N_O7	N_O8	N_O9	N_O10	N_O11	N_O12
Injury number – crown %	N_O13	N_O14	N_O15	N_O16	N_O17	N_O18
Injury number – rear %	N_O19	N_O20	N_O21	N_O22	N_O23	N_O24

4.8 Weighting for impact site

Module 4 defines the distribution of impacts with regard to helmet location. The weighted average injury number shall be calculated as follows, thus giving the results in tables 12, 13 and 14.

N_F(1) = 0.236 x N_F1 + 0.532 x N_F7 + 0.022 x N_F13 + 0.21 x N_F19
N_F(2) = 0.236 x N_F1 + 0.532 x N_F8 + 0.022 x N_F14 + 0.21 x N_F20
N_F(3) = 0.236 x N_F3 + 0.532 x N_F9+ 0.022 x N_F15 + 0.21 x N_F21
N_F(4) = 0.236 x N_F4 + 0.532 x N_F10 + 0.022 x N_F16 + 0.21 x N_F22
N_F(5) = 0.236 x N_F5 + 0.532 x N_F11 + 0.022 x N_F17 + 0.21 x N_F23
N_F(6) = 0.236 x N_F6 + 0.532 x N_F12 + 0.022 x N_F18 + 0.21 x N_F24

N_K(1) = 0.236 x N_K1 + 0.532 x N_K7 + 0.022 x N_K13 + 0.21 x N_K19
N_K(2) = 0.236 x N_K1 + 0.532 x N_K8 + 0.022 x N_K14 + 0.21 x N_K20
N_K(3) = 0.236 x N_K3 + 0.532 x N_K9+ 0.022 x N_K15 + 0.21 x N_K21
N_K(4) = 0.236 x N_K4 + 0.532 x N_K10 + 0.022 x N_K16 + 0.21 x N_K22
N_K(5) = 0.236 x N_K5 + 0.532 x N_K11 + 0.022 x N_K17 + 0.21 x N_K23
N_K(6) = 0.236 x N_K6 + 0.532 x N_K12 + 0.022 x N_K18 + 0.21 x N_K24

N_O(1) = 0.236 x N_O1 + 0.532 x N_O7 + 0.022 x N_O13 + 0.21 x N_O19
N_O(2) = 0.236 x N_O1 + 0.532 x N_O8 + 0.022 x N_O14 + 0.21 x N_O20
N_O(3) = 0.236 x N_O3 + 0.532 x N_O9+ 0.022 x N_O15 + 0.21 x N_O21
N_O(4) = 0.236 x N_O4 + 0.532 x N_O10 + 0.022 x N_O16 + 0.21 x N_O22
N_O(5) = 0.236 x N_O5 + 0.532 x N_O11 + 0.022 x N_O17 + 0.21 x N_O23
N_O(6) = 0.236 x N_O6 + 0.532 x N_O12 + 0.022 x N_O18 + 0.21 x N_O24

Table 12. Injury Number – Flat Anvil

Accident Severity	1	2	3	4	5	6
Injury number – weighted average	N_F(1)	N_F(2)	N_F(3)	N_F(4)	N_F(5)	N_F(6)

Table 13. Injury Number – Kerb Anvil

Accident Severity	1	2	3	4	5	6
Injury number – weighted average	N_K(1)	N_K(2)	N_K(3)	N_K(4)	N_K(5)	N_K(6)

Table 14. Injury Number – Oblique Impact

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N_O(1)	N_O(2)	N_O(3)	N_O(4)	N_O(5)	N_O(6)

4.9 Weighting for impact surface

Module 5 defines the distribution of impacts with regard to impact surface. The final injury numbers shall be calculated for each accident severity as follows, thus giving the results in table 15.

N(x) = 0.384 x N_F(x) + 0.016 x N_K(x) + 0.60 x N_O(x)
For all values of x from 1 to 6

Table 15. Injury Number – Final

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N(1)	N(2)	N(3)	N(4)	N(5)	N(6)

4.10 Final Assessment

The Final Assessment for each helmet model and size shall be calculated by summing the six injury number scores as follows.

Final Assessment = N(1) + N(2) + N(3) + N(4) + N(5) + N(6)

5. PERFORMANCE RATING

The Final Assessment corresponds to the number of fatalities that may occur, each year, on UK roads, if all riders and pillion passengers wore such helmets. The results for a size medium R22-05 helmet may be considered to be baseline, thus, lower values represent lives that may be saved and higher values represent lives that may be lost.

The Final Assessment may be simplified, for instance, by using a 5 star Performance Rating as for Euro-NCAP, in which case the transfer function from the Final Assessment to the Performance Rating may be chosen to appropriately represent the range of protection provided by the helmets within the Consumer Testing Programme. This will be further discussed during the next phase of the CIS programme.

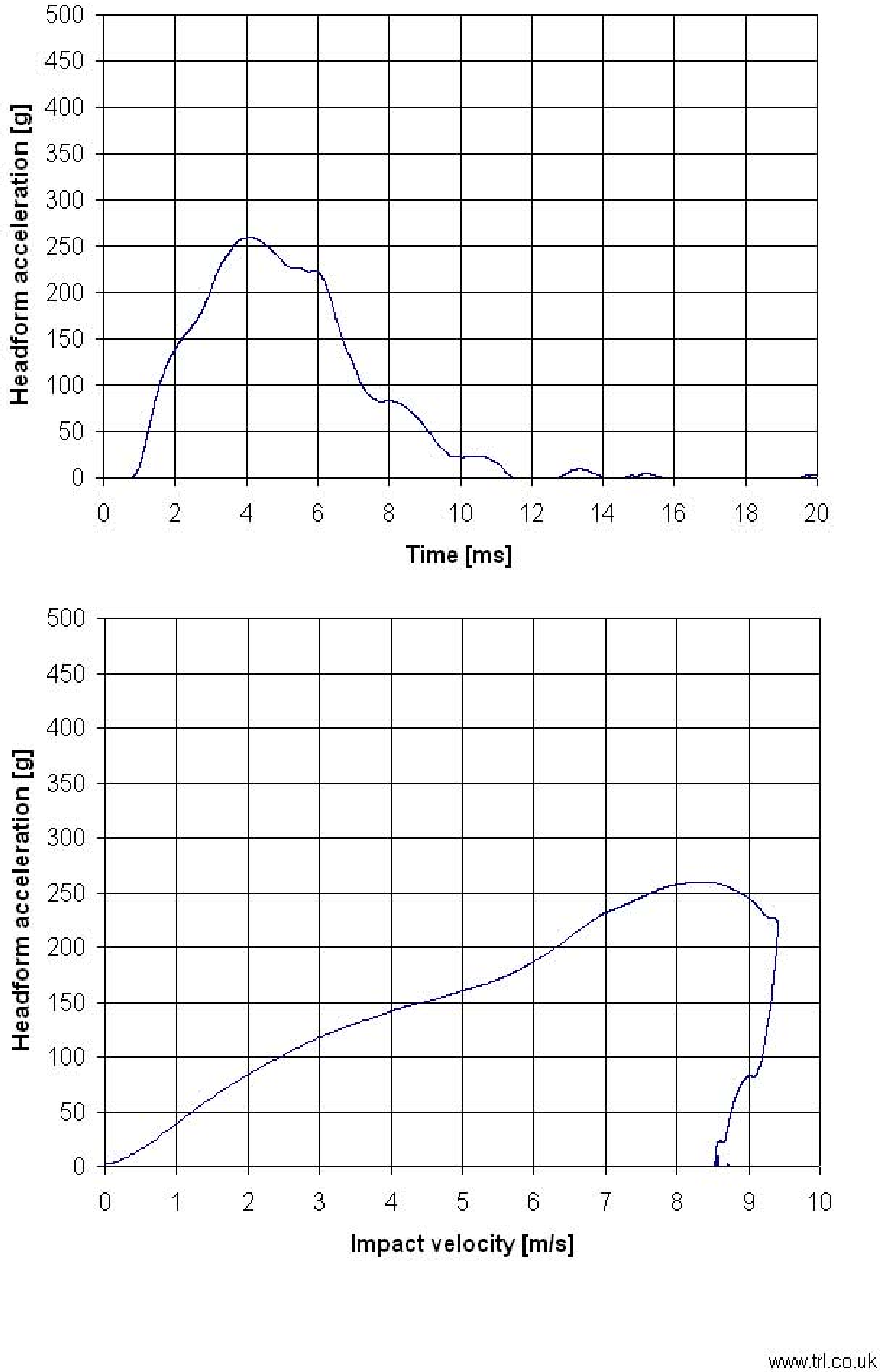


Figure 1 Graphical results showing

(i) acceleration history

(ii) acceleration vs impact velocity

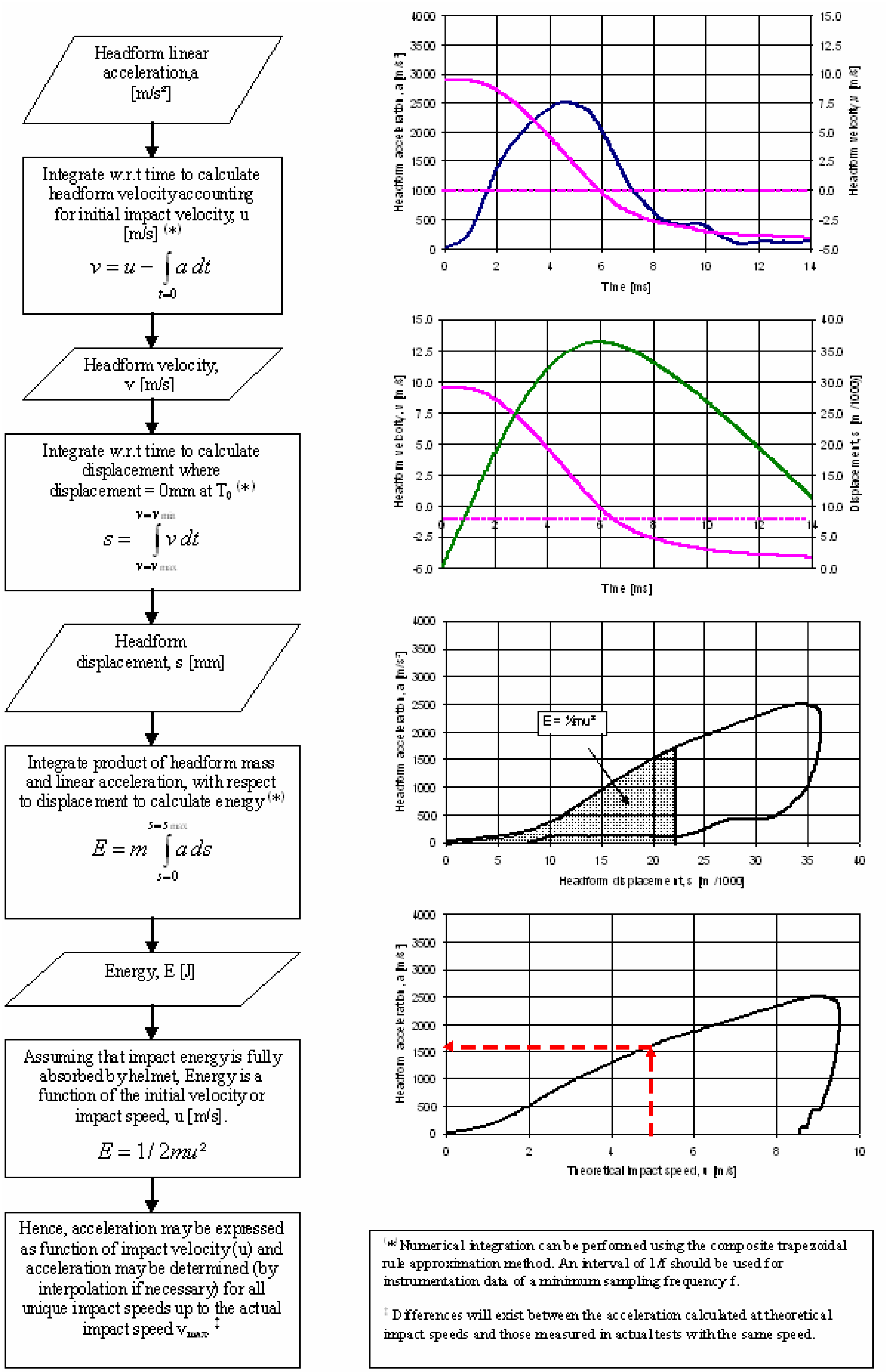


Figure 2. Flow chart for integration calculation

MODULE 1. EQUIVALENT TEST SPEED

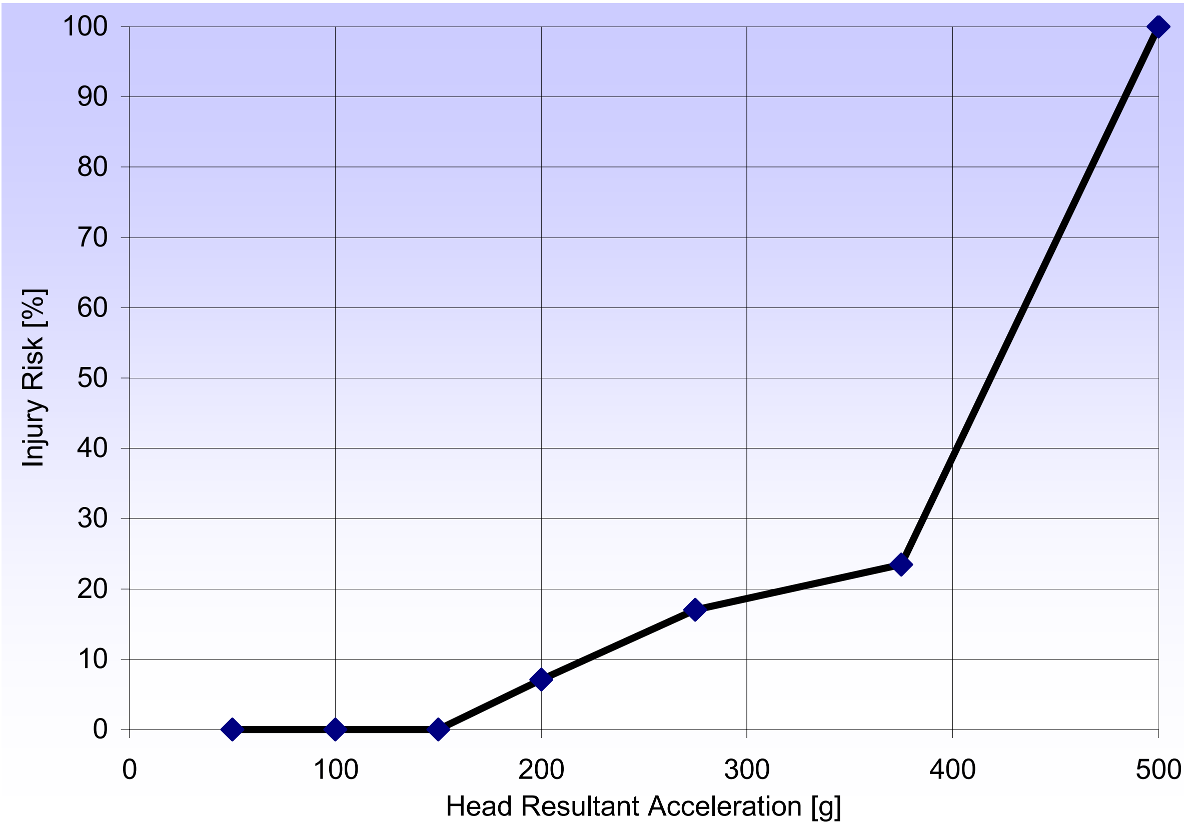
The equivalent test speed is the laboratory test speed that is equivalent to the average impact conditions for each accident severity.

Accident Severity	1	2	3	4	5	6
Flat anvil equivalent test speed[1] [m/s]	3.2	5.0	6.6	7.9	8.8	9.5
Kerb anvil equivalent test speed[1] [m/s]	3.7	5.4	6.8	8.3	9.0	9.5
Flat anvil equivalent test speed[2][m/s]	2.7	4.0	5.2	7.0	8.1	9.5

[1] data used for assessment of linear impact

[2] data used for assessment of oblique impacts

MODULE 2. HEAD INJURY RISK CURVE



Shadow AIS	0	1	2	3	4	5	6
Headform acceleration [g]	50	100	150	200	275	375	500
Injury risk [%]	0.0	0.0	0.0	7.1	17.0	23.5	100

Note. The data assumes a linear response between each reference acceleration value.

For example. The risk at, say, 225 g = 7.1 + (225-200)/(275-200)*(17.0-7.1) = 10.4%

MODULE 3. ACCIDENT EXPOSURE

United Kingdom accident cases where the rider or pillion passenger (PP) suffered a head impact, where the head injury was the most severe of all injuries sustained, and an improved helmet may be beneficial.

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Number riders and pillion passengers	4089	2193	452	493	492	21

MODULE 4. DISTRIBUTION OF IMPACTS BY LOCATION ON HELMET

The distribution of impacts by location on helmet.

Impact Site	**Distribution [%]**
Front	23.6
Side	53.2
Crown	2.2
Rear	21
Total	100

MODULE 5. DISTRIBUTION OF IMPACTS BY SURFACE TYPE

The distribution of accidents by impact surface.

Impact Surface	**Distribution [%]**
Flat anvil	38.4
Kerb anvil	1.6
Oblique impact	60.0
Total	100

6. RESULTS

The full results for each of the six helmet types are presented graphically in **Figure 3**, **Figure 4**, **Figure 5**, **Figure 6**, **Figure 7** and **Figure 8**

MHAP
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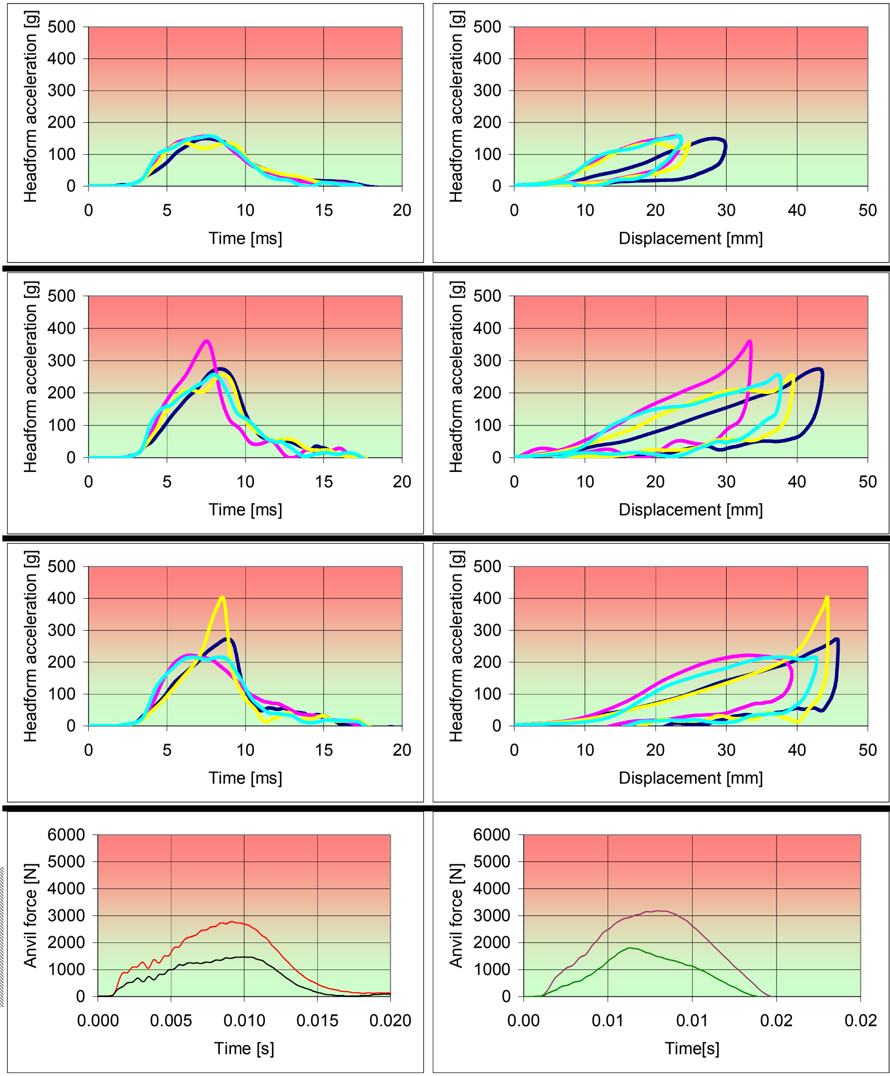
June 2006

v1.03

Make	Shoei
Model	Z-One
Type	Full face
Size	540mm (Small)
Mass	c. 1500g
Relailed as approved to	Reg22.05

MHAP RATING X



Flat **6.0m/s**

- B, Front (d19iy) 150g HIC 889
- X, Side L (b20iy) 157g HIC 1100
- P, Crown (e20iy) 135g HIC 941
- R, Rear (h20iy) 158g HIC 1144

Flat **9.5m/s**

- B, Front (c19iy) 274g HIC 3271
- X, Side L (a20iy) 360g HIC 4333
- P, Crown (c20iy) 256g HIC 3084
- R, Rear (f20iy) 257g HIC 2978

Kerb **9.5m/s**

- B, Front (b19iy) 273g HIC 2904
- X, Side L (e19iy) 222g HIC 2575
- P, Crown (c04jy) 404g HIC 3753
- R, Rear (d04jy) 216g HIC 2862

Oblique **15º, 8.5m/s**

Coefficient of friction = 0.52

- Normal (2778N)
- Tangential (1469N)
- Normal (3181N)
- Tangential (1806N)

Figure 3. Results for R22-05 (Shoei Z-One) Size Small

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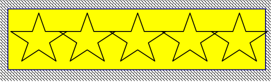
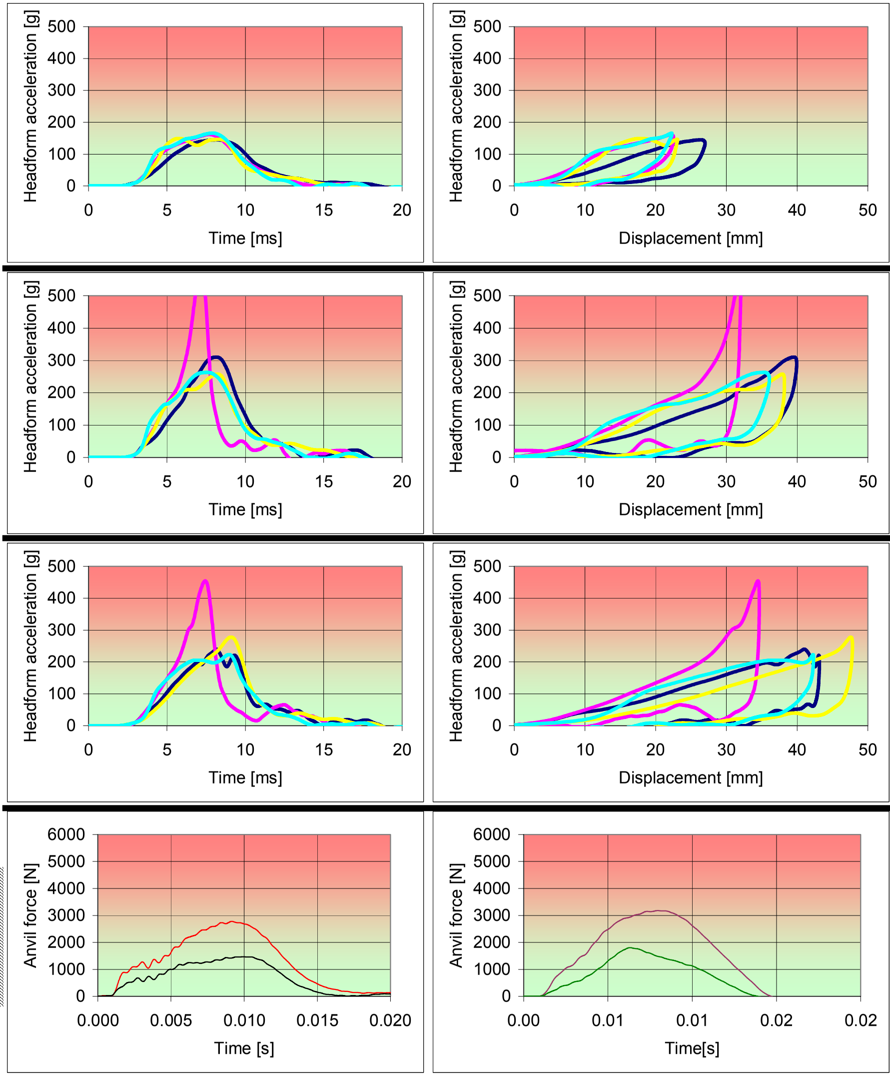
June 2006

v1.03

Make	Shoei
Model	Z-One
Type	Full face
Size	570mm (Medium)
Mass	c. 1500g
Relailed as approved to	Reg22.05

MHAP RATING X





Flat 6.0m/s

- B, Front (j26iy) 145g HIC 933
- X, Side L (t26iy) 162g HIC 1111
- P, Crown (j03jy) 149g HIC 1044
- R, Rear (e04jy) 166g HIC 1262

Flat 9.5m/s

- B, Front (a26iy) 310g HIC 3931
- X, Side L (m26iy) 569g HIC 6895
- P, Crown (b03jy) 258g HIC 2967
- R, Rear (l03jy) 263g HIC 3375

Kerb 9.5m/s

- B, Front (f26iy) 240g HIC 2371
- X, Side L (p26iy) 454g HIC 5043
- P, Crown (c03jy) 278g HIC 2822
- R, Rear (m03jy) 223g HIC 2616

Oblique 15º, 8.5m/s

Coefficient of friction = 0.52

- Normal (2778N)
- Tangential (1469N)
- Normal (3181N)
- Tangential (1806N)

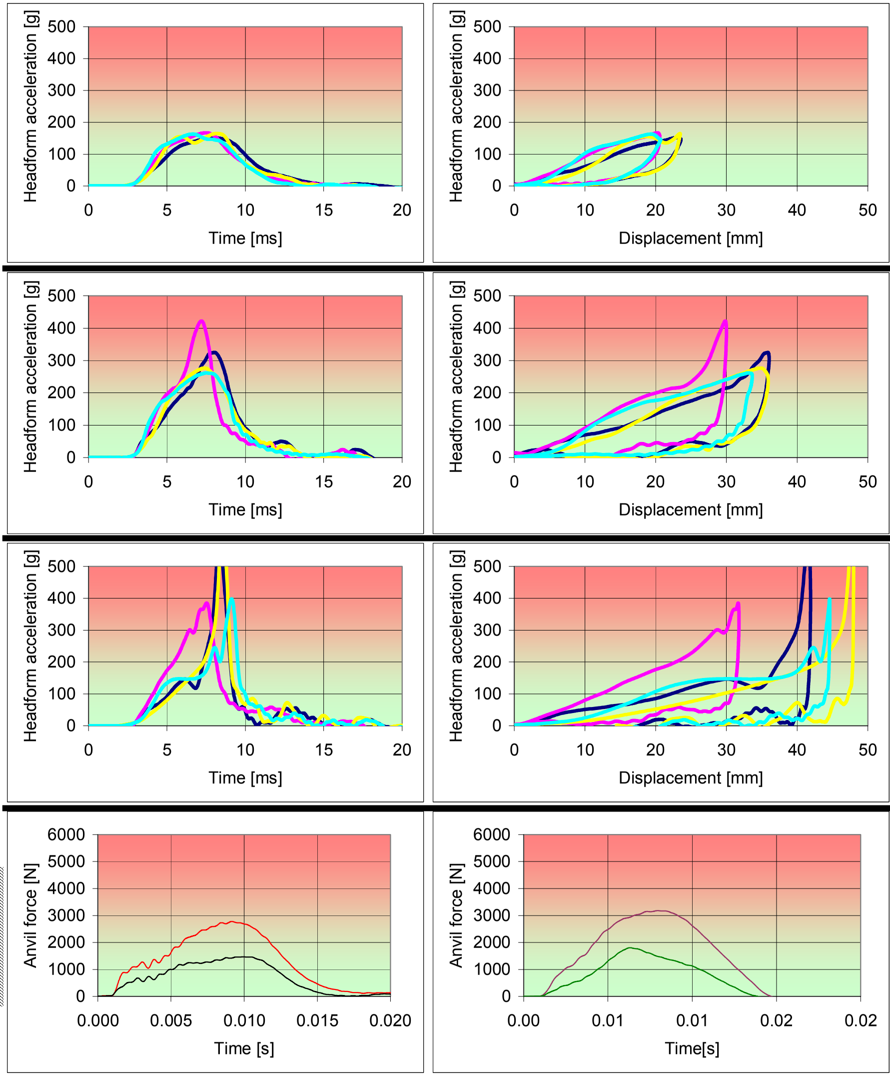
Figure 4. Results for R22-05 (Shoei Z-One). Size Medium

MHAP
DOC REF - MHAP 2006/001-J
June 2006

v1.03

Make	Shoei
Model	Z-One
Type	Full face
Size	600mm (Large)
Mass	c. 1500g
Relailed as approved to	Reg22.05

MHAP RATING X



Flat **6.0m/s**

- B, Front (k20iy) 152g HIC 1055
- X, Side L (n20iy) 167g HIC 4191
- P, Crown (q20iy) 165g HIC 1187
- R, Rear (t20iy) 163g HIC 1219

Flat **9.5m/s**

- B, Front (i20iy) 325g HIC 3826
- X, Side L (l20iy) 422g HIC 4845
- P, Crown (o20iy) 277g HIC 3560
- R, Rear (r20iy) 262g HIC 3533

Kerb **9.5m/s**

- B, Front (j20iy) 606g HIC 4818
- X, Side L (m20iy) 385g HIC 4187
- P, Crown (p20iy) 629g HIC 4872
- R, Rear (s20iy) 398g HIC 2686

Oblique **15º, 8.5m/s**

Coefficient of friction = 0.52

- Normal (2778N)
- Tangential (1469N)
- Normal (3181N)
- Tangential (1806N)

Figure 5. Results for R22-05 (Shoei Z-One). Size Large

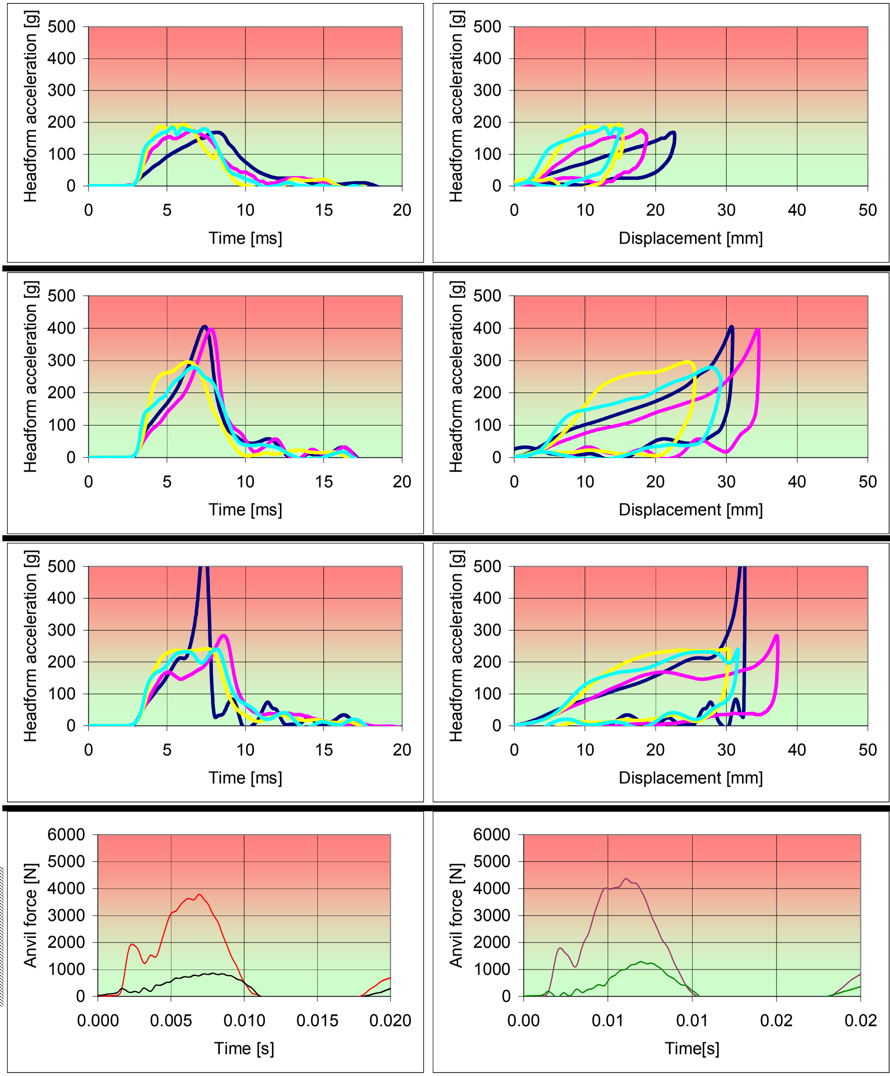
MHAP v1.03

DOC REF - MHAP 2006/001-J

June 2006

Make	Phillips Helmets Ltd
Model	PHPS
Type	Full face
Size	570mm (Medium)
Mass	c. 1500g
Relailed as approved to	Prototype (N/A)

MHAP RATING X



Flat **6.0m/s**

- B, Front (k24ky) 169g HIC 996
- X, Side L (l24ky) 176g HIC 1196
- P, Crown (m24ky) 195g HIC 1439
- R, Rear (n24ky) 184g HIC 1631

Flat **9.5m/s**

- B, Front (b26iy) 405g HIC 4456
- X, Side L (n26iy) 397g HIC 3906
- P, Crown (d03jy) 295g HIC 4157
- R, Rear (n03jy) 279g HIC 3617

Kerb **9.5m/s**

- B, Front (g26iy) 601g HIC 4851
- X, Side L (q26iy) 283g HIC 2494
- P, Crown (e03jy) 242g HIC 3383
- R, Rear (o03jy) 240g HIC 3082

Oblique **15º, 8.5m/s**

Coefficient of friction = 0.22

- Normal (3781N)
- Tangential (859N)
- Normal (4369N)
- Tangential (1286N)

Figure 6. Results for PHPS helmet. Size Medium

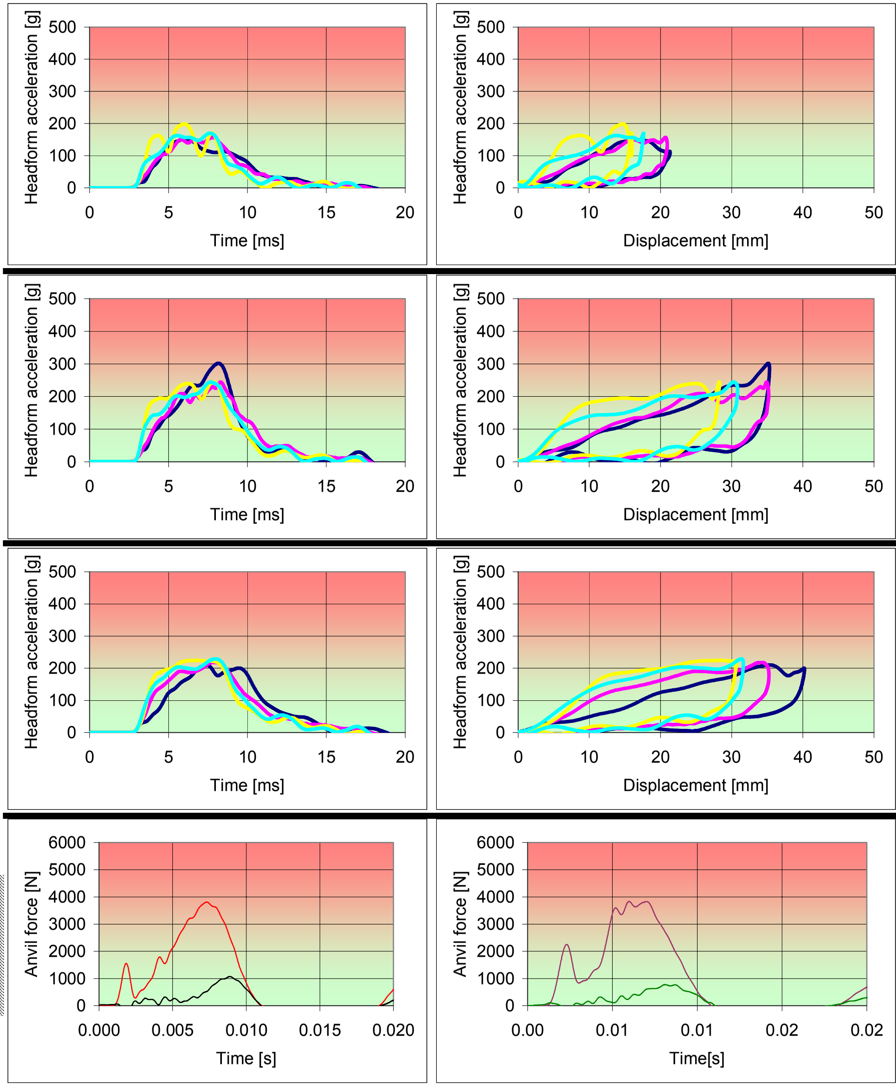
MHAP
DOC REF - MHAP 2006/001-J
June 2006

v1.03

Make	TRL
Model	TRL prototype with Membrane
Type	Full face
Size	570mm (Medium)
Mass	c. 1500g
Relailed as approved to	Prototype (N/A)

MHAP RATING X

☆☆☆☆☆



Flat 6.0m/s

- B, Front (k26iy) 150g HIC 871
- X, Side L (u26iy) 157g HIC 982
- P, Crown (k03jy) 199g HIC 1330
- R, Rear (a04jy) 170g HIC 1155

Flat 9.5m/s

- B, Front (c26iy) 302g HIC 3476
- X, Side L (o26iy) 244g HIC 2775
- P, Crown (f03jy) 245g HIC 3259
- R, Rear (p03jy) 244g HIC 2911

Kerb 9.5m/s

- B, Front (a03jy) 210g HIC 2396
- X, Side L (r26iy) 218g HIC 2512
- P, Crown (g03jy) 224g HIC 3103
- R, Rear (q03jy) 229g HIC 2819

Oblique 15º, 8.5m/s

Coefficient of friction = 0.14

- Normal (3811N)
- Tangential (1074N)
- Normal (3834N)
- Tangential (777N)

Figure 7. Results for TRL S100L Advanced Prototype Helmet. Size Medium

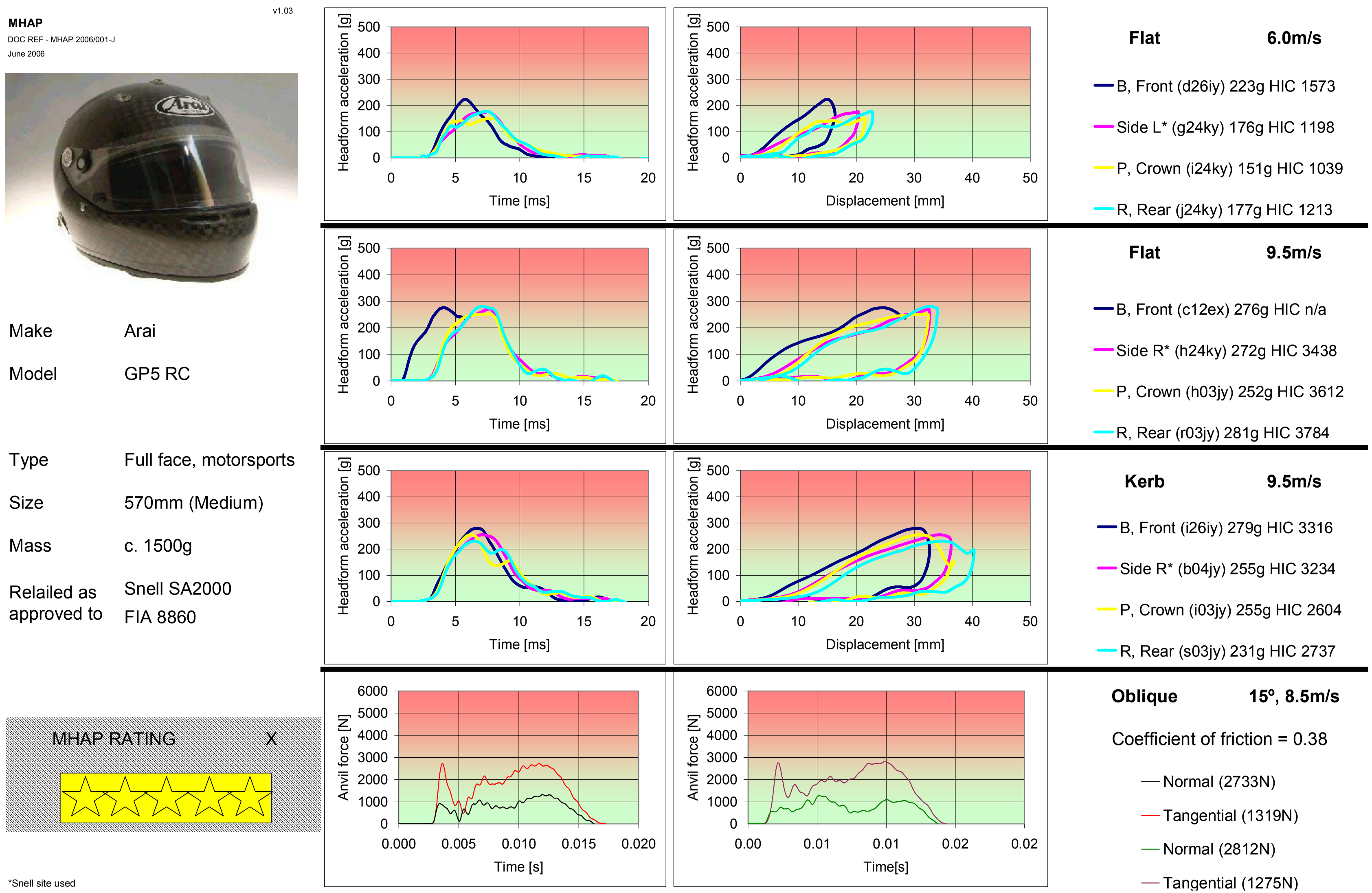


Figure 8. Results for FIA8860 helmet (Arai GP5 RC). Size Medium

Appendix G. Consumer Information Scheme

(i) Test Protocols

(ii) Assessment Protocols

(iii) Results Presentation

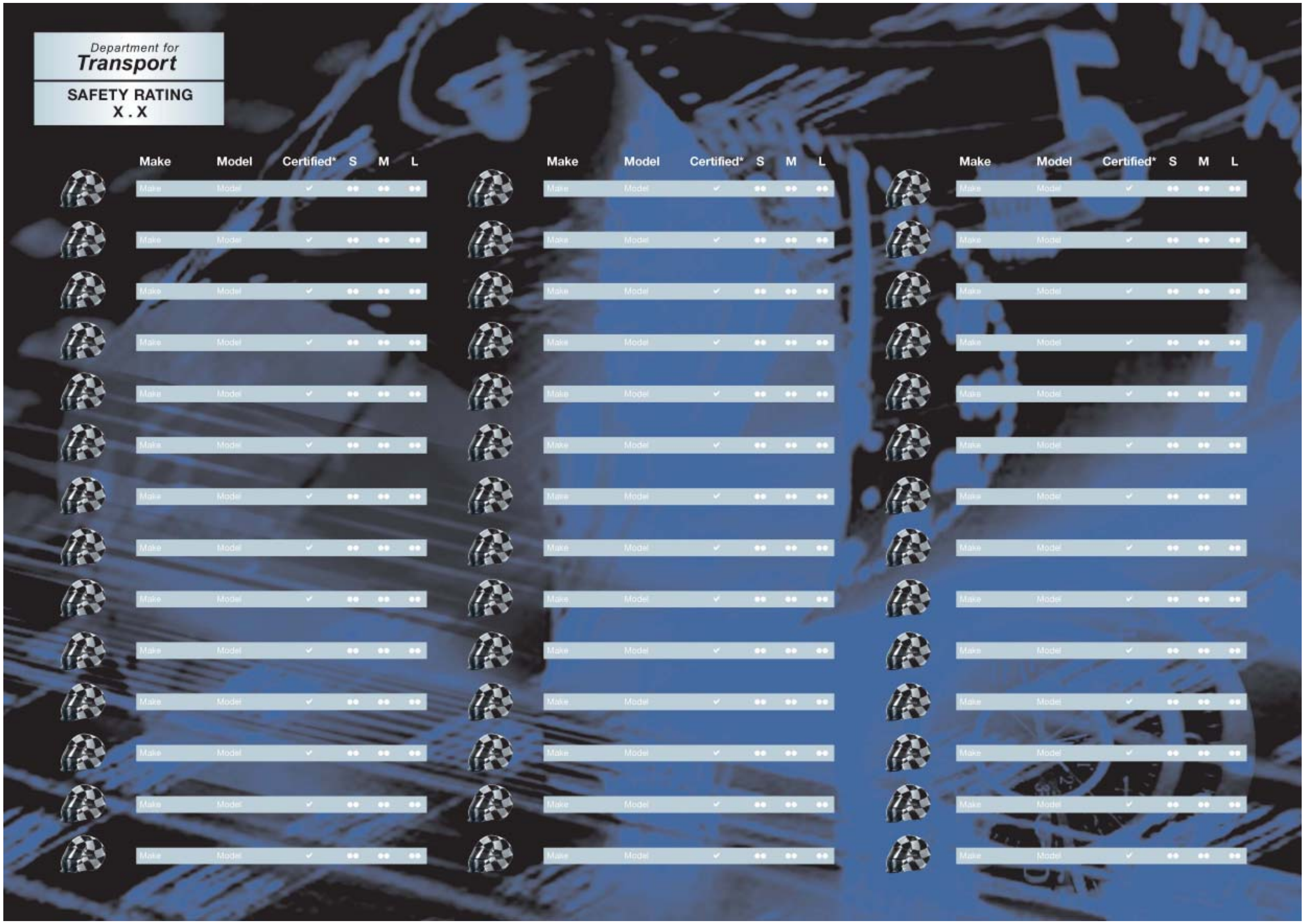


Figure 1. Draft layout for results presentation. Version 1.

Figure 2. Draft layout for results presentation. Version 2.

Figure 3. Draft layout for Helmet Label. Version 1.

Figure 4. Draft layout for Helmet Label. Version 2.

Figure 5. Draft layout for Helmet Label. Version 3.

Figure 6. Draft layout for Helmet Label. Version 4.

Appendix H. ESV 2005 Conference, Washington

(i) Technical Paper

(ii) Presentation

The following documentation is a reproduction of paper #05-0329 entitled "Advanced Motorcycle Helmets" which was presented at the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV) in June 2005 and forms part of the published conference proceedings. The slides from a technical presentation given by V StClair are included in Part (ii) of this Appendix.

Appendix H. ESV 2005 Conference, Washington

(i) Technical Paper

(ii) Presentation

ADVANCED MOTORCYCLE HELMETS

Andrew Mellor
Vincent StClair
TRL Limited
United Kingdom
Paper 05-0329

ABSTRACT

More than 5,000 motorcycle riders or pillion passengers are killed annually on European roads and a further 70,000 are seriously injured. In addition to the physical and emotional trauma, the financial cost of these injuries is estimated to exceed 10 billion Euros. The COST 327 European Research Action on motorcycle helmets reported that improvements in helmet design could save up to 1,000 lives per year across the European Union. Approximately 80% of motorcyclists killed on European roads sustained head impacts and in half of these cases, the head injury was the most serious.

TRL has developed with industry an advanced protective helmet which provides a higher level of protection than current helmets to BS 6658A, ECE Regulation 22-05 or Snell M2000. The helmet consists of a lightweight carbon composite shell fitted with an optimised energy absorbing liner and a low friction sacrificial outer surface. The advanced helmet is designed to reduce both linear and rotational acceleration loadings to the head.

In order to quantify the benefits of the advanced helmet, the impact response was measured during a range of impact conditions. The results were related to the AIS scale using correlation coefficients developed by TRL from an accident replication programme. It was shown that the advanced helmet could reduce injury risk by up to 20% for AIS 6 injuries and up to 70% for AIS 5 and AIS 4 injuries. The performance of the helmet during less severe impacts (corresponding to AIS 3, 2 and 1) was designed to be equivalent to current helmet designs.

Given this potential, the UK Department for Transport is collaborating with domestic and European partners in a new project to encourage the introduction of more protective motorcycle helmets. This paper describes the work to date and prospects for the future.

INTRODUCTION

Research conducted by the COST 327 European Research Action [1] on motorcycle helmets concluded that head injury severity increased, quite remarkably, with head impact speed. More than 5,000 motorcycle riders or pillion passengers are killed annually on European roads and a further 70,000 are seriously injured. It was postulated that if helmets could be made to absorb 24% more energy then some 20% of the AIS 5-6 casualties would sustain reduced injuries of only AIS 2-4. Furthermore, an increase in helmet energy absorbing characteristics of some 30% would reduce 50% of the AIS 5/6 casualties to AIS 2-4.

Research was carried out in parallel by TRL and industry to develop a prototype of an advanced helmet design capable of satisfying both the safety performance specified by COST 327 and geometric, mass and ergonomic requirements based on current motorcycle helmets designed to BS 6658A [2] or ECE Regulation 22-05 [3].

There were two principal objectives for the new helmet (A) ultra stiff shell structure and optimised liner (B) low friction outer surface.

A) The aim of the ultra stiff shell structure was to ensure that the outcome of a linear impact (or component thereof) was independent of the profile of the impacted surface. Thus the protection provided by the helmet corresponded to the characteristics of the liner material and thickness. The liner could then be optimised for internally induced deformation caused by the head moving into the liner. By this approach, externally induced deformation that arises, for example, by the shell of a current helmet deforming when striking a kerbstone anvil, was reduced to a negligible amount.

B) The aim of the low friction surface was to reduce tangential impact loads during oblique impact conditions, thus minimising the rotational accelerations imparted to the head, whilst correspondingly reducing the resultant force and, therefore, reducing the resultant linear acceleration.

This paper describes the development programme for the new helmet and demonstrates how the COST 327 objectives were exceeded. An injury benefit analysis was conducted based on the safety performance of the new helmet. The analysis considered the distribution of injury mechanisms and severities for the riders injured on roads in Great Britain and determined the extent to which the distribution may be improved if advanced helmets had been worn. It was concluded that up to 20% of fatal rider injuries in Great Britain could be prevented. If the same proportion of injury reduction could be achieved on European roads more than 1,000 lives per year could be saved.

The advanced prototype helmets were produced using relatively expensive materials and processes. It was, therefore, important to consider the cost of such helmets if mass produced to achieve significant sales penetration. The dominant cost issues are discussed within this paper, together with new work which, it is hoped, will reduce these further to allow for greater penetration.

HEAD INJURY MECHANISMS

A helmet is designed to protect the rider in the event of an accident by absorbing impact energy and reducing the loading imparted to the head via the helmet. In order to maximise the protection provided by a helmet, it is important to identify the mechanisms by which a head becomes injured. The term ëhead injuryí comprises various kinds of trauma to the skull and its contents. Usually, several different types of head injury occur simultaneously in a traffic accident. The anatomical location of the lesions and their severity determine the physiological consequences. Injuries may be divided into cranial injuries (skull fractures) and intracranial ìsoft tissueî injuries. Indeed, skull fracture can occur with or without soft tissue damage and vice versa.

Skull fracture occurs when the loading on the skull exceeds the strength of the bone and can be either open or closed. Skull fractures may be divided into facial, vault and basal. The most threatening form of skull fracture is basilar skull fracture. A characteristic of motorcycle accident victims is that fractures of the vault are rare among helmeted riders, but that basilar skull fractures are frequently encountered, both in helmeted and unhelmeted riders [4 and 5]. Soft tissue damage occurs, during an impact, due to high strains within the vascular and neurological tissues as a result of both linear and rotational loadings to the head.

The risk of both types of injury (skull fracture and soft tissue) can be reduced by improving the energy absorbing performance of the helmet. The advanced TRL protective helmet achieves this with a liner-shell combination of appropriate stiffness to minimise linear acceleration during high energy impacts. In addition, the outer surface of the helmet provides very low friction, so that the rotational accelerations imparted to the head are minimised.

SPECIFICATION FOR MOTORCYCLE HELMET SHELL ñ LINEAR IMPACT

The objective of the new helmet was to exceed the safety performance objectives of the COST 327 European Research Action on motorcycle helmets. A target improvement in linear impact energy absorption of 75% was proposed; corresponding to impact tests at 10m/s compared with 7.5m/s for ECE Regulation 22-05.

This could be achieved, in part, by optimising the performance of the shell to be very stiff and able to resist excessive shell deformations and thus transmit loads more efficiently to the energy absorbing liner. It was proposed that the mass of the shell should not be greater than that of current designs and should be reduced, if possible. It was accepted that the thickness may need to be increased, compared with current designs (which are typically 3mm), in order to achieve the objectives. A maximum thickness of 10mm was proposed. The materials were specified such that a helmet shaped structure with double curvature could be achieved and volume production would be practicable. In addition, it would be beneficial for the structure to possess inherent damping qualities that would minimise rebound during impacts.

To meet these objectives, flat coupons tests (see below) were used to develop helmet shell materials and further full geometry tests to identify optimal liner materials. Further prototype helmet tests were completed to evaluate the performance benefits of the advanced helmet over current helmet designs.

PERFORMANCE ASSESSMENT USING FLAT COUPONS

The impact characteristics of the shell were assessed together with consideration of temperature and moisture stability, mass, thickness and scope for production. Durability was not considered at this stage. TRL developed specific test procedures to enable the evaluation of shell structures using flat samples of shell material. The cost of manufacturing and testing flat shell samples was very much lower than for helmet shaped shell structures, therefore a greater number of potential designs could be evaluated. The dynamic loads exerted during the flat sample tests were representative of those exerted during complete helmet test, therefore it was possible to evaluate the flat shell structures for use in complete helmets.

It was important that the results from the tests on flat samples represented the performance of complete helmets, constructed with the same materials. In order to ensure this, the test procedures were representative of a falling headform test. The acceleration-history of the impactor during these flat coupon tests was related to the acceleration-history of a helmeted headform during similar impact conditions.

Linear impact tests - Flat shell samples measuring 120mm x 70mm were attached to a ëbedí of energy absorbing foam measuring 120mm x 70mm x 35mm using double sided adhesive tape. The foam used had energy absorbing properties similar to the Expanded Polystyrene (EPS) used in motorcycle helmets. The foam/shell specimen was attached to the base of a 2.5kg mass, with the shell facing outwards. The specimen was impacted onto a steel hemi-spherical anvil with a 25mm radius. The anvil was designed to simulate the shell-stresses developed during a helmet impact onto the ECE Regulation 22 kerbstone anvil. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 5m/s, 7.5m/s and 10m/s.

Temperature and moisture tests - The samples were pre-conditioned for a minimum of 4 hours at -20^{o}C, +25^{o}C, +50^{o}C and with moisture conditioning by means of submersion in a water bath. The samples were placed on a rigid anvil, with the shell facing upwards, and impacted with a 2.5kg mass fitted with the steel hemi-spherical impact surface as above. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 7.5m/s.

Analysis and results - For each test the acceleration history of the impactor was recorded. By single integration of this result the velocity history was calculated and hence the rebound velocity was determined. By double integration of the acceleration result, the displacement history was calculated and this enabled the maximum dynamic displacement to be determined.

A specification was defined for the flat coupons to achieve the proposed helmet shell performance. This was considerably more advanced than that of current helmet designs, and was thought to be close to the limit of what was technically achievable. The requirements were closely met and allowed the helmet performance to be optimised within the constraints of a current helmet mass. A summary of this specification is given in the Table 1 below;

Table 1 - Performance target for flat coupons

Size	120mm * 70mm
Thickness	Maximum of 10mm
Mass	Maximum of 50g
In-plane tensile strength	Peak tensile stress will occur at the *inner surface* and will be dependant on the thickness of the structure. In the region of 250N/mm≤ for a 5mm thick structure or 60N/mm≤for a 10mm thick structure.
In-plane compressive strength	Peak compressive stress will occur at the *outer surface* and will be dependant on the thickness of the structure. In the region of 250N/mm≤ for a 5mm thick structure or 60N/mm≤for a 10mm thick structure.
In-plane bending stiffness	10 times as stiff as 3mm GRP (or 5mm unreinforced polycarbonate).
Through-thickness compressive strength	Management of compressive forces without excessive dimpling to the outer skins. Peak compressive stresses approximately 30N/mm≤ at 1.5mm shell deformation.
Operating conditions	-20^{o}C to +50^{o}C with extremes of moisture

FLAT COUPON LINEAR IMPACT TESTS

The structural requirement for the shell structure was to transmit the impact force between the impact surface and the energy absorbing liner material, without excessive deflection or structural failure. In order to achieve this, the structure must also resist the high local contact stresses at the point of impact, without excessive local deformation.

To define acceptable levels of shell deformation, TRL investigated the impact performance of an infinitely stiff shell structure which does not deflect during impact. This was achieved by impacting samples of the energy-absorbing foam between parallel plates in accordance with the procedures used for shell evaluation discussed above. In order to transmit the impact forces to the energy absorbing liner, the maximum acceptable shell deformation was estimated to be 3mm during a 7.5m/s impact and approximately 5mm during a 10m/s impact.

The linear impact performance of the coupon structures were further analysed using the acceleration-time history and acceleration-displacement of the impactor. At 7.5m/s the peak deformation of the impactor was 18mm and at 10m/s the peak deformation of the impactor was 27mm. These results were combined with the target values for shell deformation to prescribe target displacement values of 21mm at 7.5m/s (18mm+3mm) and 32mm at 10m/s (27mm + 5mm).

In addition to impactor displacement, it was possible to evaluate the results in terms of impactor acceleration and define appropriate limits for these performance parameters. At 7.5m/s, the infinitely stiff shell achieved a peak acceleration of 200g and when tested at 10m/s the peak acceleration was 300g. The acceleration results from tests on less stiff shells were, implicitly, lower than those for the infinitely stiff shell *(except when the shell was so soft that the impactor bottomed out, hence producing a very high acceleration result)*. It was therefore proposed that the novel shell structures should achieve acceleration levels slightly lower than for the infinitely stiff shell tests. Based on this concept, the prescribed target values for peak impactor acceleration were;

i. at least 180g during impact at 7.5m/s
ii. no more than 300g during impact at 10m/s

Although a high stiffness is a fundamental requirement of the ënovel shell designí, it may be an advantage for the shell to deform or yield during severe impact conditions, so that the space occupied by the thickness of the shell may be fully utilised. This characteristic was also investigated during the evaluation of the ënovel structuresí.

Test samples for linear impact tests

The following test samples were evaluated;

1 Polycarbonate - 5mm thick
2 Polycarbonate - 10mm thick
3 Nimrod helmet shell sample - 5mm thick
4 Aluminium plate - 5mm thick
5 Carbon-sandwich (CS-01) - 4.1mm
6 Carbon-solid (CS-02) - 2.9mm
7 Carbon-experimental (CS-08) - 3.0mm

Results for linear impact tests

A summary of the tests data is provided in Table 2. The design values are also included.

The baseline polycarbonate and aluminium materials did not achieve the target performance values. These materials were found to have an insufficient strength to weight ratio such that when the mass criterion was met, the impact performance was not achieved, and when the thickness (and therefore strength) was increased to meet the impact performance, the mass became prohibitively high.

Three different variations of composite design were used. All three were constructed using carbon fibre composite materials. CS-01 was a sandwich construction with a syntactic foam core, CS-02 was a solid laminate and CS-08 was an experimental laminate. Both CS-01 and CS-02 achieved all the target values for mass, thickness, deformation and acceleration. CS-08 met all but the deformation target during the 10m/s test, with a deformation of 34mm compared with the target of 32mm. It was found that the performance of all the carbon structures was stable after the temperature and water conditioning.

Table 2. Summary of test results from Carbon composite coupon structures

Sample	Mass [g]	Thickness [mm]	Peak Deformation [mm]		Peak Acceleration [g]	
			7.5 m/s	10 m/s	7.5 m/s	10 m/s
Rigid flat plate			18	27	202	300
Target	***≤50***	***≤10***	***≤21***	***≤32***	***≥180***	***≤300***
PC (5.0mm)	50	5	**23**	**35**	**157**	**364**
PC (10mm)	**100**	10	18	28	195	288
Nimrod (5.0mm)	45	4.5	**25**		**144**	
Al (5.0mm)	**117**	5	18	26	204	293
CS - 01 (4.1mm)	40.6	4.8	21	30	200	298
CS ñ 02 (2.9mm)	36.2	3.0	20	32	210	242
CS - 08 (3.0mm)	39.7	3.0	21	**34**	193	293

Results in **bold** did **not** achieve target values

In summary, CS-01 and CS-02 achieved all the design targets and provided significantly improved performance compared to the baseline materials. These two materials were selected for testing with full-geometry helmet constructions.

SPECIFICATION FOR MOTORCYCLE HELMET SHELL ñ SURFACE FRICTION

COST 327 [1] reported that reducing the tangential force during an impact by 50% may reduce the injury outcome by one AIS category. It was, therefore, agreed that the new helmet should be developed with a shell system designed to minimise surface friction. A bespoke test method was devised to assess the potential solutions for the reduction of rotational motion by measuring the effective surface friction of flat coupon test samples. The tests samples included low friction coatings and a sacrificial layer designed to peel away with very little force.

The test configuration consisted of pseudo-dynamic surface abrasion tests using flat samples of shell material. Two test methods, using the same apparatus were utilised depending on the technique presented to reduce friction. Samples that presented a surface with a low coefficient of friction were evaluated using configuration ëAí. Samples that presented a sliding-layer failure mechanism were evaluated using configuration ëBí. The results from both methods were compared directly. TRL tested three variants with three tests per variant. Figure 1 shows the apparatus used.

The samples were located in a rigid housing and positioned against the flat horizontal track surface 300mm long and 150mm wide. A normal force was applied using a pneumatic actuator to clamp the sample against the track surface. The magnitude of this load was approximately 2,000N (to simulate the typical normal force during an oblique impact test to ECE Regulation 22-05 Method A). A tangential force was subsequently applied using a pneumatic actuator to slide the track surface relative to the test sample. The stroke of the tangential actuator was 100mm. The normal and tangential loads were measured with load-cells and the acceleration of the track surface carriage was measured with an accelerometer. The instrumentation data was recorded at a rate of 10,000 samples per second and filtered in accordance with SAE J211. A filter frequency of CFC180 was chosen after careful consideration.

For configuration (A): samples measuring 25mm x 25mm and between 2mm and 25mm thick, with a 2mm radius on one edge, were mounted in a rigid sample holder and clamped against a flat carriage fitted with 80 grit aluminium oxide paper. For configuration (B): samples measuring 120mm x 70mm and between 2mm and 25mm thick were mounted on a carriage and a 80 grit aluminium oxide tool measuring 25mm x 25mm was clamped against the surface of the sample.

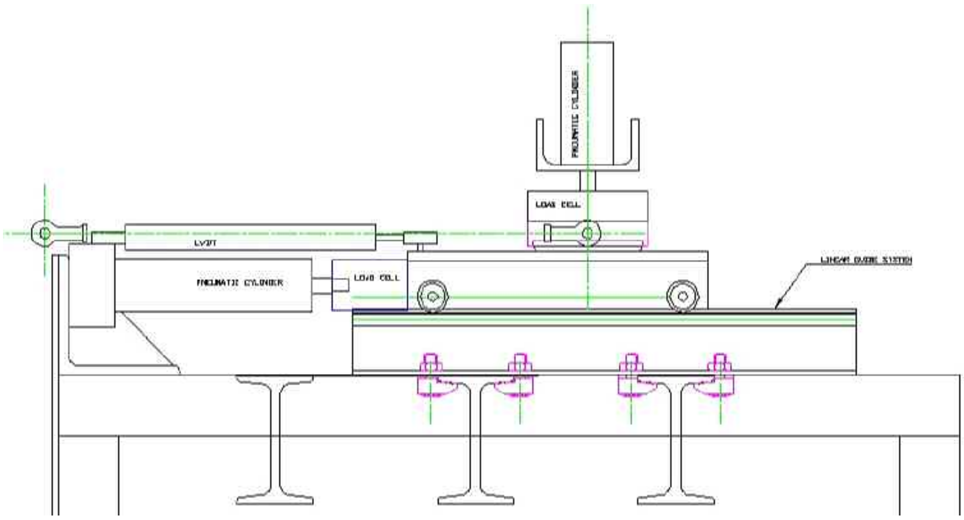


Figure 1. Low velocity, transient, surface friction test apparatus

Test samples for surface friction tests

For both configurations, the carriage was translated perpendicular to the clamping force over a minimum distance of 65mm and with a maximum speed of approximately 1.5m/s. By measuring the normal and tangential loads during the event, it was possible to calculate the effective dynamic coefficient of friction of the sample.

Three coupon samples were investigated as detailed below:

1 Polycarbonate (configuration A)
2 Carbon fibre composite with toughened epoxy matrix (configuration A)
3 Sacrificial layer (configuration B)

Test results for surface friction tests

A summary of the results are provided in Table 3 below. The baseline polycarbonate material achieved a peak friction of μ0.77 and a sliding friction of μ0.42. The carbon fibre material achieved significantly reduced friction values of μ0.17 peak and μ0.12 sliding, a reduction of almost 80% in peak friction. The sacrificial layer achieved the lowest values of μ0.10 peak and μ0.09 sliding, a reduction of almost 90% in peak friction. Both systems were further evaluated using full helmet shell tests.

Table 3. Summary of test results from flat coupon structures

Sample	Normal force [N]	Coefficient of friction (μ)	
		Peak	Sliding
Polycarbonate	1,900	0.77	0.42
Carbon fibre *(CS-01)*	2,000	0.17	0.12
Sacrificial layer	1,900	0.10	0.09

FULL GEOMETRY HELMET SHELL TESTS

Tests were conducted on full-geometry prototype helmet samples in order to develop and evaluate the linear impact and oblique impact performance as defined by ECE Regulation 22-05.

LINEAR IMPACT DEVEOPMENT TESTS

The aim of the linear-impact development tests was to evaluate full-geometry prototype helmets with carbon shells to the laminate specification determined in flat coupon testing. The shells were fitted with Expanded Polystyrene (EPS) energy absorbing liners of different densities (25g/l and 30g/l) in order to determine the best compatibility between shell and liner. The prototype helmets were full-faced geometry construction, in size 57 (medium), and conformed to the extent of protection requirements of ECE Regulation 22-05. The impact area of the shell was profiled to closely fit the energy absorbing liner. The linear impact tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg. A total of five linear impact tests were conducted on each helmet design, with tests at 7.5m/s and 10m/s onto both the flat and kerbstone anvils with temperature conditioning at ñ20^{o}C, 25^{o}C and +50^{o}C.

Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. The results are shown in table 4 below. The baseline performance at 10m/s onto the kerbstone anvil (front) was 954g and onto the flat anvil (crown) was 299g. The carbon shell concept provided a significant improvement over the current motorcycle helmet design with a 10m/s kerbstone anvil (front) impact result of 235g (CS-02) and a 10m/s flat anvil (crown) result of 230g.

The results were analysed in detail to determine the best solution in terms of liner density and shell construction (solid laminate or sandwich), as described below.

Liner Density - During tests at 10m/s the 30g/l EPS liner achieved 235g on the front (CS-02) and 292g on the rear (CS-01) compared with 319g on the front and 890g on the rear for the 25g/l EPS liner. Based on these results, 30g/l EPS was considered to be the best solution for the main area of the energy absorbing liner. However, it was decided that the crown area should be of a lower density to compensate for the increased volume of liner that is compressed during a crown impact test due to the head geometry in this region. Evaluation of 25g/l EPS during crown impacts at 10m/s revealed a peak acceleration of 230g (CS-01) and 242g (CS-02). A 25/30g/l dual density EPS liner was therefore chosen as the best solution for the performance evaluation of the advanced helmet.

Shell construction - The results for the two carbon shell concepts were similar as can be seen by comparing the results for side impact onto the flat and kerb anvil: 185g and 173g respectively for the solid shell and 200g and 186g respectively for the sandwich shell. However, the solid shell had two advantages over the sandwich shell;

(1) reduced thickness, thus providing space for additional liner material
(2) potentially lower production costs.

The solid shell (CS-01) was chosen as the best solution for the performance evaluation of the advanced helmet.

Table 4. Results from linear impact tests

Helmet	Liner density [g/l]	Impact velocity [m/s]	Impact site	Impact anvil	Temperature [ʃC]	Peak acceleration [g]
CS - 01 Carbon- Solid laminate	25	10	Front	Kerb	+50	319
	25	10	Crown	Flat	-20	230
	25	10	Rear	Kerb	+25	292
	30	7.5	Side R	Flat	+25	185
	30	7.5	Side L	Kerb	+25	173
CS - 02 Carbon- Sandwich	30	10	Front	Kerb	+50	235
	25	10	Crown	Flat	-20	242
	25	10	Rear	Kerb	+25	890
	30	7.5	Side R	Flat	+25	200
	30	7.5	Side L	Kerb	+25	186
Baseline current		10	Front	Kerb	+25	954
		10	Crown	Flat	+25	299

FULL GEOMETRY SURFACE FRICTION DEVELOPMENT

The aim of the surface friction development tests was to develop a low friction surface coating or system to reduce the tangential forces during an oblique impact. Two systems, identified during flat coupon testing, were evaluated together with an additional hardened metallic surface as detailed below.

1. Carbon composite (toughened epoxy matrix)
2. Sacrificial layer
3. Tungsten carbide (hardened metallic surface)

The surface friction tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg impacting onto the 15^{o} abrasive anvil at 8.5m/s. Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. A summary of the results is provided in Table 5. The carbon composite shell and tungsten carbide surface significantly improved performance during the oblique impact tests, with frictional values of μ0.42 and μ0.39 respectively, compared to the baseline value of μ0.69. However, the sacrificial layer provided the greatest improvement with a friction coefficient of μ0.16, which represented a 77% percent improvement over the baseline result. The sacrificial layer was, therefore, chosen as the best solution for the performance evaluation of the advanced helmet.

Table 5. Results from surface friction tests
(ECE Regulation 22-05 limit for tangential force is 3,500N)

Helmet	Impact velocity	Impact anvil	Peak force [N]		
			Normal	Tangential	Friction
CS-01 Carbon shell with toughened epoxy matrix	8.5m/s	15° abrasive	2640	1118	0.42
CS-02 Carbon shell with sacrificial layer	8.5m/s	15° abrasive	2066	323	0.16
CS-01 Carbon shell with Tungsten carbide layer	8.5m/s	15° abrasive	3162	1250	0.39
Baseline helmet Full-faced GRP to BS6658A (average)	8.5m/s	15° abrasive	2874 2709 3187 2455 (2806)	1890 2000 2060 1806 (1998)	0.66 0.74 0.65 0.74 (0.69)

PERFORMANCE EVALUATION OF ADVANCED HELMET PROTOTYPE

The protection provided by the advanced helmet was assessed by comparing the impact performance of the advanced helmet with that of current motorcycle helmet designs conforming to ECE Regulation 22-05. This was achieved by performing both linear and oblique impacts with the helmets fitted with a Hybrid II headform instrumented with a nine-accelerometer array to measure linear and rotational accelerations. The linear impact tests were conducted onto the kerb and flat anvils as prescribed by ECE Regulation 22-05 with impact velocities up to 10m/s. The results from the linear tests were used to characterise the relationship between impact velocity and peak linear acceleration. The oblique impact tests were conducted onto the abrasive anvil as prescribed by ECE Regulation 22-05 (Method A) and additional tests were conducted using a variety of impact conditions established by the COST 327 replication programme, to simulate real accidents.

The results from these tests were analysed, as described below, to determine the response of both helmet designs in terms of AIS injury severity for a given impact severity. Because an impact to the head induces both linear and rotational motions, it was necessary to develop a method of assessing the performance and protection provided by the helmet with regard to both mechanisms. The GAMBIT assessment criterion was chosen for this study because it considers both linear and rotational motions and allows both impact components to be combined to give an indication of injury severity[1]. Although the COST 327 report found that the relationship between GAMBIT and AIS was low (r^2 = 0.0751), the replication data was reviewed and results from motorsport accident replication tests were included. This analysis produced a correlation coefficient of 0.57 (r^2 = 0.3214). It should be noted that the fatal cases were not included in this study. The following section describes the methodology for comparing the performance of the current and advanced helmets in terms of AIS injury outcome.

The relationship between impact velocity and peak linear acceleration, shown in Figure 2, was determined using test data from helmet tests onto rigid anvils. The advanced helmet was designed to provide protection during normal impacts up to 10m/s onto the rigid anvils compared with 7.5m/s for current helmets. The results show that the advanced helmet provides similar protection to the current helmet up to approximately 7m/s (normal impact velocity). At higher velocities the protection provided by the advanced helmet is considerably increased.

The advanced helmet was designed to provide improved protection during oblique impacts by having a very low friction outer surface. Figure 3 shows the relationship between linear and rotational accelerations for both current and advanced helmets based on the results from the ECE Regulation 22 (Method A) tests and the accident replication tests. The figure also shows a linear regression between the two parameters. It can be seen that the advanced helmet achieves

[1] The analysis needed such a relationship in order to carry out the risk of injury reduction analysis. In the absence of other combinational criteria, GAMBIT was used.

considerably lower rotational accelerations for a given linear acceleration. The results from Figure 2 and Figure 3 were combined to provide a relationship between equivalent normal impact velocity and peak rotational acceleration (Figure 4). It can be seen that the advanced helmet provides slightly improved protection up to approximately 7m/s and significant improved protection for higher impact speeds. The accident replication results, for the current helmet, were further analysed by plotting the normal impact velocity component against the peak rotational acceleration. The equation of the line of best fit was found to be $y = 1230.9x^{1.362}$. This line, as presented in Figure 4, was found to very closely agree with the rotational acceleration response curve for the current helmet and, therefore, was considered to support the validation of this methodology.

The relationship between impact velocity and GAMBIT results was determined by combining the results from Figure 2 (linear acceleration) and Figure 4 (rotational acceleration) using the equation below (see Figure 6).

$$GAMBIT = \sqrt{(g/250)^2 + (rad/s^2/10{,}000)^2}$$

The relationship between impact velocity and AIS (Figure 6) was determined using the results in Figure 5 and the following expression which was established from the analysis of accident replication data;

$$AIS = 2.0273 Ln(GAMBIT) + 2.0933$$

The results in Figure 6 can be used to compare the performance of the current and advanced helmets in terms of AIS injury outcome. Based on this study, it was possible to estimate the injury reduction benefits of the advanced helmet for those accident types where it was considered that an improved helmet could reduce the level of head injury. The following AIS injury reductions were used for the next part of this study.

- AIS 6 injuries reduced to AIS 4
- AIS 5 and 4 injuries reduced to AIS 3
- AIS 3 remain AIS 3 *
- AIS 2 remain AIS 2 *
- AIS 1 remain AIS 1 *

** although the AIS 1, 2 and 3 levels are shown to be reduced with the advanced helmet (Figure 6), the reductions were less than one whole AIS level. And, therefore, for the purpose of this study it was considered that the advanced helmet would provide the same injury outcome for these accidents.*

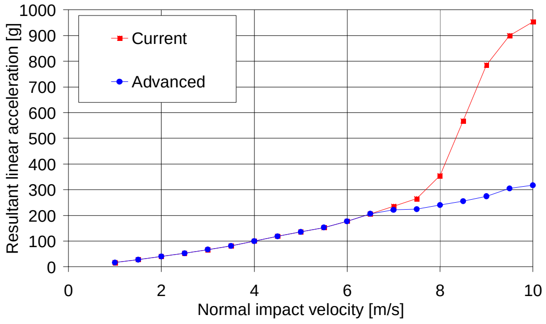


Figure 2. Relationship between impact velocity and linear acceleration for current and advanced helmets

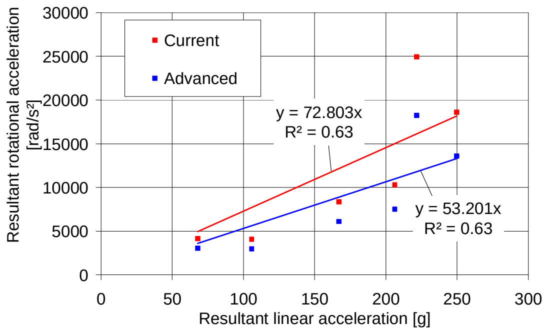


Figure 3. Relationship between linear acceleration and rotational acceleration current and advanced helmets

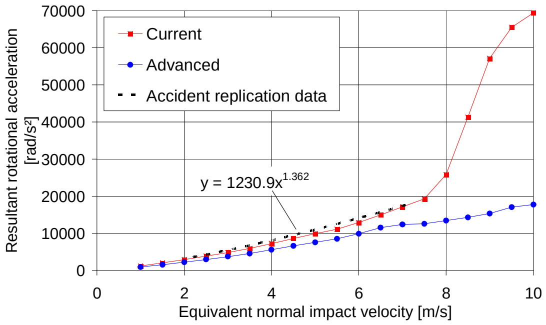


Figure 4. Relationship between impact velocity and rotational acceleration for current and advanced helmets

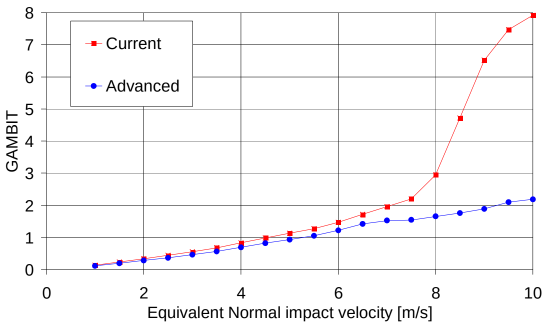


Figure 5. Relationship between impact velocity and GAMBIT for current and advanced helmets

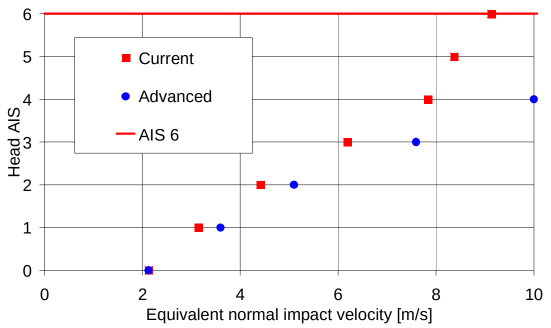


Figure 6. Relationship between impact velocity and AIS injury severity for current and advanced helmets

INJURY REDUCTION ANALYSIS

Assessment of benefits

Number of casualties who may benefit from an improved helmet - In order to evaluate the number of motorcyclists that may potentially benefit from an advanced helmet it was necessary to examine the national accident data. Table 6 indicates the number of Two-Wheeled Motor Vehicle (TWMV) casualties, by casualty severity, for the years 1999 to 2002 [6].

For the purposes of the cost benefit analysis the mean casualty severity values (1999-2001) were used. COST 327 [1] accident data analysis has suggested that 81.3% fatal, 67.9% serious, and 37.7% slight injured riders sustained head impacts which corresponded to 470 fatal, 4,493 serious and 7,744 slight.

Table 6. Motorcycle casualties (1999-2001; RABG 2002 [6])

Casualty severity	1999	2000	2001	1999-2001 (mean)
Fatal	547	605	583	578
Serious	6,361	6,769	6,722	6,617
Slight	19,284	20,838	21,505	20,542

It was important to consider specifically the cases for which head was the most severely injured body region as these cases would benefit most from an improved helmet design. Based on data presented by Chinn [7], the head was the most severely injured body region in 80% of fatal and 70% of serious cases where a head impact was sustained, which corresponded to 376 fatal and 3,145 serious cases. It was estimated that the proportion of slight injuries where the head was the most severely injured body region was 60% corresponding to 4,647 cases. A summary of these results is provided in Table 7 below.

Table 7. Annual number of motorcycle accidents where riders or pillions suffered head injuries

Casualty severity	All casualties (1999-2001) (A)	Casualties with head injury (B)	Casualties with head injury *and head most severely injured region* (C)
Fatal	578	470 (81.3% of A)	376 (80% of B)
Serious	6,617	4,493 (67.9% of A)	3,145 (70% of B)
Slight	20,542	7,744 (37.7% of A)	4,647 (60% of B)

AIS distribution of casualties who may benefit from an improved helmet - The AIS (AAAM, 1990) distribution of those casualties whose head was the most severely injured body region was estimated by reviewing 158 cases from the COST 327 accident replication project for which detailed accident and injury data has been analysed. The AIS injury distribution is presented in Table 8, below.

Table 8. Head AIS injury distribution for fatal, serious and slight motorcycle casualties

	Head AIS						
Casualty severity	6	5	4	3	2	1	All
Fatal*	33.3 %	33.3 %	22.2 %	11.1 %	0 %	0 %	100 %
Serious*	0 %	13.0 %	13.0 %	17.4 %	56.5 %	0 %	100 %
SlightÜ	0 %	0 %	0 %	0 %	12 %	88 %	100 %

* based on analysis of 158 cases from COST 327

Übased on COST 327 final report

The AIS distribution (Table 8) was combined with the estimated number of casualties whose head was the most severely injured body region (Table 7) to derive the data presented in Table 9 below. The numbers of slight casualties in Table 9 were distributed according to data contained within the COST 327 final report which indicated that 88% of slight injures are AIS 1 in severity; the remainder of injuries were assumed to be AIS 2 injuries.

Table 9. AIS injury distribution for casualties with head most severely injured body region

	Head AIS						
Casualty severity	6	5	4	3	2	1	All
Fatal	125	125	84	42	0	0	376
Serious	0	409	409	547	1,777	0	3,145
Slight	0	0	0	0	558	4,089	4,647
All severities	**125**	**534**	**492**	**589**	**2,335**	**4,089**	**8,167**

Further analysis of the Cost 327 cases was made to determine whether or not the advanced helmet design would have provided improved protection to the wearer. The impact kinematics, impact type and impact mechanisms were considered, including an assessment of the linear and rotational injury potential. It was important to consider both the type and the severity of the impacts to determine which cases exceeded the protective capability of even the advanced protective helmet. Other cases involved impacts with aggressive structures or impacts through the visor that would not be protected by the advanced helmet. Table 10 presents a summary of this analysis with an estimate of the proportion of cases of each AIS severity that may have benefited from the advanced protective helmet.

Table 10. Proportion of casesÜ for which an advanced helmet may provide additional protection.

	Head AIS					
Casualty severity	6	5	4	3	2	1
Fatal	16.7 %	66.7 %	100 %	100 %		
Serious		100 %	100 %	75 %	92 %	
Slight					92 %	40 %

Ü*cases with head injury and head most severely injured region*

The values in Table 10 were combined with the values in Table 9 to provide an estimate of the number of casualties that may have had an improved injury outcome with the advanced helmet. This calculation assumes that every motorcycle rider, irrespective of factors (such as rider age, motorcycle make or model and engine capacity) is equally likely to be involved in an accident. These results are presented in Table 11.

Table 11. Number of casualties where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Casualty severity	**Head AIS**						**Total**
	6	5	4	3	2	1	
Fatal	21	84	84	42			**230**
Serious		409	409	410	1,635		**2,863**
Slight					513	1,636	**2,149**
All severities	**21**	**492**	**492**	**452**	**2,148**	**1,636**	**5,241**

Thus, if all motorcycle riders wore helmets to the performance specification of the advanced helmet, there is potential to improve injury outcome for 230 fatal, 2,863 serious and 4,647 slight per annum (see Table 11). The next part of the analysis was to quantify the *magnitude* of benefit that would be afforded by the advanced helmet. A summary of this analysis is provided in Table 12 below.

Table 12. Comparison of AIS injury outcome for current and advanced helmet designs

AIS current helmet	AIS advanced helmetÜ
6	4
5	3
4	3
3	3
2	2
1	1

ÜAIS injury severity for those accidents where it was considered that the improved helmet may improve the injury outcome

Assessing the injury distribution for the advanced helmet - Using the AIS injury reduction levels presented in Figure 6 (summary in Table 12) it was possible to consider those accidents where an advanced helmet would have benefited the rider (Table 11) and determine the overall level of injury reduction. Table 13 shows the AIS distribution for both current and advanced helmets, assuming the advanced helmet had been worn for all the cases presented in Table 11. Table 14 shows the injury severity in terms of fatal, serious or slight, based on the values AIS values in Table 13. This analysis assumes that the distribution of injury severity (fatal, serious, slight) remains constant within each AIS classification for both current and advanced helmets.

The difference between the results in Table 14 and those in Table 11 represents the overall annual injury reduction that may be achieved with the advanced helmet, as shown in Table 15.

- The advanced helmet was found to have the potential of saving 94 lives and 434 serious injuries each year, approximately 20% and 7% respectively. If the same proportion of injury reduction could be achieved on European roads more than 1,000 of the 5,000 fatally injured riders and pillion passengers could be saved each year and a further 5,000 of the 70,000 serious injuries could be prevented.

Table 13. AIS severity distribution for current and advanced helmetsÜ

	AIS						Total
AIS distribution	6	5	4	3	2	1	
Current helmet	21	492	492	452	2,148	1,636	5,242
Predicted Advanced helmet	0	0	260	992	1,725	2,265	5,242

Ü*for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection*

Table 14. Injury severity distribution assuming the advanced helmet had been wornÜ

	AIS						Total
Casualty severity	6	5	4	3	2	1	
Fatal	0	0	44	92	0	0	136
Serious	0	0	216	901	1313	0	2,429
Slight	0	0	0	0	412	2265	2,677
All severities	0	0	260	992	1,725	2,265	5,242

Ü*for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection*

Table 15. Estimated annual injuries for current and advanced helmet design

	Current	Advanced	Reduction
Fatal	230	136	94
Serious	2,863	2,429	434
Slight	2,149	2,677	-528
All	5,242	5,242	0

COSTS AND MARKET PENETRATION

The advanced helmet is produced using relatively expensive materials and processes. The cost for each prototype carbon shell was approximately £1,000 including materials, production process and autoclave time etc. It was, therefore, important to consider the key cost issues if such helmets were to be mass produced to achieve significant sales penetration.

It was estimated that if such helmets were produced in medium volume, the production costs could be reduced to approximately £200, with a corresponding minimum retail price of £300 ñ around £150 more than a typical current helmet.

This price would be competitive with high end market products and sales volumes of up to 10% per year may be achievable. According to the UK Department for Transport (DfT) figures, there were 760,000 licensed Two-Wheel Motor Vehicles (TWMVs) in Great Britain in 1999 [8] It was assumed that the average rider purchases a new helmet every five years, giving estimated annual helmet sales of 152,000 units. This is consistent with the number of new registrations for TWMV; 168,000 in 1999 [8] since a proportion of TWMV riders may purchase a new vehicle but already own a helmet.

If 10% of all new helmets sold conformed to the new level of performance, the fleet penetration of this new helmet would be 2% in year one, 4% in year two, 6% in year three, 8% in year four and 10% in year five (a total of 76,000 units sold by year five).

With a fleet penetration of 10%, the new helmet has the potential to save approximately 10 lives and 45 serious injuries each on roads in Great Britain. Nevertheless, it is understood that in order for future standards to be based on the performance of the new helmet, it would be desirable to significantly reduce the production costs.

A WAY FORWORD

Given the potential performance of new helmet technology, the DfT has prompted a collaborative research effort with like-minded partners to develop the test methods that will be needed to assess new advanced helmet designs.

A partial Regulatory Impact Assessment (RIA) has been prepared for the UK DfT which suggests that a consumer information scheme might be the most practical way to encourage the supply and uptake of advanced motorcycle helmets to work towards a 20% reduction in motorcyclist fatalities.

On this basis, TRL, using their experience of Euro-NCAP and Primary NCAP, are currently developing a possible consumer information scheme for motorcycle safety helmets. Initially, interest is being sought from key stakeholders and research partners with proposals being developed for discussion in a small technical working group and with industry. Pilot assessments on a range of current and advanced helmets will be reported in a media-friendly format to complete the delivery of a ready to implement scheme. The actual tests will be based on those in Regulation 22-05, but amended as appropriate to ensure that better helmets can be identified and the objectives of the scheme achieved. Details of this and earlier related work may be found on www.mhap.info.

Further work, including physiological performance, is being taken forward in a new COST project and it is hoped that the costs of advanced helmets can be reduced through an EC 6th Framework Programme project under consideration.

CONCLUSIONS

- An advanced prototype helmet has been developed by TRL and industry which exceeds the safety performance specified by COST 327, offering improved protection from both linear and rotational loadings to the head.

- This was achieved with a lightweight carbon composite shell fitted with an optimised high-efficiency expanded polystyrene energy absorbing liner and a low friction sacrificial shell surface.

- The advanced helmet has the potential to achieve significant safety benefits over a conventional motorcycle helmet. It was estimated that the advanced helmet has the capability to reduce AIS 6 injuries to AIS 4 and AIS 5 and 4 injuries to AIS 3.

- National accident data was analysed in conjunction with data from COST 327 and the TRL motorcycle accident replication programme. It was estimated that of the 578 motorcycle riders (or pillions) killed each year (during 1999 and 2000) 93 lives could be saved if all riders had been wearing the advanced helmet. And a further 434 of the 6,617 serious injuries could be prevented.

- If the same proportion of injury reduction could be achieved on European roads, more than 1,000 of the 5,000 fatally injured riders could be saved each year and 5,000 of the 70,000 serious injuries could be prevented.

- It was estimated that the cost of producing the advanced helmet may be in the region of £200 per helmet. Thus a minimum retail price would likely be £300 - approximately £150 more than a typical current motorcycle helmet.

- Given the potential of the new helmet technology and performance, the DfT is leading a collaborative research effort to produce the test methods that could be used to assess the protection offered by new advanced helmet designs.

- A proposal has been submitted for an EC 6th Framework Programme project to take the current work forward and minimise the cost of advanced motorcycle helmets.

ACKNOWLEDGEMENTS

The DfT and TRL would like to thank all members of COST 327 for their valued contributions, without which this research would not have been possible.

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Appendix H. ESV 2005 Conference, Washington

(i) Technical Paper

(ii) <u>Presentation</u>

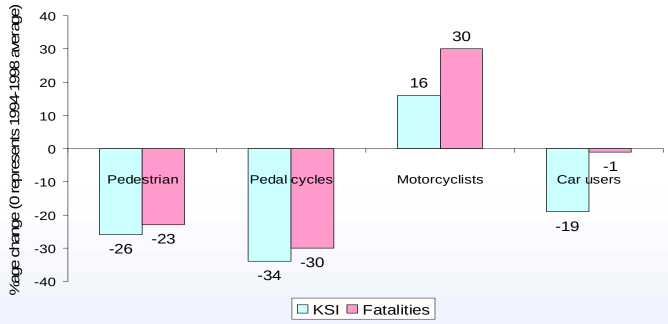
Advanced Motorcycle Helmets

Vincent St.Clair and Andrew Mellor

9th June 2005

NEED FOR NEW HELMETS

- **UK government road casualty reduction strategy (2000)**
  - 40% reduction in adult KSI



- **2010 - motorcyclists predicted to be 30% of fatalities**

COST 327

Motorcycle specific research - COST 327

- **Data collection and analysis**
  - 253 accident cases
    - Accident report
    - Medical report
    - Damaged helmet
- **Accident replications**
  - 21 accident cases
    - Linear and rotational acceleration
    - Correlation with injury

REPLICATION OF DAMAGE

Shell damage

Liner damage

COST 327 RECOMMENDATIONS

Helmet improvements:

- **30% lower head impact energy**

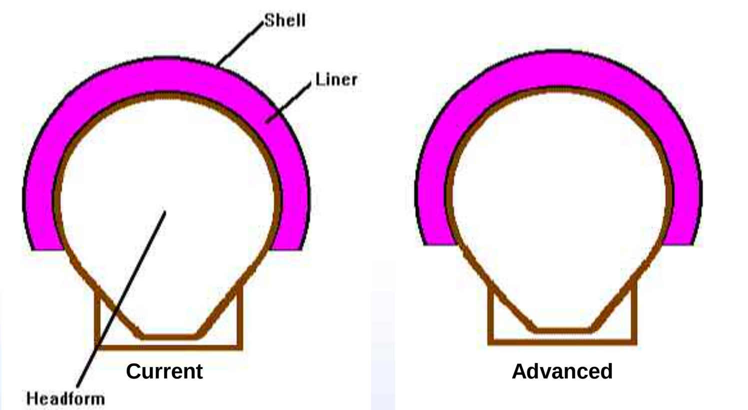
  = 50% AIS 5-6 reduced to AIS 2-4

- **Median speed for AIS 5-6 head injury: 57km/h (16m/s).**

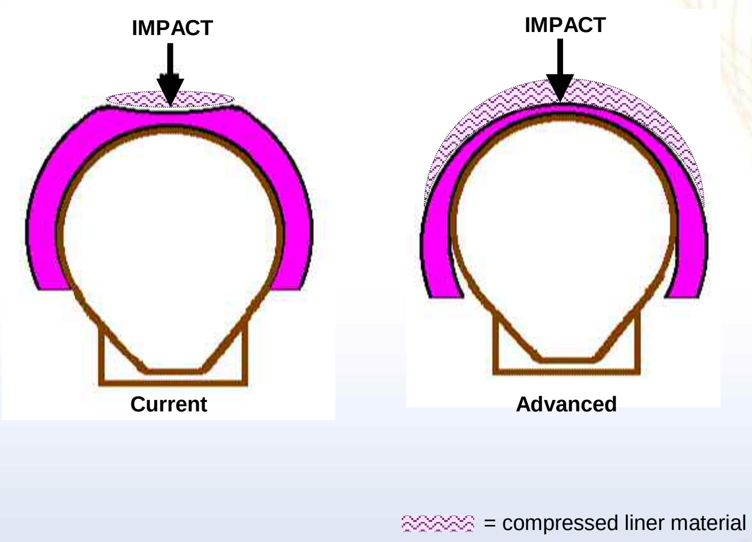
ADVANCED HELMET DESIGN

- **Helmet design parameters**
  - Increased energy absorption
  - Improved linear impact protection
  - Improved rotational protection
  - Current geometry and mass
- **Principle**
  - High stiffness shell & optimised liner
  - Low friction helmet surface

Shell stiffness

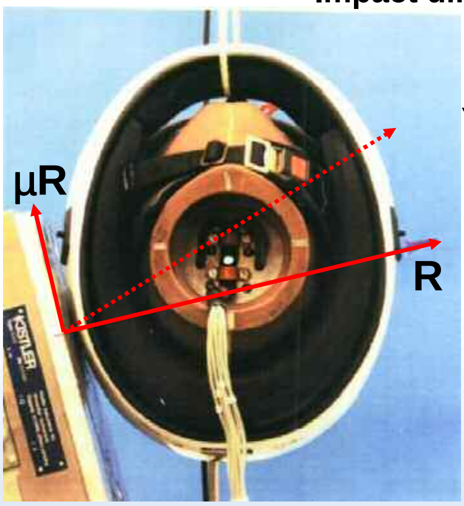


Shell stiffness



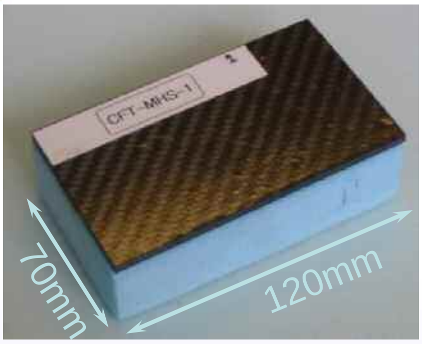
Shell friction

Impact direction



$\ddot{\theta} = f(\mu)$

Evaluation of shell materials



- Shell materials (2.9 - 10mm)
- Liner EPS substitute (35mm)

Linear impact testing of flat shell substrate

Summary of shell evaluation

- **Linear impact**

Sample	Mass [g]	Thickness [mm]	Peak Deformation [mm]		Peak Acceleration [g]	
			7.5 m/s	10 m/s	7.5 m/s	10 m/s
Target	***≤50***	***≤10***	***≤21***	***≤32***	***≥180***	***≤300***
PC (5.0mm)	50	5	**23**	**35**	**157**	**364**
Al (5.0mm)	**117**	5	18	26	204	293
Carbon fibre (2.9mm)	36.2	3.0	20	32	210	242

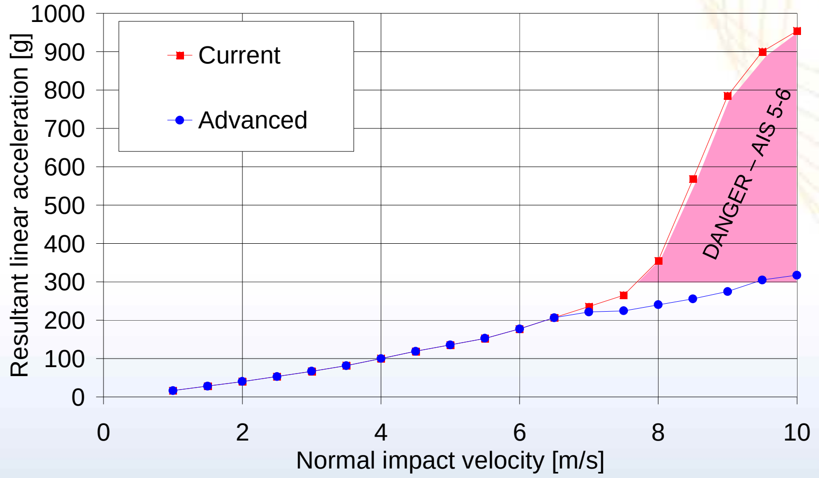
- **Surface friction**

Sample	Normal force [N]	Coefficient of friction (μ)	
		Peak	Sliding
Polycarbonate	1,900	0.77	0.42
Carbon fibre	2,000	0.17	0.12
Sacrificial layer	1,900	0.10	0.09

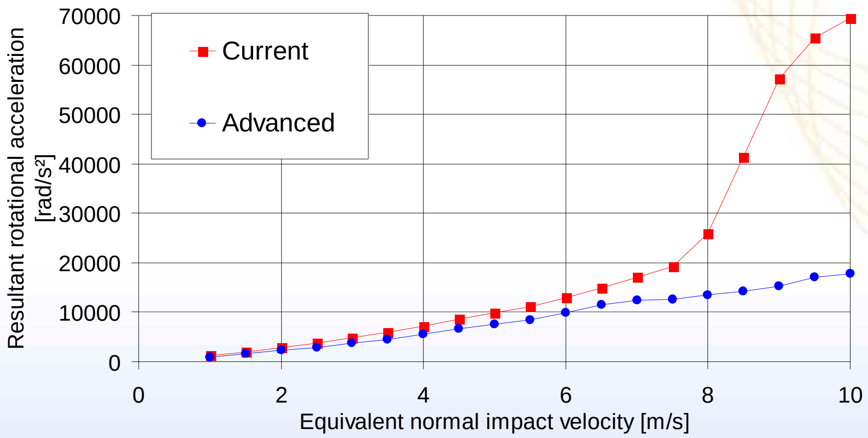
PROTOTYPE EVALUATION

- **Comparison with typical current EC Reg22 approved helmet**
- **EC Reg22 configuration**
  - Free motion headform
  - Kerb, Flat and Oblique (15º)
- **Performance evaluated to 10m/s (235J)** (linear impacts)

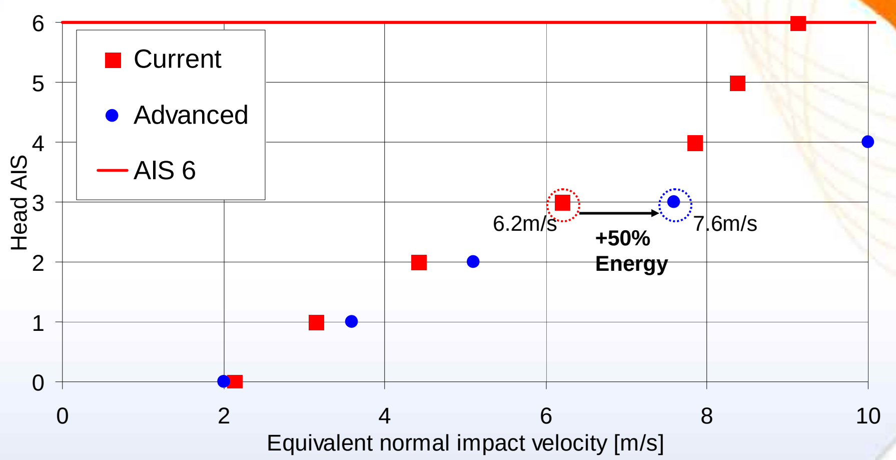
Linear impact performance



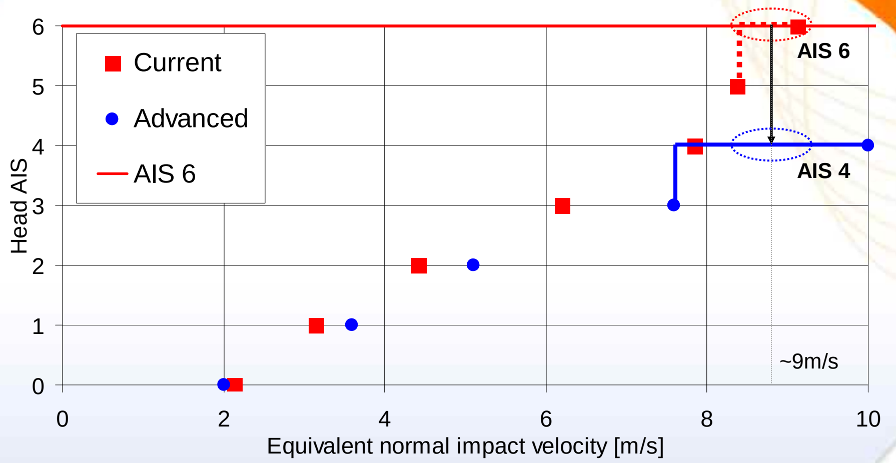
Oblique impact performance



Prototype evaluation



Prototype evaluation



INJURY BENEFIT ANAYSIS

- In UK - 578fatal, 6617serious (1999-2000)
- Advanced helmet prevents 20% fatalities/year
  (93 fatal and 434 serious /year)
- Europe - 1000fatal and 5000 serious prevented/year

TRL

WAY FORWARD

- **EC Framework 6 Project**
- **Legislation or CIS?**
  - New Consumer Information Scheme e.g. NCAP
  - New Regulation or revisions to existing (EC) regulation

TRL