Technical Session Eight

Motorcycle Safety

Chairman: Yoshio Nakamura, Japan

Development of a Safety Concept for Motorcycles—Results From Accident Analysis and Crash Tests

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Abstract

The high proportion of seriously injured persons and fatalities in traffic accidents involving motorcycles makes it clear that the protection of the motorcyclist is still not satisfactory. Since the middle of the Seventies it has therefore been an objective of accident research to reduce the injury risk of the motorcycle driver. By way of introduction, a survey is given of the current studies in Germany and abroad for improving motorcycle safety and of the different concepts.

The accident analyses, crash tests and mathematical simulations, carried out by the HUK-Verband, showed that the most important objective in reducing the severity of injuries is the optimization of the path of movement of a motorcyclist involved in an accident. Findings with regard to single vehicle accidents and with regard to the different collision types, if a motorcycle collides with another vehicle, are presented.

It can be seen that in both the accident in which no other vehicle was involved and in the different motorcycle/car-collision types, the reduced accident severity of the motorcyclist resulted from the controlled separation from his machine. This can be influenced by constructive measures, such as, for example, knee-pads, optimized tank and handle-bar designs, additional construction elements and possibly by an airbag in front of the motorcyclist.

Proposals for such safety designs are presented and their possible effects are estimated and discussed. On the basis of these scientific results questions relating to the practical application are dealt with.

Introduction

"Motorcycling has got safer," the motorcycle magazines in the Federal Republic of Germany announce, referring to the decline in the accident figures that can be observed in the last few years. A look at these figures, even in relation to the registrations, confirms this statement /1/.

Since 1982, the year with the largest number of motorcycle accidents and the largest number of motorcyclists killed (Figure 1), the clear downward trend has continued, although the increase in registrations still continues.

This pleasing development is due to various parameters, which, however, as they are related to active safety, will only be mentioned briefly.

The most important points which led to this development are improved training, the increasing number of places of further training, better traffic education for all road-users and technical improvement with regard to the driving stability and the brake systems /2,3,4,5,6,7,8/.

Unfortunately, this trend cannot be observed in the area of passive safety, i.e. measures aimed at reducing the severity of injuries, or, generally, the consequences of accidents.

The number of motorcyclists killed related to 1,000 traffic accidents shows (Figure 2), in the last few years, a very constant trend, i.e. over the last five years we can say that the risk has remained almost unchanged for an accident with a motorcycle.

Passive safety has therefore not yet been realised in the area of two-wheeler accidents.

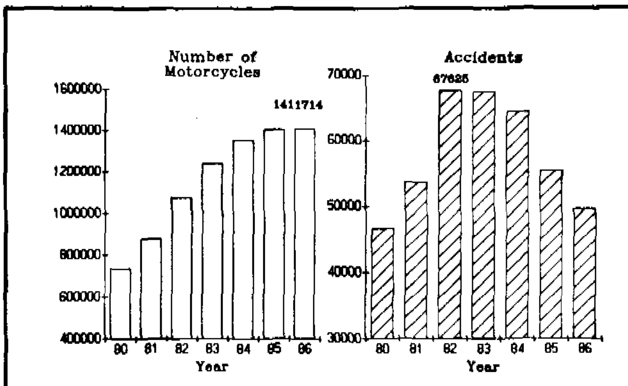


Figure 1

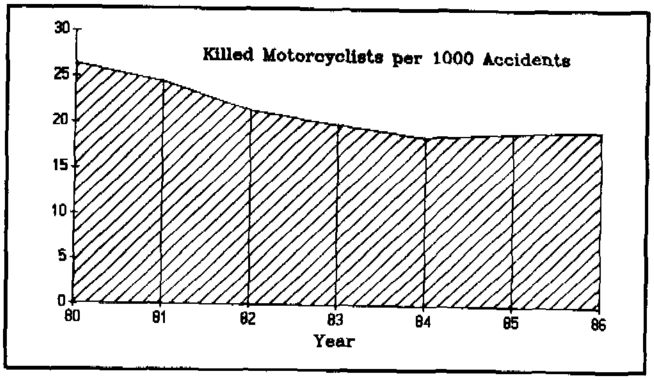


Figure 2

Man-Vehicle-Environment

A safety concept for motorcycles must cover all areas of the road traffic (Figure 3). This means that passive safety must also be related to the areas "Man" and "Environment" and must not deal solely with the "Vehicle".

Safety elements in the area "Man" relate mainly to the protective clothing and the crash helmet.

The most recent developments in this field show a clear increase in safety compared to the protective suits of only 5 to 10 years /9,10,11/.

One of the new materials, a special foam substance, only mentioned here as one example, is worked into the suit and thus increases the protective effect in the event of the direct application of force /13/. At the same time, however, movement is not impaired, so that these additional protective plates do not have a negative effect on active safety.

In the area "Environment" passive safety must concentrate, first and foremost, on neutralising aggressive obstacles at the side of the road /14,15/, but further improvements still have to be worked out for the other road-users /16/.

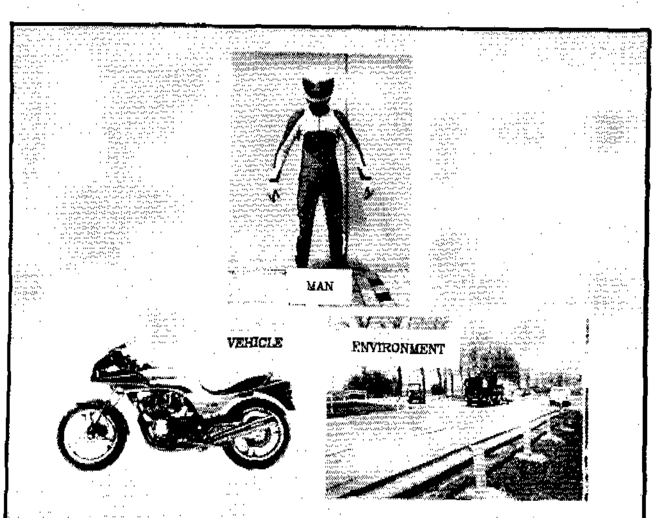


Figure 3

The most recent work in this field shows a construction with which the posts of guardrails can be enclosed. This reduces the impact against the guardrail posts, which often results in critical injuries and amputations.

Arranging the rest of the road demarcations with the motorcyclist in mind and neutralising the accident opponent's vehicle contours are also elements of importance in this area.

There remains the vehicle itself, which in the last 30 years has undergone hardly any changes as far as passive safety is concerned.

But the prerequisite for the development of a safety concept for motorcycles is the knowledge of how accidents happen, i.e. the motorcyclist's extremely different movement sequences as they occur in motorcycle accidents and the chances of injury which these involve have first to be analysed /17/.

Accident Systematic and Injury Distribution

A classification system which should be capable of describing *all* the possible motorcycle accidents does not work because of the large number of possible accident sequences and/or kinds of movements. For this reason it has proved practicable to divide up the ways in which motorised two-wheelers are involved in accidents into four main accident groups (Figure 4) which make a fundamental distinction in the ways in which the injuries arise but allow variations within the group /18/. These accident groups are:

- side collision (the motorcycle is hit)
- frontal collision (the motorcycle hits another vehicle with its front)
- grazing collision
- single accident

The first division is into single accidents and collisions. The collision groups themselves must be

Figure 4

subdivided into three different movement sequences, because a combined assessment of these accidents tell us nothing clearly about how the injuries arise.

The frequency of these accident groups (Figure 5) shows that the collision of a motorcycle with another road-user dominates.

A large number of undetected cases must be expected in the proportion of single accidents, since many of these accidents are not recorded by the police or by an insurance company. This is the only possible explanation for the fact that about one-third of all motorcyclists killed—this figure has remained constant over the last few years—lost their lives in single accidents, although the proportion of single accidents never exceeds about 20% in all the material /1/.

In the distribution of the injuries related to the two collision types "frontal- and side collision" (Figure 6) it can be seen that the proportion of injuries to the lower extremities come first and are nearly equal. The difference of these two accident groups is shown by the injuries of the head. For the frontal collision it is therefore the main aim to reduce the risk of head injuries.

Generally you can say, that the injury risk for a motorcycle-user is lower when he is engaged in a side-collision. In a frontal-collision, in nearly every body region the frequency of injury is higher.

Realisation of Safety Concepts

The frequency of the last-mentioned accident group, the severitiy of injury within this group and the possibility of constructively working out improvements for this accident group, were, at the beginning of the research work in the two-wheeler sector, the reasons for concentrating on this accident group alone /20/.

In the meantime improvements and new safety elements have also been developed for the remaining accident groups and they will be presented below. But in the practical application of the safety elements developed it is important that a safety element which works well in one accident group should by no means

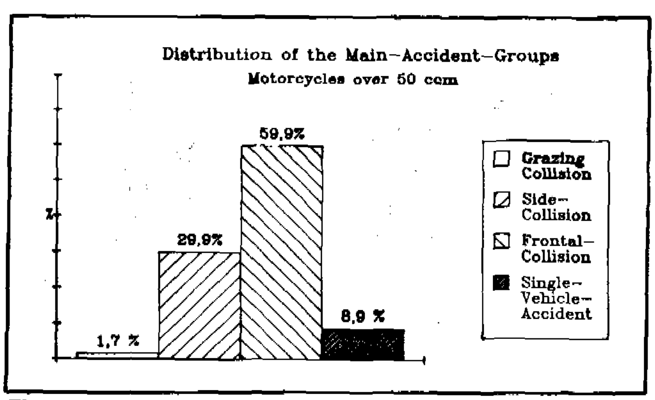


Figure 5

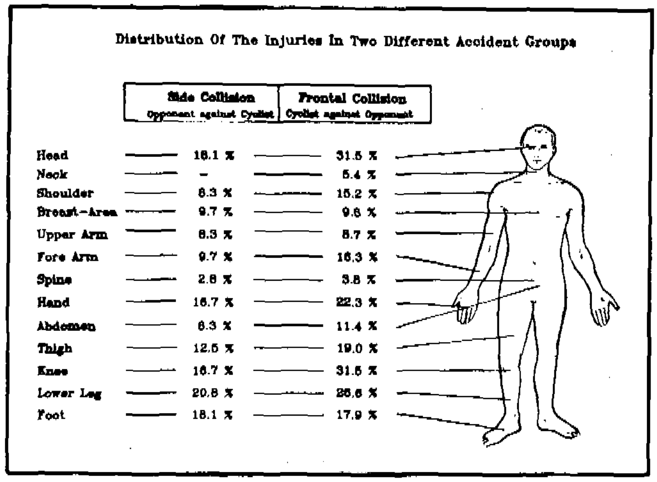


Figure 6

have negative effects on one of the other accident groups. On the one hand, this special search for safety elements and, on the other hand, comprehensive knowledge of the overall two-wheeler's accident picture has led to the development of a concept, some of the main features of which have already been taken up by the manufacturers.

Directions of Passive Safety

So how can the motorcyclist's injury risk be reduced? In recent times two directions (Figure 7) have taken shape, both of which aim at reducing injuries but which go fundamentally different ways.

One of these directions is concerned with the possibility of influencing the movement path of the motorcyclist, so that dangerous contacts with his motorcycle and/or with the accident opponent can be avoided. This direction concentrates on avoiding the motorcyclist becoming entangled with his own machine and on deflecting the body when impact with an obstacle occurs.

In the second case, the motorcyclist should be held more firmly in position by creating a restraint system which, similar to the one used for car occupants, passes on a tolerable deceleration resulting from the design of the machine to the driver.

The practical solution provides for a safety belt or knee pads in front of the driver's chest /21,22,23/.

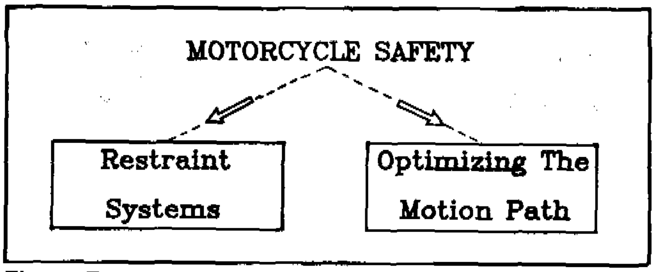


Figure 7

A prerequisite for this equipment to work is the controlled speed reduction by an appropriate design of a deformable zone. But this is not possible with a normal motorcycle, since the design of the motorcycle would have to be fundamentally changed if a restraint device of this kind is to fulfill its purpose.

An example (Figure 8) of what this may look like in reality was presented at the last ESV-Conference in the fringe programme two years ago and with this kind of vehicle a gain in safety by using a safety belt is within the bounds of possibility, but for the normal construction of a motorcycle the idea of a safety belt should not be pursued any further.

Influencing the flight path, that is the second possibility of realising a passive safety concept for the motorcycle, can be integrated into the present-day design of a motorcycle.

Frontal Collisions

Optimizing the motion path

The basis of this concept was the result of studies which showed that, in comparable accidents, i.e. collisions in which a motorcyle runs into an accident opponent, the motorcyclists were injured least severely when they were able to "fly over" their accident opponent /24,25,26/. This may take place completely or partially; in any event the direct impact of the head against the car must be avoided.

The evaluation of these accidents shows that the severity of injury in the case of a "fly-over" was, in every speed range, below the injury severity of the motorcyclist who impacted directly with the accident opponent.

A comparison of the injuries to the individual parts of the body (Figure 9), broken down according to "fly-over" and "impact", also makes it clear that the frequency of the serious head injuries decreases in the case of a "fly-over".

Distribution Of The Injuries In Different Motion Sequences

	" Impact " AIS 5 – 6	" Impact " AIS 3 – 4	" Impact " AIS 1 – 2	" Fly-Over " AIS 1 – 2	" Fly-Over " AIS 3 – 4	" Fly-Over " AIS 5 – 6
Head	14%	15%	79%	42%	3%	6%
Neck						
Shoulder		4%	21%	29%		
Breast-Area	2%	6%	6%	6%		
Upper Arm		4%	14%	7%	1%	
Fore Arm		10%	14%	12%	1%	
Spine			2%		1%	
Hand		2%	31%	29%	4%	
Abdomen	2%	6%	4%	13%	3%	
Thigh		6%	14%	29%	7%	
Knee			44%	36%		
Lower Leg		6%	19%	34%	12%	
Foot		2%	21%	20%		

Figure 9

With the lower extremities, the differences are not as clear. This is due to the fact that, even in the case of a "fly-over" the motorcyclist's legs can be caught on the handlebars or can graze the accident opponent if there is no knee-pad.

First proposal for a safer motorcycle

The findings of the analyses mentioned of real-life accidents were tested and confirmed by us by means of experimental simulation and mathematical calculations.

This first test serie (Figure 10) was already presented at the last ESV Conference, and, as a result of these experiments, a safety motorcycle /27/ was presented which possessed the following additional and/or altered characteristics.

By combining knee-pads in front of the legs of the driver with a touring handlebar it was possible, on the one hand, for the driver to avoid leg contact with his own handlebar and the accident opponent and, at the same time, to reduce a direct impact of the head against the edge of a car's roof by means of an

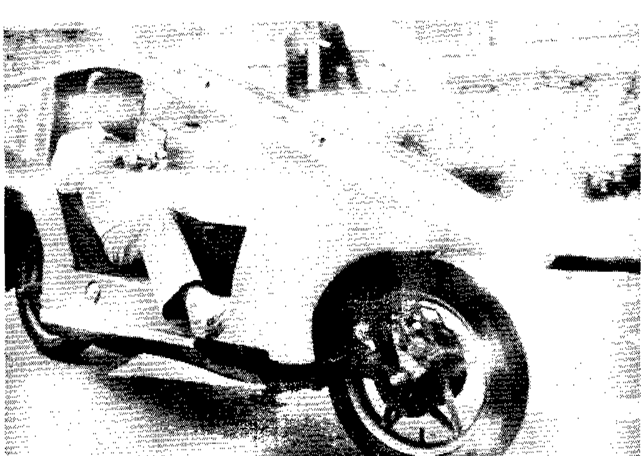


Figure 8

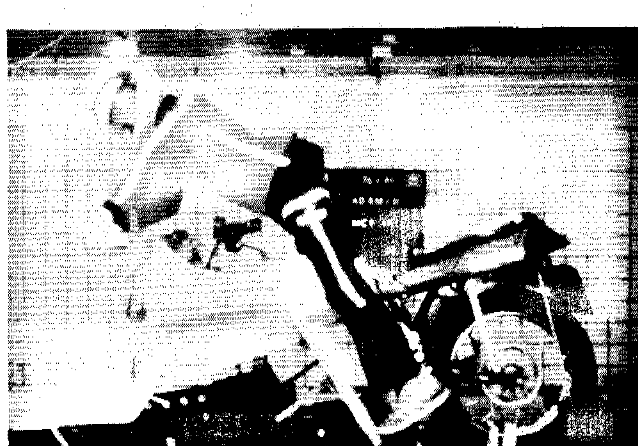


Figure 10

upright sitting position. On impact the motorcyclist did not become entangled in his machine and the prerequisite for a "fly-over" with reduced injury risk was created. This concept is supported by a ramp-like design of the tank, since it is the lower part of the driver's body which first strikes this part of the machine after a pause of about 30 ms. Raising the seat also results in further advantages, but it is in contradiction to considerations of driving dynamics, since the position of the centre of gravity has an effect on the handling of the motorcycle. A suggestion proposed by us at that time was to design the seat with a variable height, so that even drivers of different physiques would be able to handle one and the same motorcycle ideally.

A further, although very small, contribution, namely to take the head away from the accident opponent's danger zone, can be made by an anti-dive system, when, during an emergency braking, the dipping of the front wheel fork and thus the lowering of the body are avoided. Even the few centrimetres thus gained in height can be decisive for the severity of the injuries.

These measures that were proposed were the first step towards optimizing the driver's movement path; but it also became clear that a direct impact could not be completely avoided. For this reason the possibility of the motorcyclist actively inducing his flight path by bringing his body into the upright position shortly before the collision was also pointed out. That is, of course, not possible in all cases, and this is the reason why a closer study was made of another safety element which up to now has only made an appearance in the car sector, the airbag.

The airbag could, under circumstances (Figure 11), perform a function within the safety elements of the motorcycle as well. The most important prerequisite is, however, that the airbag is not conceived as a restraint system, but that its function is also extended to include the influencing of the flight path.

The first tests with airbags on the motorcycle go back 15 years and unfortunately nothing is known about a continuation of this work. It was not until 1985 at the ESV Conference in Oxford that two proposals for a "two-wheeler-airbag" was published /29,30/, one of the contributions being based on a test series by our office. This test series has, in the meantime, been continued and its findings can be summed up as follows.

Experiments were carried out with and without the airbag on a sledge facility, which allows the simulation of the simplified cause of a collision.

The motion sequence without an airbag (Figure 12) shows the direct impact against the simulated obstacle. The dummy's head smashes into the obstacle in the area of the visor's opening and at the same time its legs are caught up on the handlebar.

The same experience with an airbag and a knee-pad (Figure 13) clearly shows that no contact takes place between the head and the obstacle and that the motion path of the dummy is reflected upwards. This test series was made at a speed of 40 km/h, and at higher speeds it is to be assumed that the component of the dummy's upward direction of movement will be shifted further forward.

In the case of a frontal impact therefore a safety effect of the airbag can be observed. The problems which have still to be overcome thus concentrate on the economic feasibility, since the technical realisation of the triggering device still requires extensive work. In this connection the question of the all-mechanical airbag /31/ also has to be discussed, which in an amazingly simple way makes the ignition of the airbag a purely mechanical problem, without electrical sensors.

Nevertheless, there are still some problems to be solved, the following points being of paramount importance:

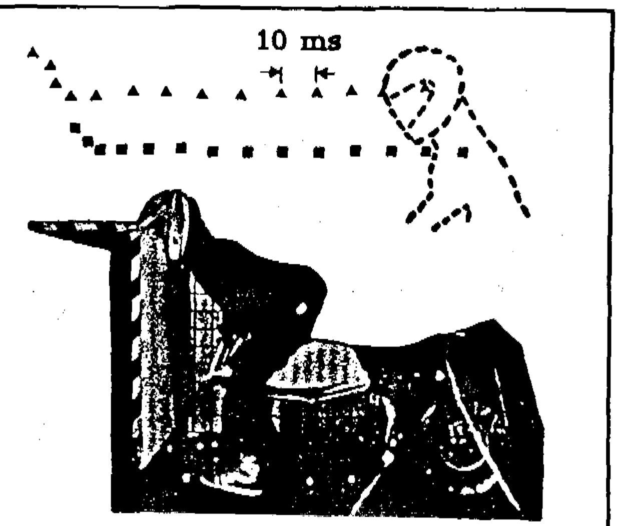
- triggering reliability
- sensor development
- economy.

Function Of A Motorcycle Airbag

Cushioning The Impact

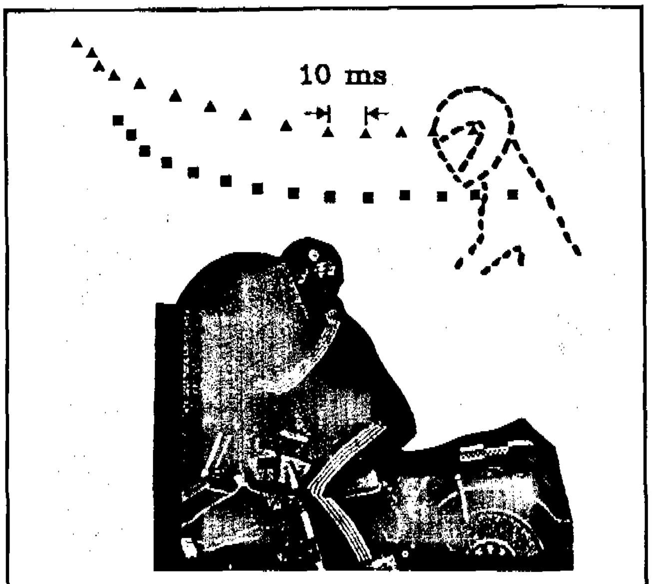
Influence On The Flight Path

Figure 11



Dummy Motion without Airbag
40 km/h Collision Speed

Figure 12



Dummy Motion with Airbag
40 km/h Collision Speed

Figure 13

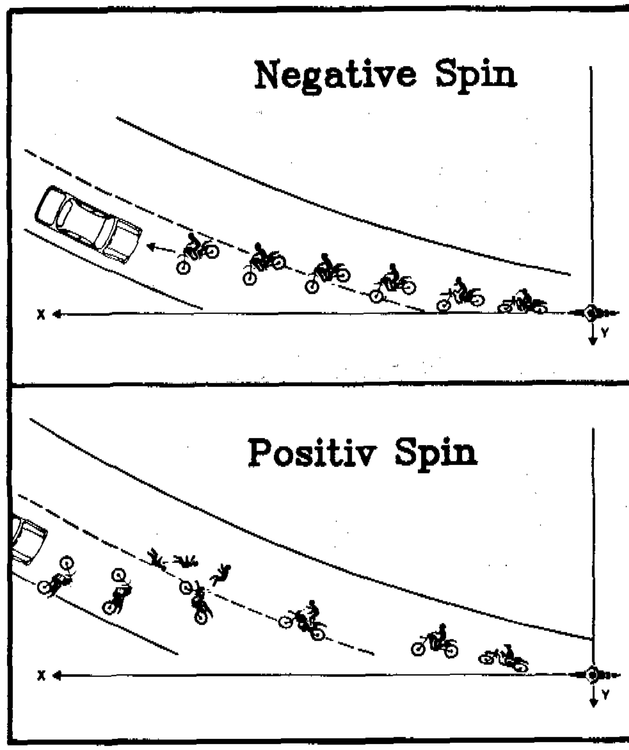


Figure 14

The usefulness of crash sensors on the basis of a special sound emission when the front wheel fork is bent is at present being examined by us. Combined with a normal deceleration element, this triggering mechanism could, under circumstances, meet the high demands required in the case of the motorcycle.

Single Accidents

For the remaining accident groups it has already been stated that the injury risk of the lower extremities comes first. At the same time it also applies to these accident groups that the injury risk of the whole body can be reduced if there is a separation of the motorcyclist from his machine. In the accident group termed "single accident" a new possibility of helping this separation to take place has emerged. By analysing 300 single accidents it was shown that a positive turning movement (positive spin) of the motorcycle (Figure 14) that has fallen over, i.e. when the motorcycle continues to turn in the curve through which it is driving, helps to bring about a separation of driver and machine /32/.

If a negative turn takes place (negative spin) and the motorcyclist cannot separate himself from his machine and he is deflected into the path of on-coming traffic together with the motorcycle and may thus become endangered by the on-coming traffic.

In a subsequent experimental and mathematical simulation it was possible to define special friction areas which have an effect on the turning movement of the skidding motorcycle.

Thus an area with the highest possible friction values in the region above the motorcycle's centre of gravity in combination with an area with a low friction value below the centre of gravity produce the best conditions for a positive turning movement. These friction areas could be integrated relatively unobtrusively into a motorcycle by means of the covering panels. In addition to this, however, the footrests, gearchange and brake would also have to be modified somewhat in their design, so that the anti-friction properties are improved.

At any rate, this development shows that by means of systematic analysis solutions can always be worked out which result in a further step towards passive safety.

Grazing Collision and Side Collision

With the last two accident groups it becomes clear how endangered the lower extremities of the motorcyclist are. In the case of these accident groups any contact is aimed at the area above the footrests up to about the level of the tank. While most grazing collisions lead to serious smashing of the knee or amputations, in the case of side collisions for the most part bruises and fractures can be observed. A safety concept for these groups has to overcome, first of all, the limited possibility of working out any design improvements.

Although the protective cages some people have proposed /33/ do help, they turn the motorcycle into a specialised vehicle once again. The only feasible way is to strengthen the covering panels, if a knee pad is already in place in front of the legs, in combination with an additional strengthening of the side bags. The protective space thus gained has, above a certain impact speed, no longer any function, but it certainly helps in all cases in which slight to medium injuries are nowadays still sustained /34,35/.

Summary

A safety concept for motorcycles must cover all areas of the traffic scene. Measures taken with the motorcyclist, such as improved protective suits and helmets, adapting the environment by neutralising dangerous road demarcations and aggressive accident opponents and optimizing the motorcycle itself result in a reduction of the injury risk. In this connection it is absolutely essential to divide up the different sequences in order to work out how the injuries arise.

A synthesis of the proposed safety elements of the individual accident groups, while observing the rule that no negative effects on the neighbouring groups can be observed, results in a safety concept for a motorcycle (Figure 15) which constitutes a clear gain in passive safety.

Depending on the accident groups, the chances of success in reducing the injury risk can be recognized. The greatest prospects of success will come about in the case of frontal collisions of motorcycles, since here the design elements can show the greatest effect. Making it possible for the motorcyclist and his machine to be separated and to overcome the obstacle—both of these actions involving a low injury risk—shows the greatest chances of success.

In the remaining accident groups it is always the impact energy of the accident opponent and/or the post-crash movement in the case of a fall which decides the final injury pattern. It is very difficult to influence these parameters by taking measures to change the usual design of the motorcycle.

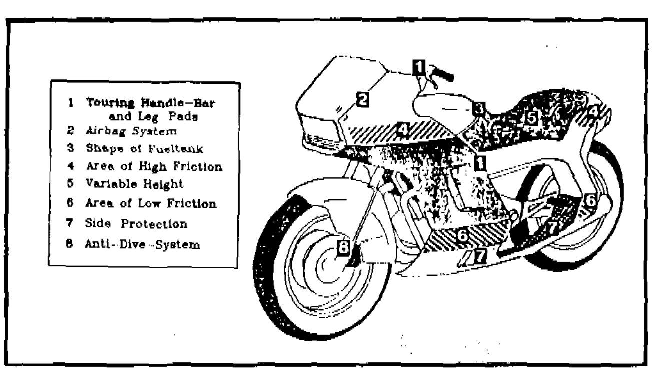


Figure 15

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A Study on Methods of Measuring Fields of View of Motorcycle Rearview Mirrors

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Abstract

This study involved 26 American motorcycle riders in an effort to establish measurement methods of rearward field of view of motorcycle rearview mirrors. A survey of rear-view mirror aiming, measurements of rider arm contour and computer simulations of rearward field of view were part of the study.

1. The survey of rear-view mirror aiming was carried out by checking the adjustments that the test riders had made on the test motorcycle with fairing mounted rear-view mirrors and on their own motorcycles. The results indicated that, to measure the rearward field of view, the rear-view mirrors should be adjusted at an angle where a light beam travelling from reference eye-point to mirror center was reflected in a horizontal and parallel manner to vehicle center line.
2. Arm contour was measured by taking photographs from the top and the side of the shoulder and arms of riders seated on two types of motorcycle mock-ups. Results showed that arm line was the significant factor in determining rider arm shadow.
3. Computer simulations of rearward field of view was conducted for three types of motorcycles. This resulted in a computer simulation program to examine the rearward field of view of motorcycle rear-view mirrors and measurement methods when using a three-dimensional manikin for motorcycles placed on motorcycle.

Introduction

A method for measuring the rearward field of view is a precondition for examining the design requirement (i.e. rear-view mirror curvature, size and mounting position) and the performance requirements (field of view reference) that determine the field of view of motorcycle rear-view mirrors.

In order to establish measurement method of rearward field of view of motorcycle rear-view mirror, it is necessary to determine the followng items.

1. Method of eye point determination as a reference point for field of view measurement.
2. Method of mirror aiming determination for selection of field of view.
3. Method of arm contour determination that prescribes inner field of view.

The method to establish eye point which is reference point for the field of view of rear-view mirror for motorcycle, and the development of the three-dimensional manikin for motorcycle which was necessary for the determination of eye point on the actual vehicle were reported based on the data of 155 American motorcycle riders at The 10th International Technical Conference on Experimental Safety Vehicles (Motoki & Asoh, 1985).

In order to use a manikin for measuring the rearward field of view of motorcycle rear-view mirrors and the method of determining arm contour had to be established.

Thus a survey was conducted to examine the rear-view mirror aiming methods of American motorcycle riders. Photographic measurements from the top and side were made of arm configurations of riders seated on a motorcycle mock-up to examine arm contour.

As the results of these studies, we propose the methods of measuring for field of view of rear-view mirror by using the three-dimensional manikin for motorcycle seated on the actual motorcycle and applications of computer simulations to examine the field of view of rear-view mirrors at the design stage.

Anthropometry

Purpose

Anthropometric measurements of a number of American motorcycle riders were made to obtain a variety of anthropometric data. These data were compared with eye-point measurement data[1] of 155 American motorcycle riders.

Method

Measuring Instruments. Anthropometers and a sliding caliper were used for the measurement.

Measuring Points. Before starting the measurements, measuring points indicated in Figure 1 that were difficult to locate visually (e.g. cervical, left and right acromions, right radiale, left and right trochanterions and sphyrion) were located manually and marked.

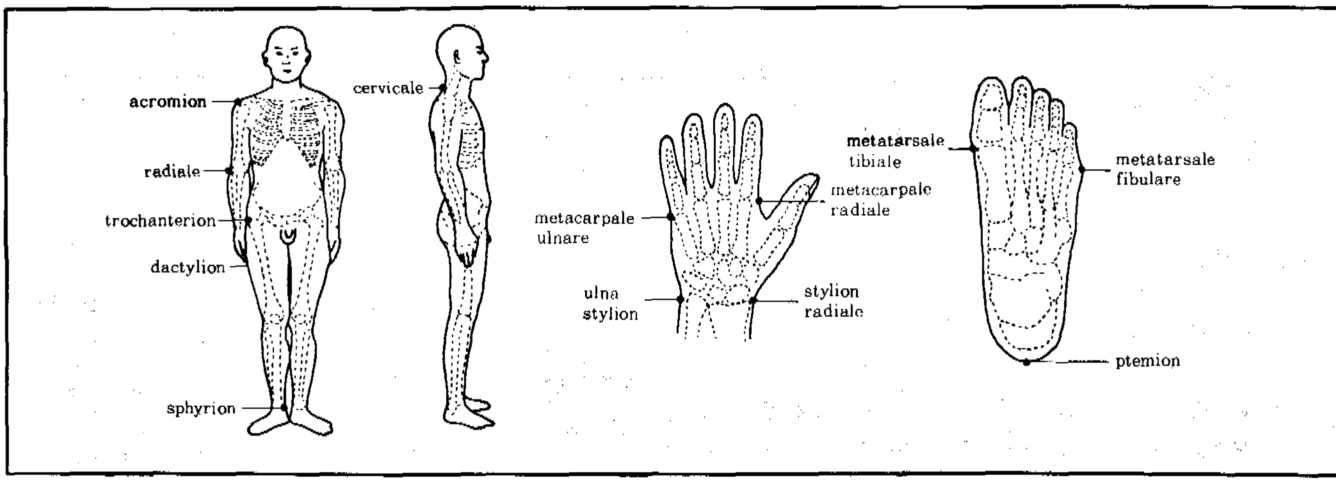


Figure 1. Measurement points

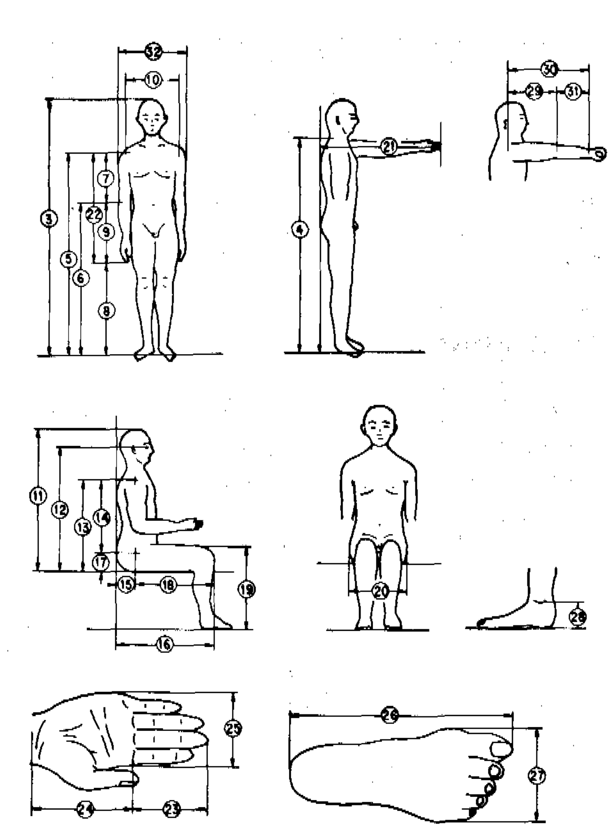
Anthropometry Items and Physical Members for Measurement. The anthropometry items and physical members for measurement are shown in Figure 2.

(1) Measurements in standing position

The subjects were placed in a natural standing position with the face forward, the right and left tragions and the right orbitale in the horizontal plane (i.e. ears and eyes horizontally). The arms were kept close to the body with the palms lightly touching thighs. (This position was not used for measurements 21, 29, 30 and 31).

(2) Measurements in seated position

The height of the chair was adjusted so that the subjects occupied a natural position with thighs nearly horizontal and the legs bent at a right angle at the knees. The head had the same position as in standing.



These 32items are as follows:
1 (Age)
2 Body weight
3 Stature
4 Cervical height
5 Acromion height
6 Radiale height
7 (Acromion height) − (Radiale height)
8 Dactylion height
9 (Radiale height) − (Dactylion height)
10 (Biacromial breadth)
11 Sitting height
12 Eye to seated surface
13 Acromion to seated surface
14 (Acromion to seated surface) − (Trochanterion to seated surface)
15 Buttock trochanter length, sitting
16 Buttock−knee length, sitting
17 Trochanter to seated surface
18 (Buttock−knee length, sitting) − (Trochanter to buttock, sitting)
19 Knee height, sitting
20 Trochanter breadth, sitting
21 Armreach from back
22 Arm length (Acromion height−Dactylion height)
23 Finger III length
24 Palm III length
25 Hand breadth at metacarpale
26 Foot length
27 Foot breadth
28 Medial malleolus height
29 Shoulder elbow length (Acromion to radiale)
30 Shoulder−wrist length (Acromion to ulha stylion)
31 Elbow−wrist length (Radiale to ulna stylion)
32 Shoulder breadth (Maximum)

Figure 2. Anthropometry Items and physical members for measurement

The subjects wore only jogging shorts while being measured.

Subjects. The subjects included 26 American motorcycle riders who used motorcycles as everyday affairs, with an average age of 29 years.

Results

Table 1 shows a comparison of the eye-point measurement data obtained in anthropometric measurements of 155 American motorcycle riders in 1985[1]) and the data gathered in measuring the 26 motorcycle riders who took part in the present study.

This comparison shows that the subjects used for the present study were an average 3 kg lighter and 21 mm lower in stature. However, anthropometric data closely related to riding position were about the same. Thus the differences were only 4 mm in biacromial breadth, 4 mm in eye to seated surface, 4 mm in acromion to seated surface and 1 mm in arm length.

Measurements in Rear-View Mirror Aiming

Purpose

The rearward field of view varies greatly with the angle of the mirror. The purpose was to measure the aiming of rear-view mirrors and examine actual conditions of mirror angle adjustments on a European type motorcycle adjusted by riders and on motorcycles owned by them.

Table 1. Comparison of anthropometric data among American riders (mean value).

Item \ Date	1985 N=155	1987 N=26	Difference 1987–1985	Item \ Date	1985 N=155	1987 N=26	Difference 1987–1985
1. (Age)	29 (7)	29 (8)	0	17. Trochanter to seated surface	89 (9)	84 (9)	–5
2. Body weight	80 (12)	77 (14)	–3	18. Knee to trochanter length	488 (24)	490 (25)	+2
3. Stature	1775 (67)	1754 (66)	–21	19. Knee height, sitting	555 (28)	554 (26)	–1
4. Cervical height	1533 (64)	1515 (64)	–18	20. Trochanter breadth, sitting	375 (26)	366 (32)	–9
5. Acromion height	1454 (63)	1439 (63)	–15	21. Armreach from back	895 (44)	882 (46)	–13
6. Radiale height	1122 (50)	1108 (52)	–14	22. Arm length	780 (34)	779 (36)	–1
7. Acromion height -Radiale height	333 (21)	332 (16)	–1	23. Finger III length	83 (5)	84 (5)	+1
8. Dactylion height	674 (38)	660 (40)	–14	24. Palm III length	109 (6)	111 (7)	+2
9. Radiale height–Dactylion height	447 (31)	448 (24)	+1	25. Hand breadth at metacarpale	89 (4)	87 (5)	–2
10. Biacromial breadth	416 (18)	412 (21)	–4	26. Foot length	268 (13)	271 (15)	+3
11. Sitting height	914 (45)	915 (38)	+1	27. Foot breadth	107 (5)	106 (8)	–1
12. Eye to seated surface	786 (33)	790 (35)	+4	28. Medial malleolus height	76 (7)	75 (6)	–1
13. Acromion to seated surface	601 (40)	597 (33)	–4	29. Shoulder–elbow length	—	320 (14)	—
14. Acromion to trochanterion height	512 (39)	513 (29)	+1	30. Shoulder–wrist length	—	573 (25)	-
15. Buttock trochanter length, sitting	125 (12)	119 (9)	–6	31. Elbow–wrist length	—	253 (14)	–
16. Buttock knee length, sitting	610 (30)	609 (30)	–4	32. Shoulder breadth	—	470 (29)	—

Note: ( ) S.D. Unit (Age: Year, Weight: kg, Dimension: mm)

Method

Coordinate System. Three-dimensional indications of data in this study employ an orthogonal coordinate system where R′-point (the point of intersection of a vertical line through R-point and seat surface; refer to JASO T 006[2]) is used as origin (see Figure 3). Vehicle reference points and riding position are represented as shown in Figure 4 (refer to JASO T 005[3]).

Test Motorcycles. One European type motorcycle (see Figures 5, 6 and Table 2) with fairing mounted rear-view mirrors and the test riders' own motorcycles were used in the test. Three of the riders' own motorcycles had fairing mounted rear-view mirrors and the other 23 motorcycles had handlebar mounted rear-view mirrors. The measurements were made with each rider seated on the test motorcycle and on his own motorcycle; thus two types of data were gathered for each rider.

Test Motorcycles and Screen Locations. Relative locations between test motorcycles and screen is shown in Figure 7. The screen was placed 10 meters behind eye-point and was orthogonal to vehicle center line. The screen was ruled into 300 mm squares and each square was provided with a code to facilitate identification.

Test Motorcycles and Camera Position. The camera was placed on the vehicle center line 8 meters in front of R′-point. The height of the camera was identical with the R′-point of European type test motorcycle.

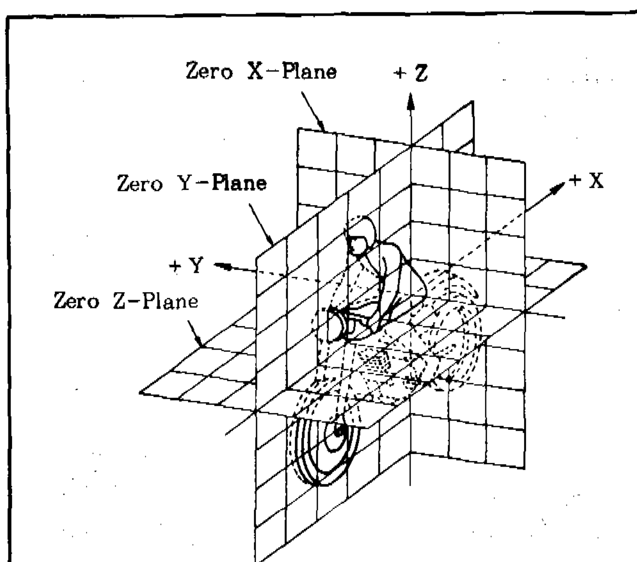


Figure 3. Three-dimensional reference system for motorcycle

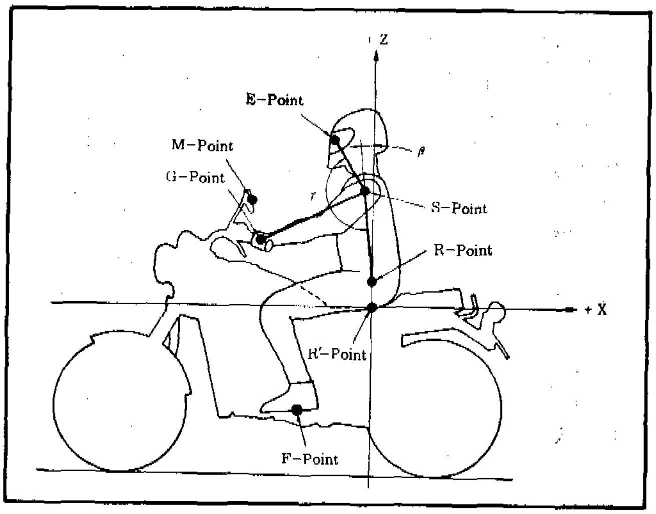


Figure 4. Marking method for riding position

Test Riders. 26 male American motorcycle riders participated in this test (as in Anthropometry).

Measuring Procedures.

(1) The riders rode the test vehicles over a 1 km straight course and adjusted the angle of the rear-view mirrors. The motorcycles brought in by the test riders were exempted from this part of the procedures.

(2) Motorcycle fixing jigs were used to fix the vehicles in an orthogonal position to the screen (see Figure 8).

(3) When the riders had taken a natural riding position on the motorcycles, it was checked that the vertical center plane of the vehicles were perpendicular. This was done with the help of the horizontal line on the focusing screen of the front camera.

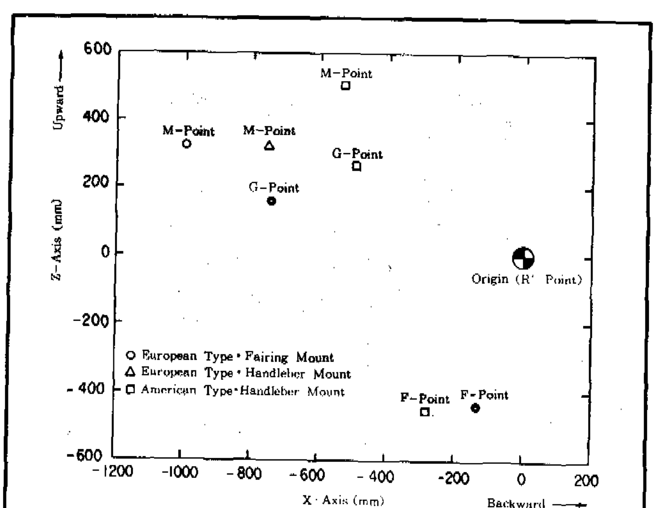


Figure 5. Locations of vehicle reference points (side-view)

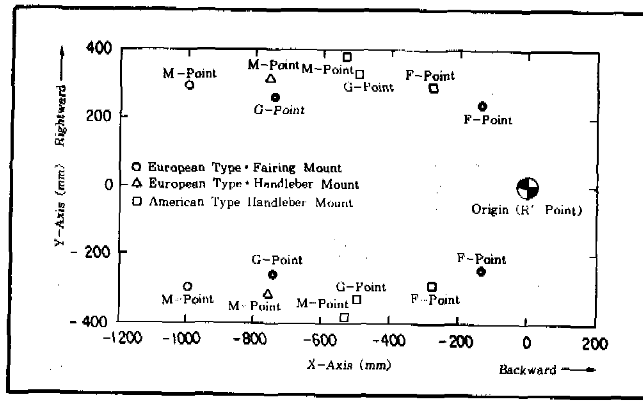


Figure 6. Locations of vehicle reference points (plan-view)

(4) The center of the right and left rear-view mirrors was marked and the distance between the two marks and their height were measured.

(5) The eye locations when a rider faced straight ahead and when he looked at the mirrors were photographed (Figures 9 and 10).

(6) The riders were asked to look at the mirrors and report which square of the screen could be seen at the center mark in the mirrors. The riders were made to look at the right mirror with the right eye and at the left mirror with the left eye.

Data Processing

(1) Eye location measurements

The 35 mm films taken during the test were read by a film analyzer with regard to the lateral difference (Y coordinate) between eye location when a rider faced forward and when he looked at the mirror.

Table 2. Locations of test vehicle reference points and rear-view mirror specification.

Type \ Item		Related Riding Position			Related Rear-View Mirror	
		R – Point	G – Point	F – Point	M – Point	Mirror Specification
1. European type • Fairing Mount (R'–Point Height from G/L: 800)	X	0	– 743	– 135	– 996	Vertical Width: 104
	Y	0	± 260	± 243	± 295	Lateral Width: 125
	Z	+ 60	+ 160	– 440	+ 325	R: 1200
2. European Type • Handlebar Mount (R'–Point Height from G/L: 800)	X	0	– 743	– 135	– 756	Ditto
	Y	0	± 260	± 243	± 315	
	Z	+ 60	+ 160	– 440	+ 320	
3. American Type • Handleber Mount (R'–Point Height from G/L: 820)	X	0	– 495	– 282	– 532	Ditto
	Y	0	± 330	± 290	± 380	
	Z	+ 60	+ 266	– 453	– 503	

Note: European type • fairing mount test vehicle was used in Mirror–aiming measurment, arm contour measurement and computer simulation. *European type • fairing mount test vehicle and American type test vehicles were used in arm contour measurement and computer simulation.* Unit (mm)

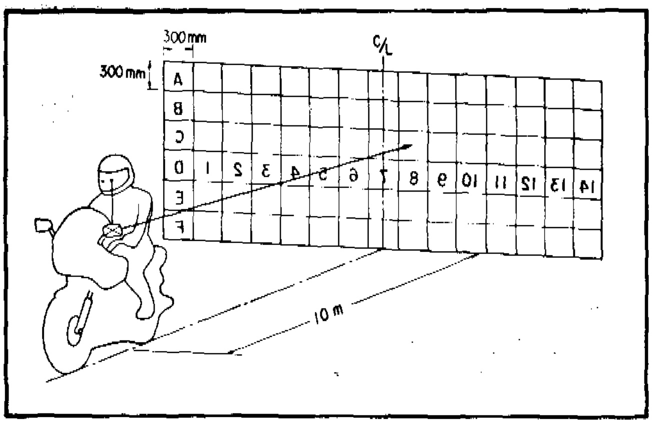


Figure 7. Measurement method of rear-view mirror aiming

Figure 9. Measurement of eye locations (looking forward)

(2) Measurement of rear-view mirror center position

The average value for mirror center position of right and left rear-view mirrors adjusted by the riders are calculated.

(3) Measuring rear-view mirror aiming

The distribution of square positions on the screen as reported by the riders and the median of the squares was examined.

Results and Consideration

Eye Location Differences. The mean value of the lateral difference (Y coordinate) between eye location when a rider faced forward and when he looked at the mirror was established for the 26 riders. A comparison showed that the difference in case of European type test motorcycle with fairing mounted rear-view mirrors was 15 mm and 35 mm for the riders' own motorcycles. This discrepancy was due to the difference between the mirror locations of European type test motorcycle and the rider's own motorcycles.

Rear-View Mirror Center Position. The average value for mirror center position of the right and left rear-view mirrors adjusted by the riders are given below. On the European type motorcycle with fairing mounted rear-view mirrors the center position was 295 mm outside of vehicle center line and 1125 mm high. On the riders' own motorcycles it was 345 mm outside of vehicle center line and 1241 mm high.

Rear-View Mirror Aiming

(1) The distribution of rear-view mirror aiming and median value

The distribution of rear-view mirror aiming and median for the different test mirrors as reported by the riders are shown in Figures 11, 12, 13 and 14.

The distribution of rear-view aiming showed that the lateral deviation was greater than the vertical deviation, as the more than 3.6 meter wide distribution on the screen 10 meters to the rear testified.

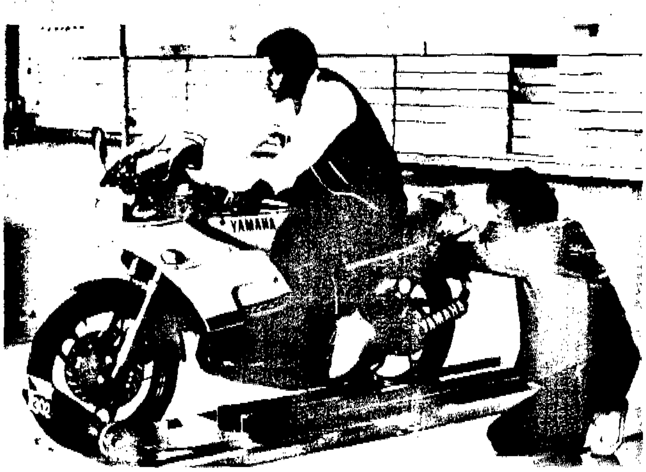


Figure 8. Test motorcycle (European type, fairing mount) with fixing jig

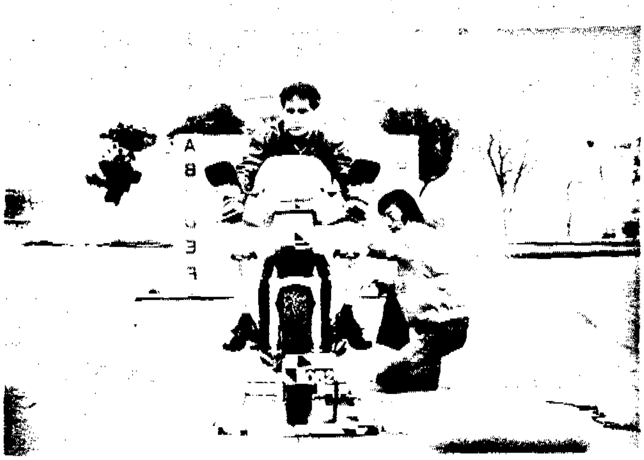


Figure 10. Measurement of eye locations (looking at right-side mirror)

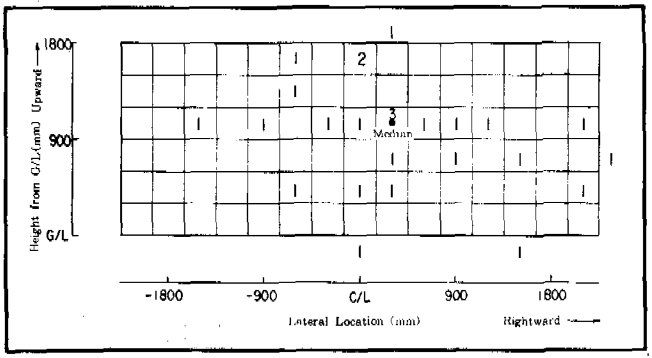


Figure 11. Distribution of rear-view mirror aiming (European type fairing mount, right-side mirror)

The medians of rear-view mirror aiming indicated that for a European type motorcycle with fairing mounted rear-view mirrors it was straight behind the rear-view mirror (in case of right mirror) and at a point between one straight behind the mirror and the vehicle center line (in case of left mirror). For the riders' own motorcycles, it was at a point between one straight behind the mirror and the vehicle center line (in case of right mirror), and in the vicinity of the vehicle center line (in the case of left mirror).

The above shows that the lateral distribution in aiming position of any type of rear-view mirror adjusted by a rider is quite great and the representative value (median) is straight behind the rear-view mirrors or in the vicinity of the vehicle center line.

(2) The variation in the rear-view mirror aiming depending on change in eye location

Fig. 15 indicates the variation in rear-view mirror aiming (median) depending on changes in eye-location.

This study shows actual measured values established from eye locations when looking at the rear-view mirror and an estimate of rear-view mirror aiming based on reference eyepoint (according to JASO 005

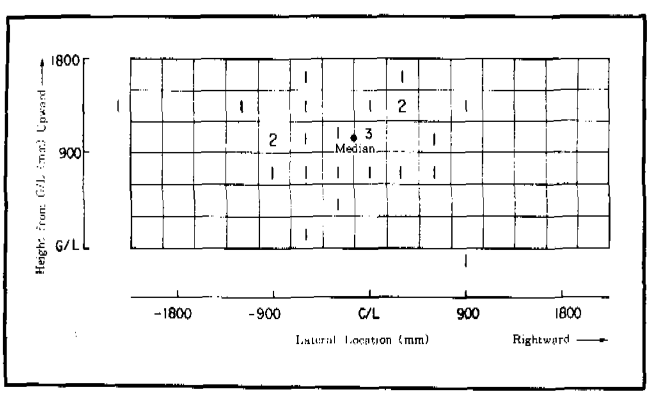


Figure 12. Distribution of rear-view mirror aiming (European type fairing mount, left-side mirror)

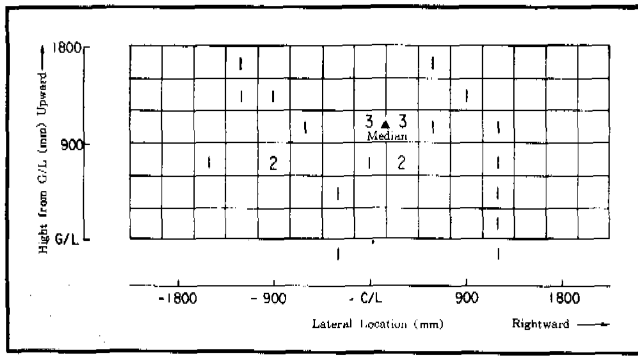


Figure 13. Distribution of rear-view mirror aiming (rider's own motorcycle, right-side mirror)

eye-points when facing forward) for European type motorcycles with fairing mounted rear-view mirrors.

Since the lateral difference between eye locations when the rider is looking straight ahead and when he is looking at the mirror is 15 mm, the rear-view aiming from reference eye-point varies by 210 mm towards the outside even when the angle of the rear-view mirrors is the same. This result indicates that rear-view mirror aiming position from reference eye-point lies straight behind the rear-view mirrors or slightly to the outside for European type motorcycles with fairing mounted rear-view mirrors (see Figure 15).

Eye-Point Selection and Adjustment of Rear-View Mirror Aiming in Measuring Rearward Field of View. It found that it was easier and more useful to rely on reference eye-point as a reference point for measuring rearward field of view than to use rider eye location when looking at the mirror—a location that varied with rear-view mirror mounting position.

Consequently, the following methods of selecting eye-point and adjusting rear-view mirror aiming for measuring rearward field of view was regarded as suitable.

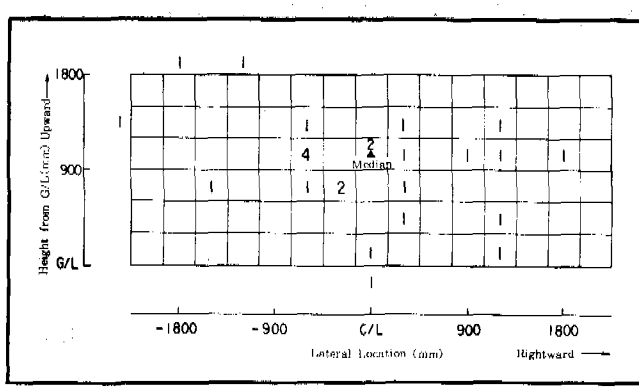


Figure 14. Distribution of rear-view mirror aiming (rider's own motorcycle, left-side mirror)

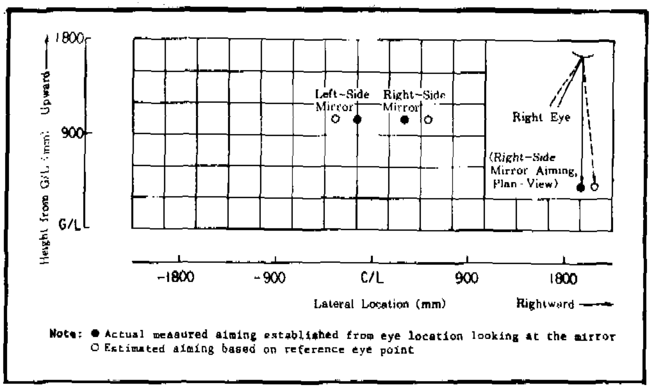


Figure 15. Variation in rear-view mirror aiming depending on eye location change

(1) The reference eye-points for the binocular condition prescribed by JASO T 005[3] was used.

(2) In case of rear-view mirror aiming, the angle of the mirrors was adjusted so that a light beam from reference eye-point towards the center of the mirror would be reflected in a parallel and horizontal manner to vehicle center line. Adjustments were made by using a light beam for left eye point for the left mirror and one coming from the right for the right mirror.

Measurement of Arm Contours of American Riders

Purpose

To obtain arm contours of American riders seated on a motorcycle mock-up by measuring their shoulder configuration.

Arm line, a straight line formed by connecting the extreme outer positions of the shoulder and the wrist positions obtained in anthropometric measurements was compared with actual arm contour and checked for agreement. Arm line was a factor introduced to simplify the test methods.

Method

Motorcycle Mock-Up. The hand grips on the motorcycle mock-up used permitted both lateral and longitudinal adjustments. Both European and American type motorcycle mock-ups were employed (see Table 2). Measurements on the European mock-up were performed under standard conditions and also with the position of the hand grips modified 35 mm inwards, outwards, forwards and rearwards.

Mock-Up and Camera Position. The camera was positioned on a line (right side) going through R'-point which was orthogonal to the vehicle center plane and a vertical line (top) going through R'-point. The distance between R'-point and the camera was 8 meters.

Test Rider. 26 male American were used as test riders (as in anthropometric measurement).

Measurement Procedures. After the anthropometric measurements, the riders were seated in a position close to actual riding position (seated and both arms stretched forwards horizontally) and the right acromion, the right radiale and the right ulna stylion were located manually and marked. Photographs were taken of the riders seated on the mock-up in a position that corresponded to a natural riding position with the side camera and front camera synchronized (see Figures 16, 17, 18 and 19).

Data Processing. The 35 mm films taken during the test were analyzed for the following data. On the side view film (X and Z coordinates) the positions of the marks could be directly analyzed and on the plan view

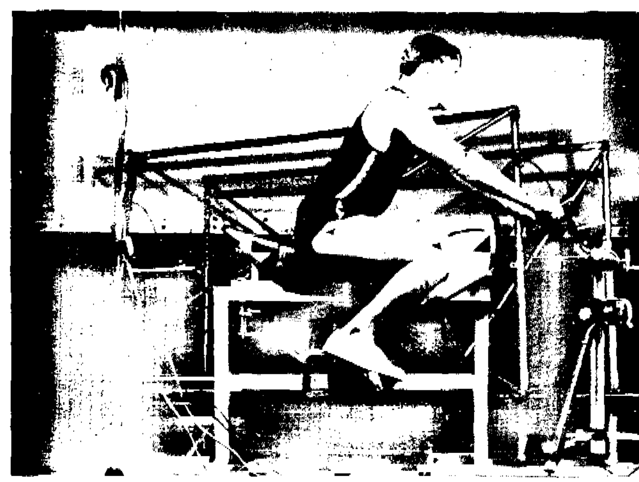


Figure 16. Motorcycle mock-up (European type) and riding position (side view)

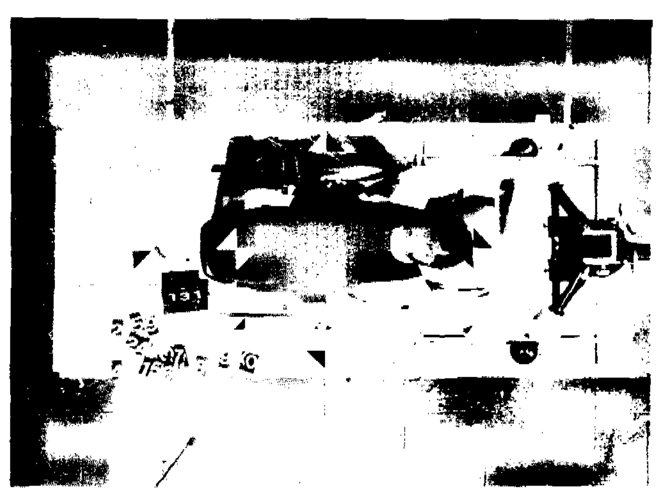


Figure 17. Motorcycle mock-up (European type) and riding position (plan view)

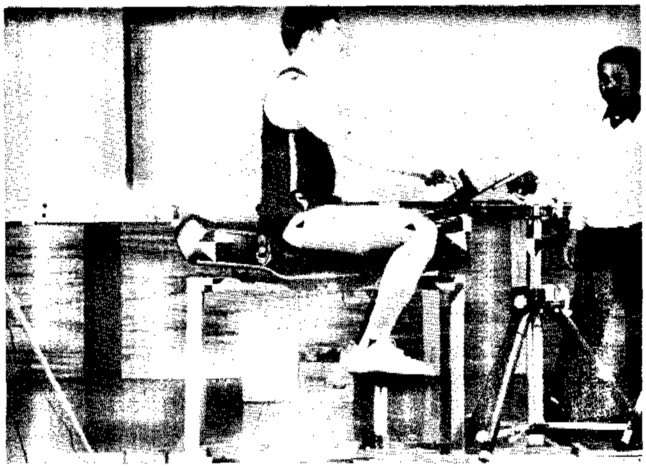


Figure 18. Motorcycle mock-up (American type) and riding position (side view)

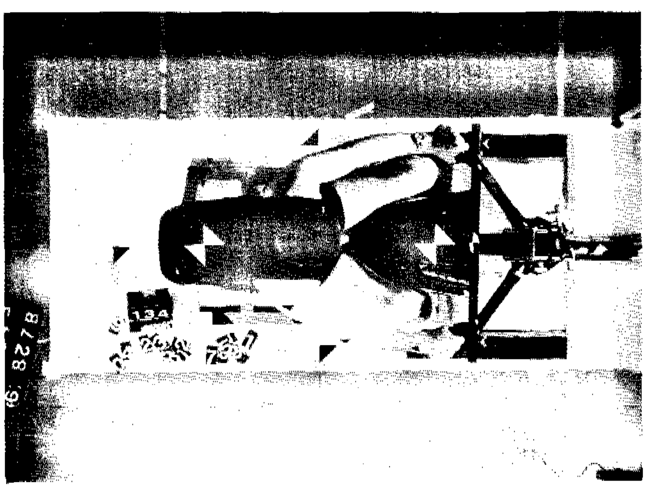


Figure 19. Motorcycle mock-up (American type) and riding position (plan view)

film (X and Y coordinates) the position of the points to be analyzed (the intersection of the outer line of the arm and straight lines parallel to the Y-axis that went through the positions of the mark; see Figure 20) could be found.

(1) Side view film
Position of mark on right shoulder (X and Z coordinates)
Position of mark on right elbow (X and Z coordinates)
Position of mark on right wrist (X and Z coordinates
Position of mark on test vehicle (X and Z coordinates)

(2) Plan view film
Position to be analyzed on right shoulder (Y coordinate)
Position to be analyzed on right elbow (Y coordinate)

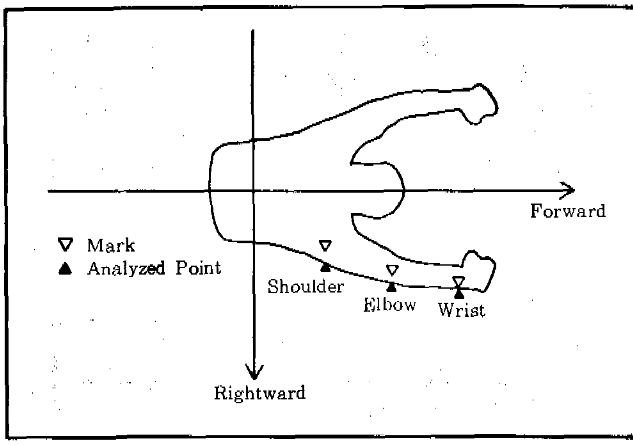


Figure 20. Marks and analyzed points

Position to be analyzed on right wrist (Y coordinate)
Position of marks on test vehicle (Y coordinate)

These data were fed into a computer to obtain the extreme outer positions of shoulders, elbows and wrists.

Results and Consideration

The line connecting the extreme outer position of the shoulder, the elbow and the wrist as actually measured was regarded as arm contour and the straight line connecting S′-point and G′-point (positions estimated in anthropometric measurements) was regarded as arm line (see Figure 21). Both sets of points were compared and checked for agreement.

Positions in longitudinal direction and in vertical direction (X and Z coordinates) of S′-point and G′-point correspond to shoulder point (S-point) and center of effective upper hand grip (G-point) as regulated by JASO T 005[3]. The distance between right and left S′-point was 500 mm and the lateral position of G′-point was 45 mm outside of G-point. These distances are larger than the mean value of rider biacromial width (412 mm) and half of the mean value for palm width (see Table 1). The extreme outer positions of the shoulder, the elbow and the wrist obtained with the riders seated on the test motorcycles are shown in Table 3.

European Type Motorcycle. Rider arm contour on a European type motorcycle with hand grips in standard location form an almost straight line. Compared with arm line the position of the elbow is slightly lower (see Figure 22) from the side view and the position of the shoulder from the plan and front views is slightly towards the inside (Figures 23 and 24), but other positions correspond quite closely.

Even when the position of the hand grips were modified laterally or longitudinally, rider arm contour

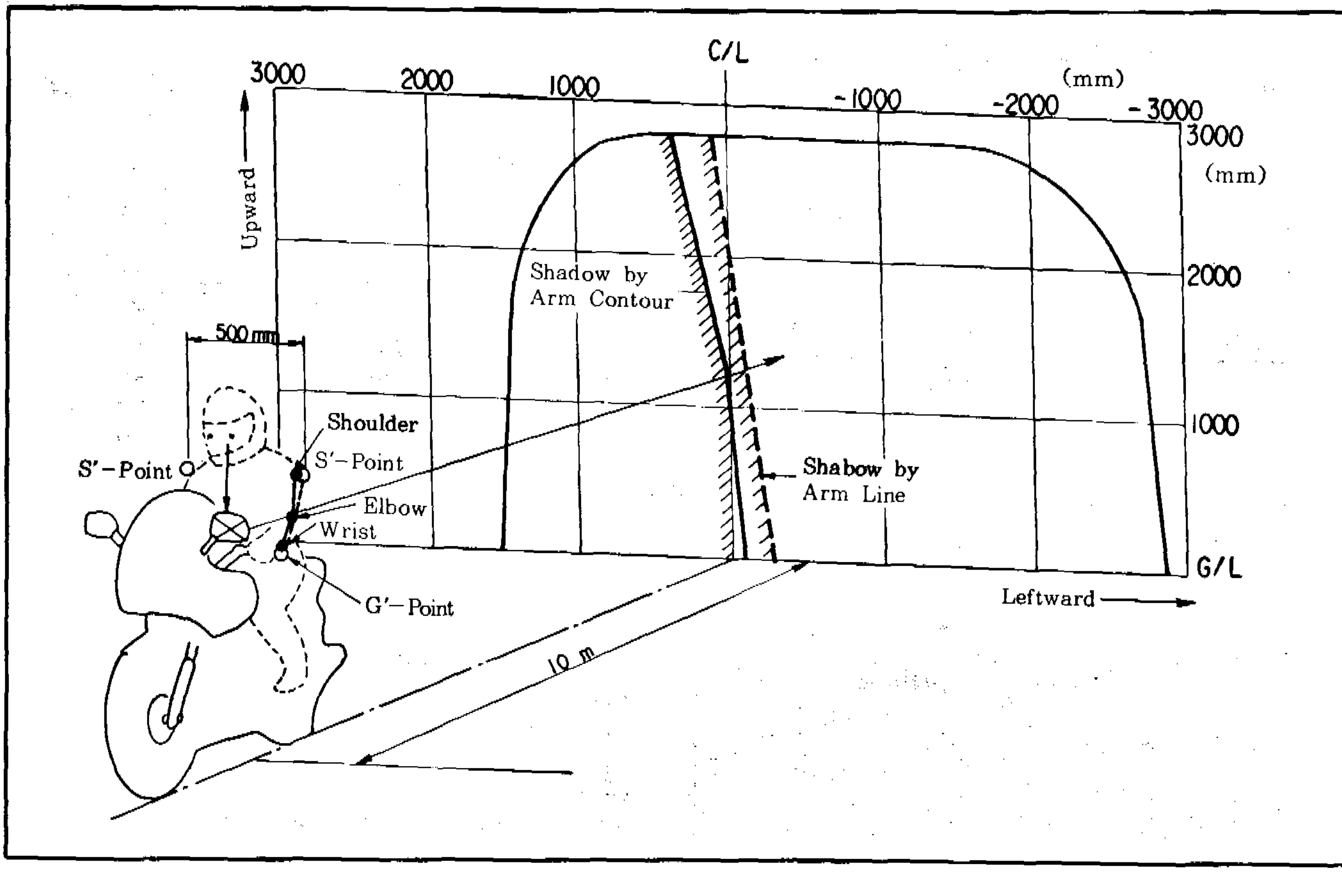


Figure 21. Evaluation method of field of view of rear-view mirror

still formed an almost straight line and compared with arm line the position of the shoulder was slightly inwards, but other positions corresponded quite closely (Figures 25, 26, 27 and 28).

Table 3. Arm contour actual measured (extreme outer positions of shoulder, elbow and wrist).

Test Vehicle / Hand Grip Location / Measured Item		European Type					American Type
		Standard	Outward 35mm	Inward 35mm	Forward 35mm	Rearward 35mm	Standard
Shoulder	X	– 240	– 245 (– 5)	– 236 (+ 4)	– 268 (– 28)	– 216 (+ 24)	26
	Y	224	226 (+ 2)	222 (– 2)	226 (+ 2)	223 (– 1)	217
	Z	530	528 (– 2)	527 (– 3)	517 (– 13)	539 (+ 9)	556
Elbow	X	– 461	– 461 (0)	– 457 (+ 4)	– 491 (– 30)	– 435 (+ 26)	– 178
	Y	278	295 (+ 17)	262 (– 16)	280 (+ 2)	276 (– 2)	315
	Z	311	313 (+ 2)	304 (– 7)	304 (– 7)	316 (+ 5)	339
Wrist	X	– 680	– 679 (+ 1)	– 681 (– 1)	– 715 (– 35)	– 653 (+ 27)	– 414
	Y	294	326 (+ 32)	264 (– 30)	295 (+ 1)	295 (+ 1)	351
	Z	189	192 (+ 3)	188 (– 1)	190 (+ 1)	192 (+ 3)	277

Note: *Numerals in thick lined frames mean standard location of hand grip.* Unit (mm)
Numerals in ( ) show deviation from standard location of hand grip.
On X-axis, "+" means rearward deviation
On Y-axis, "+" means outward deviation
On Z-axis, "+" means upward deviation

The positions of the shoulder, the elbow and the wrist when the hand grips had been modified laterally or longitudinally and the difference between these positions and standard positions are shown in brackets in Table 3.

When the hand grip position was modified 35 mm to the right or to the left, shoulder position hardly changed, whereas elbow position changed 16-17 mm

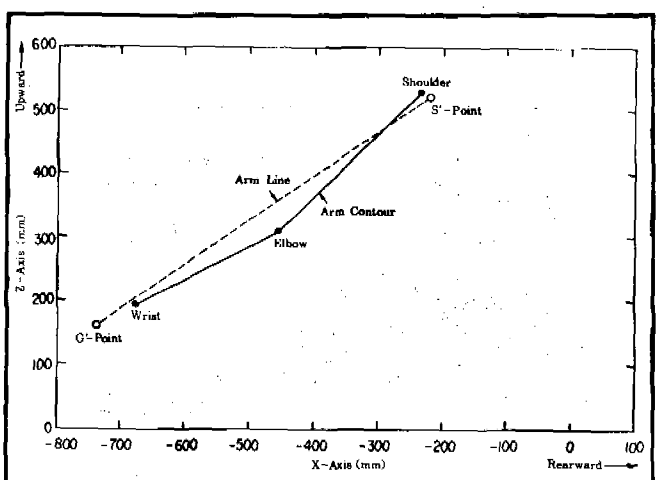


Figure 22. Arm contour and arm line (European type, side view)

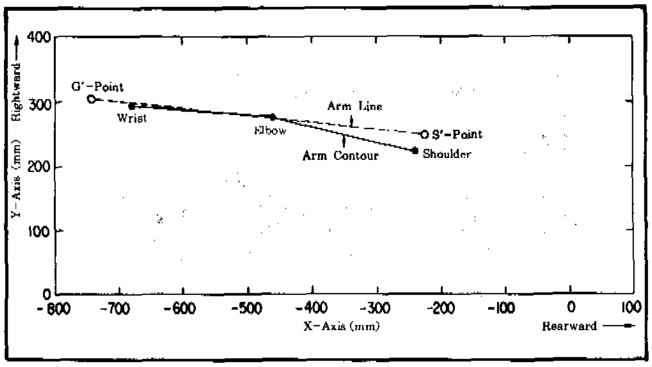


Figure 23. Arm contour and arm line (European type, plan view)

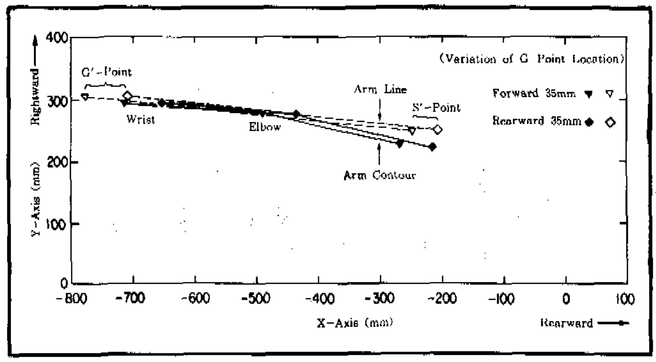


Figure 26. Arm contour and arm line variation according to variation in hand grip location in longitudinal direction (plan view)

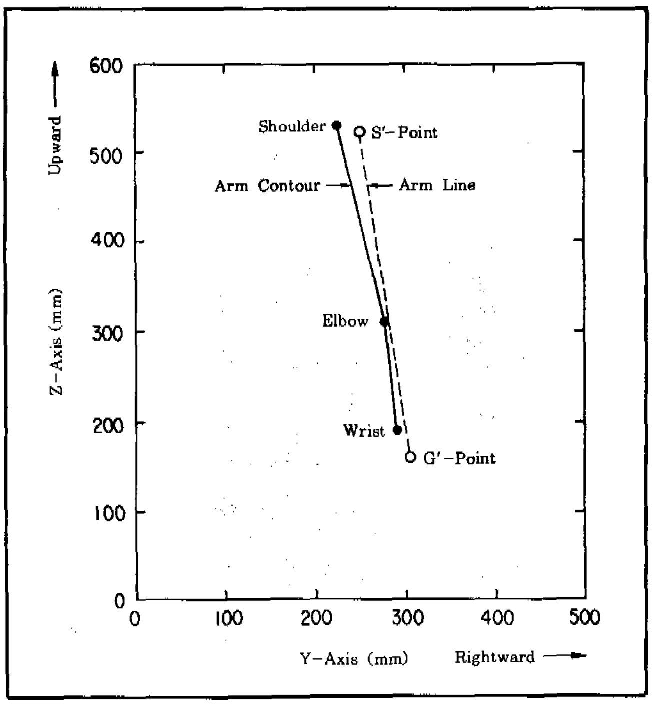


Figure 24. Arm contour and arm line (European type, front view)

and wrist position changed 30-32 mm to the right or left. When the hand grip position was modified 35 mm to the rear or front, shoulder, elbow and wrist positions changed 24-28 mm, 26-30 mm and 27-35 mm respectively to the rear or the front.

American Type Motorcycle. Rider arm contour on an American type motorcycle with hand grips in standard location form a slightly bended line from the side view and plan view, but is an almost straight line from the front view. Compared with arm line elbow and wrist positions are slightly lower (Figure 29) from the side view and shoulder position from the plan view and front views is towards the inside (Figures 30 and 31). Elbow position from the plan view is towards the outside, but is towards the inside from the front

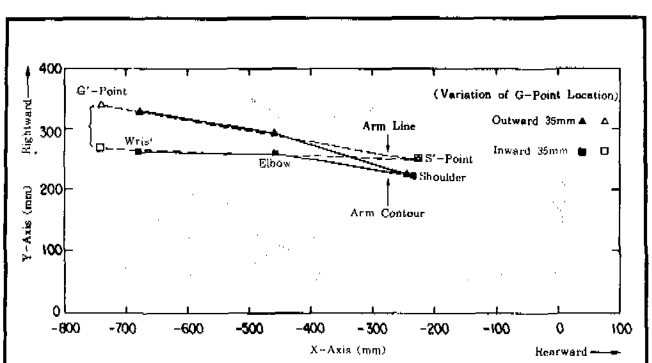


Figure 25. Arm contour and arm line variation according to variation in hand grip location in lateral direction (plan view)

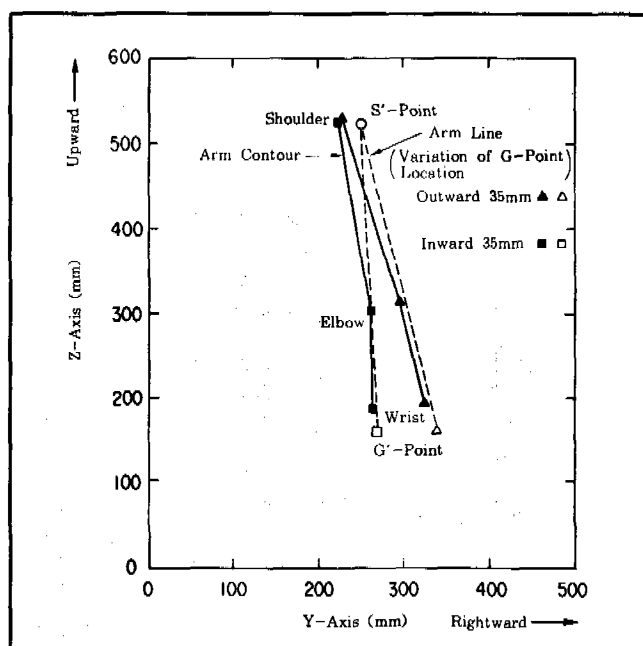


Figure 27. Arm contour and arm line variation according to variation in hand grip location in lateral direction (front view)

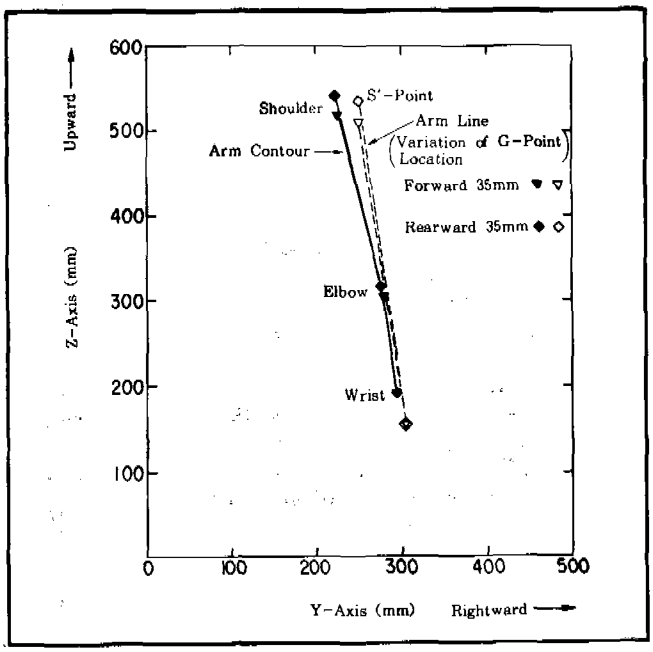


Figure 28. Arm contour and arm line variation according to variation in hand grip location in longitudinal direction (front view)

view. This is because vertical data from the plan view and longitudinal data from the front view are not included.

Consequently, in order to properly evaluate the effect of rider arm contour and arm line on the rearward field of view, it is necessary to simulate or measure the rearward field of view using three-dimensional positions for arm contour and arm line.

Computer Simulation of Motorcycle Rearward Field of View

Purpose

Three-dimensional positions of actual measurements of arm contour and estimated values of arm line were

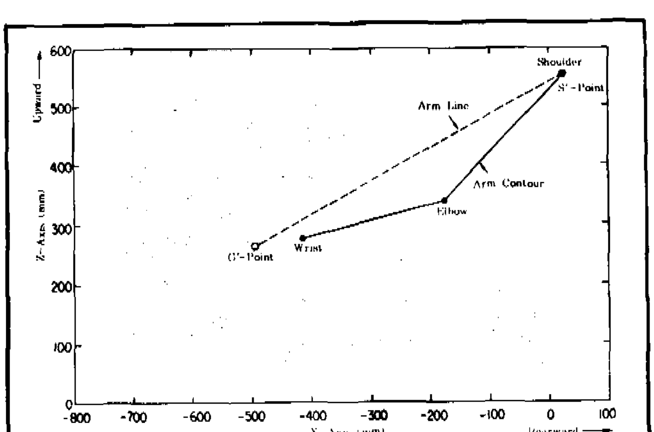


Figure 29. Arm contour and arm line (American type, side view)

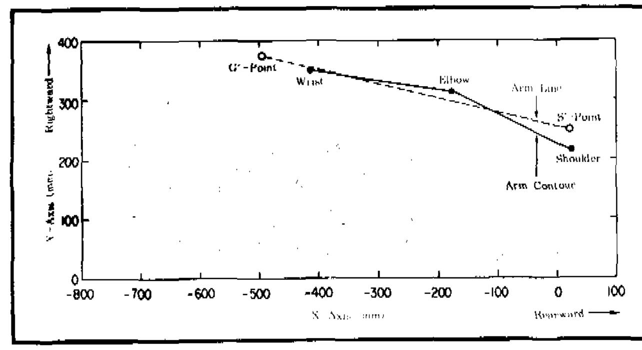


Figure 30. Arm contour and arm line (American type, plan view)

used in a simulation of rearward field of view to compare arm contour shadow and arm line shadow. The arm line factor was used to simplify test methods.

The relationship between the rear-view mirror aiming, eye-point and rearward field of view was also examined.

Method

A CAD based simulated program was used with three types of test motorcycles with rear-view mirrors mounted on the fairing or the handlebars. This corresponds to the method of evaluating motorcycle rearward field of view indicated in Figure 21.

Computation Flow Chart. The computation flow chart (items executed and items input) is shown in Figure 32. Arm contour and arm line was evaluated by the shadow (especially the value at ground level 10 meters to the rear) they projected on a screen placed 10 meters behind eye-point.

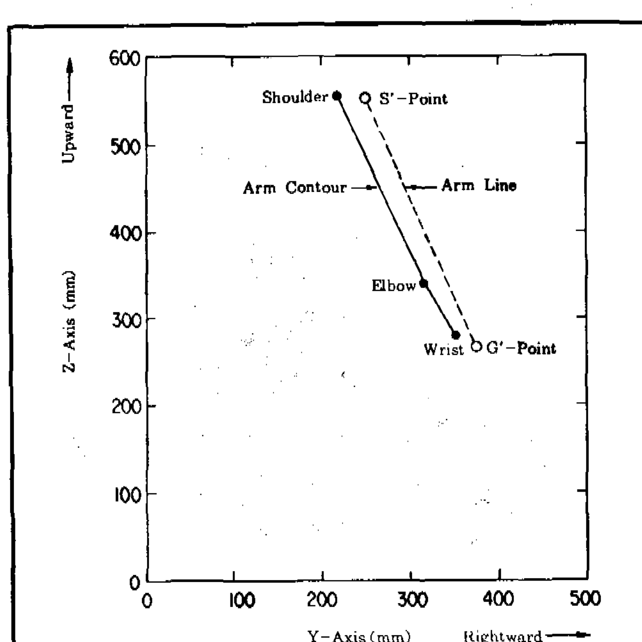


Figure 31. Arm contour and arm line (American type, front view)

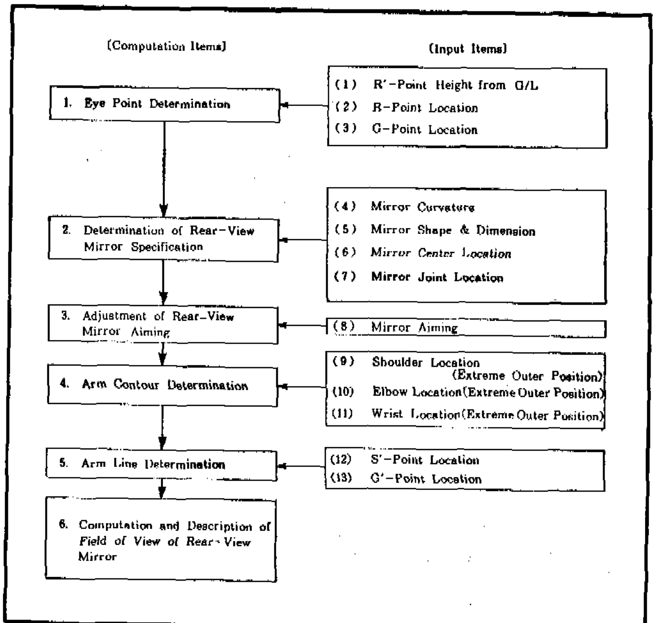


Figure 32. Computation procedure of field of view of rear-view mirror for motorcycle

Eye-Point Selection. The reference eye-points for the binocular condition prescribed by JASO T 005[3] have been used. Although eye position shifts 15-35 mm towards the mirror when a rider looks in the rear-view mirror, procedures were simplified by employing a reference eye-points which did not account for head and eye movements.

Rear-View Mirror Aiming Methods. The adjustment method employed corresponded to measurement results of rear-view aiming position. In case of reference eye-point of binocular conditions the angle of the mirrors was adjusted so that a light beam towards the center of the mirror (M-point) would be reflected in a parallel and horizontal manner to vehicle center. Adjustments were made by using a light beam from left eye position for the left mirror and one coming from the right for the right mirror.

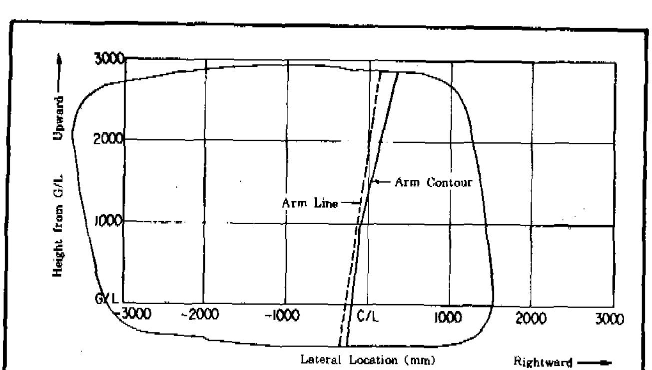


Figure 33. Field of view of left rear-view mirror mounted on European type motorcycle fairing (G-point: standard location)

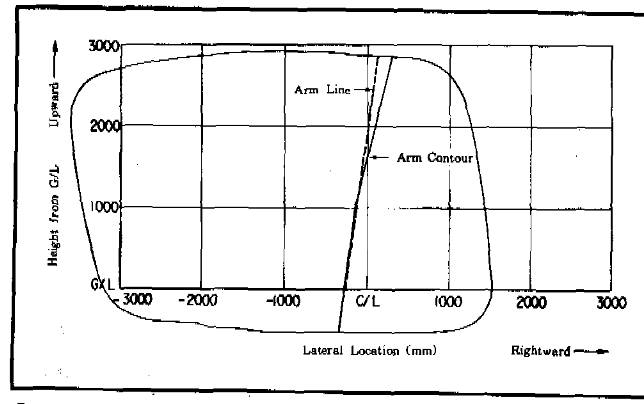


Figure 34. Field of view of left side rear-view mirror mounted on European type motorcycle fairing (G-point: standard location, wearing a 5 mm thick motorcycle suit)

Test Motorcycles. Three test motorcycles were used: two types of European motorcycles (one with fairing mounted and the other with handlebar mounted rear-view mirrors) and one American type motorcycle (see Table 2).

Test Conditions. The rear-view mirrors and the hand grips of the European type motorcycle with handlebar mounted rear-view mirrors and the American type motorcycle were in standard location (Table 2) during the test. The European type motorcycle with fairing mounted rear-view mirrors was tested with rear-view mirrors and hand grips in standard locations. It was also tested with the position of the hand grips modified 35 mm towards the outside, the inside, to the front and rear. When the position of the hand grips was modified, the position of the rear-view mirrors was also changed so that the relative position of the rear-view mirrors and the hand grips remained the same. Thus when the hand grips were moved 35 mm outwards the mirrors were also moved 35 mm outwards.

Results and Consideration

The left rearward field of view (binocular condition) from reference eye-points (binocular condition)

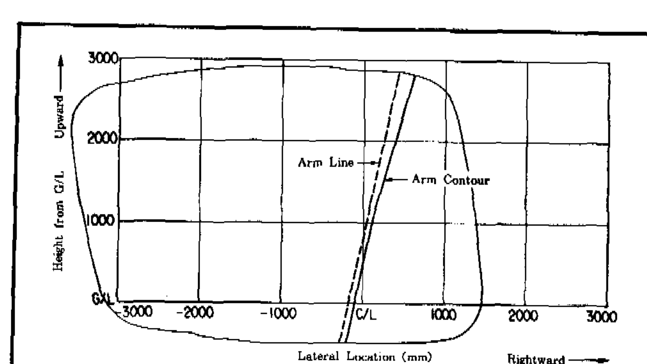


Figure 35. Field of view of left side rear-view mirror (G-point: outward 35 mm)

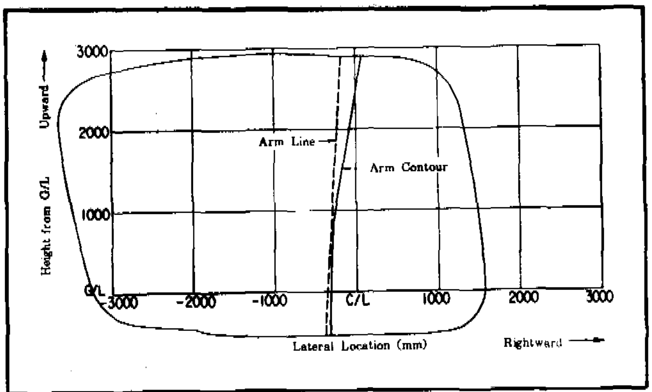


Figure 36. Field of view of left side rear-view mirror (G-point: inward 35 mm)

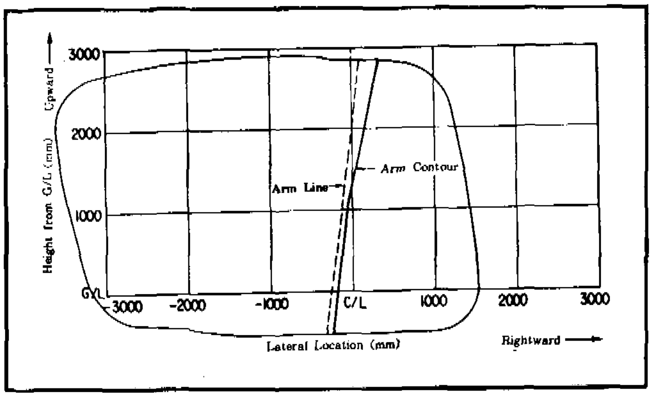


Figure 38. Field of view of left side rear-view mirror (G-point: rearward 35 mm)

for the respective conditions is shown in Figures 33-42. The Figures show projections of the left rearward field of view (binocular condition) 10 meters behind reference eye-point. The shadow caused by arm contour and arm line is the shadow seen by the left eye.

Comparisons of Shadows Caused by Arm Contour and Arm Line.

(1) European type motorcycle with fairing mounted rear-view mirrors

When the hand grips were in standard location on the European motorcycle with fairing mounted rear-view mirrors, the arm contour shadow was slightly inside the arm line shadow (about 70 mm at ground surface 10 meters to the rear) (Figure 33). When the arm contour (shoulder, elbow and wrist position) was modified 5 mm (e.g. by wearing a 5 mm thick motorcycle suit), the shadow from the elbow and downwards, corresponded to arm line (Figure 34).

When the hand grip position was modified laterally or longitudinally, arm contour was slightly inside arm line (40-70 mm at ground surface 10 meters to the rear) (see Figures 35, 36, 37 and 38).

(2) European type motorcycle with handle bar mounted rear-view mirrors

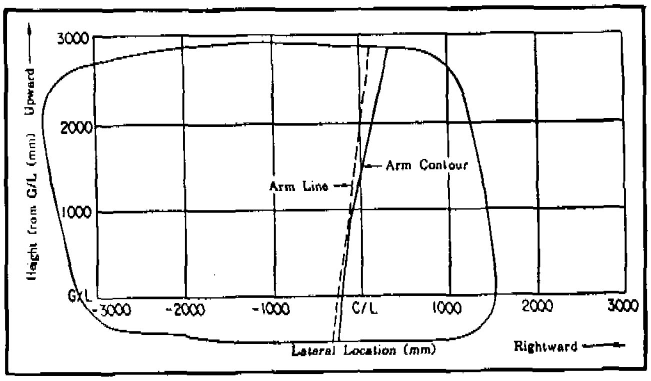


Figure 37. Field of view of left side rear-view mirror (G-point: forward 35 mm)

Arm contour for European motorcycles with handle bar mounted rear-view mirrors was also slightly inside arm line (60 mm at ground level 10 meters to the rear, Figure 39). The Shadow area caused by arm contour and arm line was small and at ground surface 10 meters to the rear the vehicle center line could easily be seen.

(3) American type motorcycles

On American type motorcycles, the arm contour is rather to the inside of arm line (there is a 270 mm difference at ground surface 10 meters to the rear, see Figure 40). However, the shadow area produced by arm contour and arm line is negligible. At ground surface 10 meters to the rear it is 1 meter inside vehicle center line.

Arm Line Used as a Method of Measuring Rearward Field of View. Riders on European type motorcycles with handlebar mounted rear-view mirrors and American type motorcycles could easily see the ground surface vehicle center line 10 meters to the rear. Thus practically there was no reason to take the influence of rider arm shadow into account.

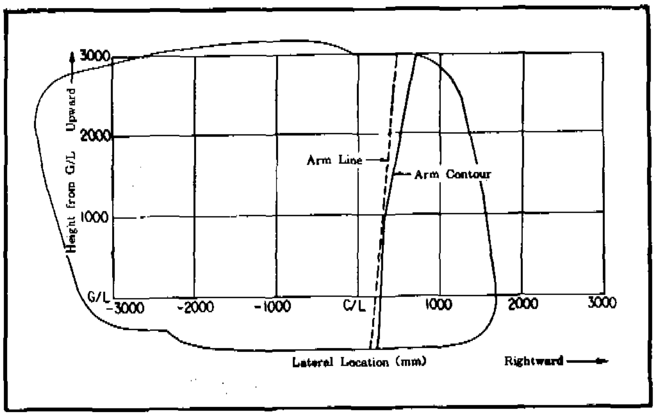


Figure 39. Field of view of left side rear-view mirror mounted on European type motorcycle handle bar

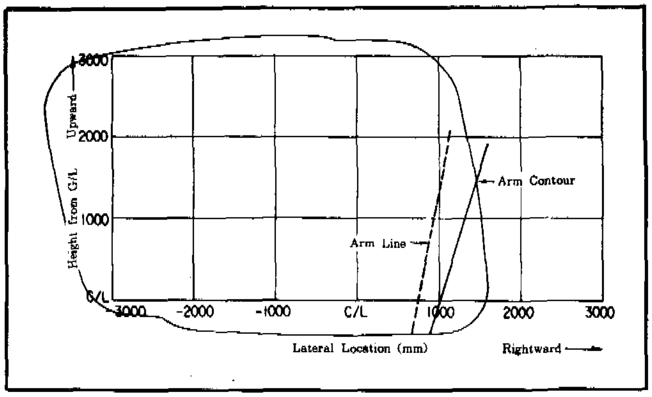


Figure 40. Field of view of left side rear-view mirror mounted on American type motorcycle handle bar

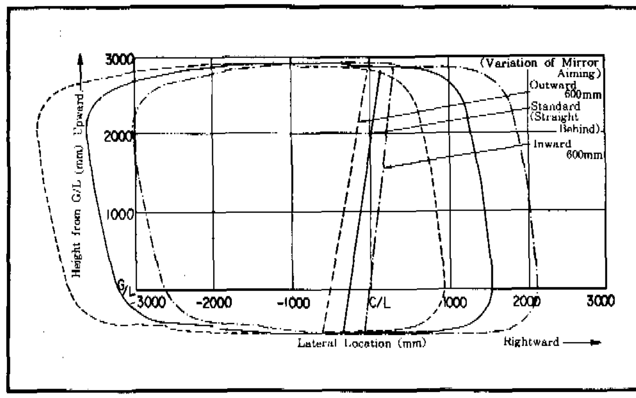


Figure 41. Field of view of left side rear-view mirror variation according to variation in mirror aiming

In case of European type motorcycles with fairing mounted rear-view mirrors where rider arm shadow had to be considered, rider arm shadow (wearing a motorcycle suit) and arm line was regarded as identical.

Consequently, to evaluate rider arm shadow in rearward field of view measurements, it is advisable to make a simplification by using the line formed by connecting S′-point and G′-point (arm line).

Variations in Rearward Field of View as Dependent on Variations in Rear-View Mirror Aiming and Eye-Point. The variations (arm line influence) in rearward field of view for European motorcycles with fairing mounted rear-view mirrors are shown in Figures 41 and 42.

(1) Variations in rearward field of view as dependent on variations in rearview mirror aiming (Figure 41)

When the rear-view mirrors were aimed 600 mm outwards, the shadow of the arm line moved 240 mm outwards as compared to when they were aimed straight behind (standard condition). When they were aimed 600 mm inwards, the arm shadow moved 240 mm inwards.

(2) Variation in rearward field of view as dependent on variations in eye-point location (Figure 42)

The following relationship prevailed between reference eye-point (the eye-point when the rider looks straight forward; as determined by JASO T 005[3]) and rearward field of view. When eye-point location shifted outwards, the rear-view aiming position (point of projection of M-point) also shifted inwards. Even when the mirror angle remained the same, a 10 mm shift in eye-point position produced a 140 mm shift in aiming position. The 15 mm eye movement required to look into the rear-view mirrors of this type of motorcycle produces a 210 mm shift in aiming position.

When eye-point location is shifted outwards, the shadow caused by arm line is also moved inwards. A 10 mm shift in eye-point location produced a 65 mm change in arm line shadow. The 15 mm eye movement required to look into the rear-view mirrors of this type of motorcycle produces a 95 mm shift in arm line shadow. The inside field of view from the actual eye position of a rider looking at the rear-view mirrors appeared 95 mm inwards as compared with the inside field of view from reference eye-point.

Consequently, an evaluation of inside field of view based on reference eye-point and arm line indicates the inside field of view actually seen by riders wearing 12 mm thick motorcycle suits. (The arm contour margin for arm line is 70 mm and the margin for eye-point variation is 95 mm i.e. a total of 165 mm; this corresponds to the effect a 12 mm variation in arm line towards the outside has on the inside field of view).

Summary

In this study to establish measurement method of rearward field of view, we measured rear-view mirror

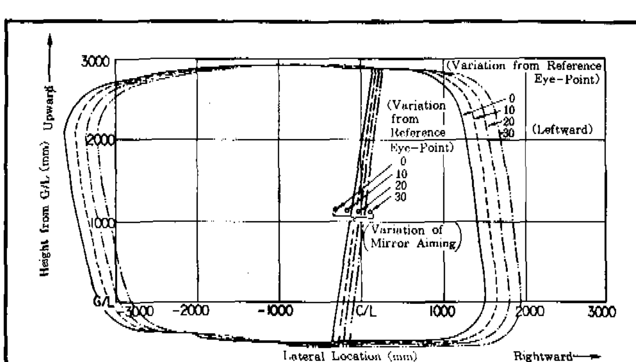


Figure 42. Field of view of left side rear-view mirror variation according to variation in eye location (leftward)

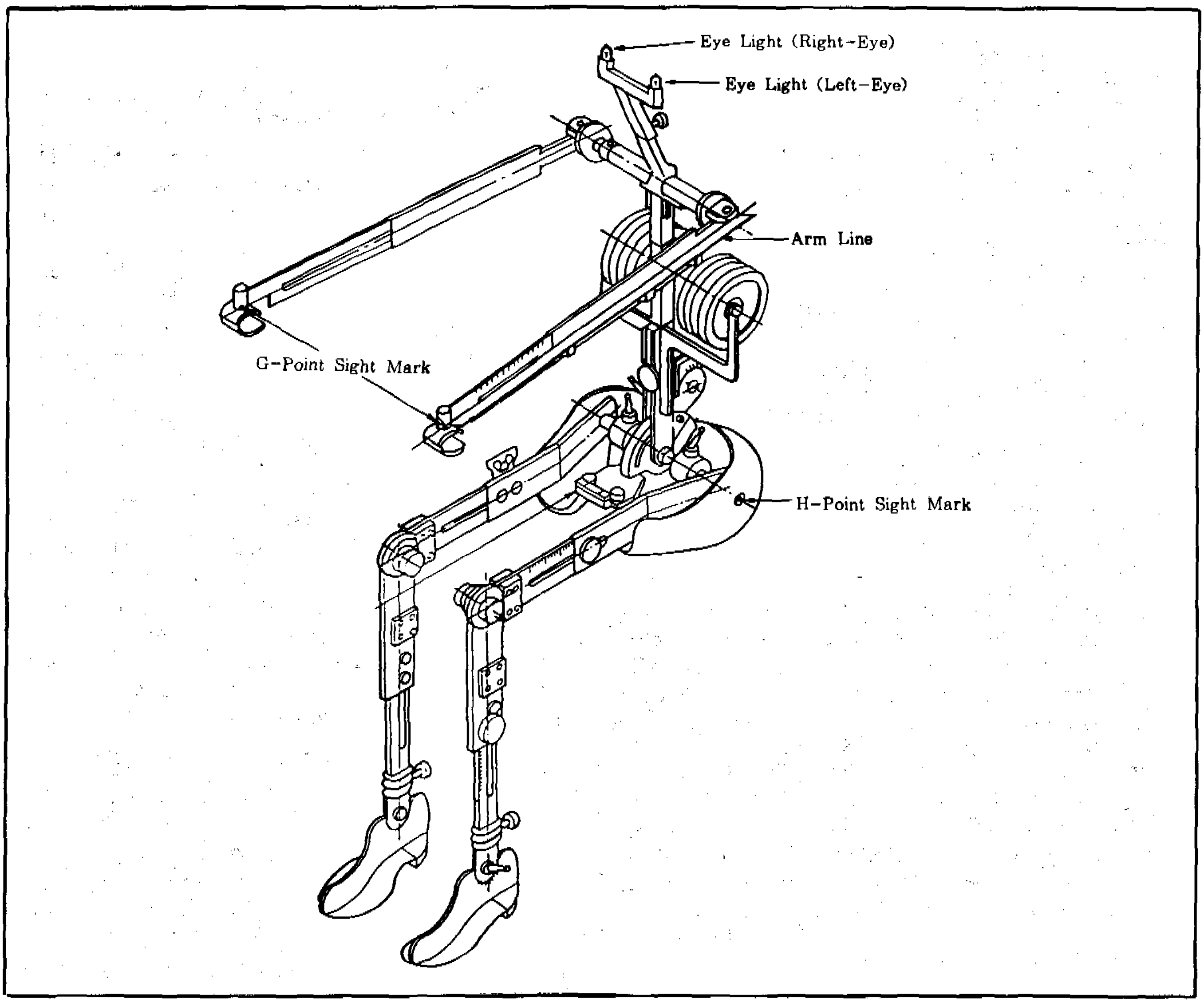


Figure 43. Three-dimensional manikin for motorcycle (with eye light and arm line)

aiming and rider arm contour, and examined those results by means of computer simulation for evaluating the rearward field of view.

In order to sufficiently evaluate design and performance factors of motorcycle rearward field of view, a quantitative study of the required field of view of motorcycle rear-view mirrors will have to be made.

Eye-Point Selection

We found it suitable to use the eye-point value prescribed in JASO T 005[3] as reference eye-point in field of view measurements. Because it is easier and more useful to rely on reference eye point than to use rider eye location when looking at the mirror—a location that varies with rear-view mirror location, and the difference between the rearward field of view from reference eye point and that from rider eye location can be compensated by motorcycle suit thickness.

Rear-View Mirror Aim

It was established that the most suitable angle of the rear-view mirrors when measuring the rearward field of motorcycle rear-view mirrors was when a light beam travelling from reference eye-point (binocular condition) to the mirror center would be reflected horizontal and in a parallel manner in relation to vehicle center line. The left rear-view mirror was adjusted with the aid of a light beam from the left eye and the right rear-view mirror with one from the right eye.

Rider Arm Contour

It seemed most appropriate to simplify the test method by using arm line, a line created by connecting S′-point and G′-point, to evaluate the effect of rider arm shadow (Figure 21). In case of European type test motorcycles with fairing mounted rear-view mirrors where the effect of rider arm shadow had to be considered, rider arm shadow (when wearing a motorcycle suit) and arm line shadow was regarded as identical.

Recommended Methods of Measuring Motorcycle Rearward Field of View

The above results were used as a basis for establishing measuring methods of rearward field of view on a motorcycle when using a three-dimensional manikin for motorcycle and making computer simulation program to examine rearward field of view at the design stage.

Methods of Measuring Rearward Field of View on a Motorcycle

The rearward field of view was evaluated as the field of view projected on a screen 10 meters to the rear of eye-point (see Figure 21). The measurement procedures were as follows:

(1) A three-dimensional motorcycle manikin was placed (Figure 43) on a motorcycle, the binocular eye-point (as stipulated by JASO T 005) was determined and an eye light device was lit.

(2) The mirrors were adjusted so that in binocular condition a light beam travelling from reference eye-point to the mirror center (M-point) would be reflected horizontally and in a parallel manner in relation to vehicle center line. The left rear-view mirror was adjusted with the aid of a light beam from the left eye and the right rear-view mirror with one from the right eye.

(3) The rearward field of view (arm line shadow) projected on the screen was analyzed.

Computer Simulation of Motorcycle Rearward Field of View at Design Stage

A CAD system was also employed in conjunction with other methods to measure the rearward field of view on motorcycles (Figure 32). This was conducted as follows.

(1) Eye-point was determined (according to JASO T 005).
(2) Rear-view mirror data were determined.
(3) Rear-View mirror angle was determined.
(4) Arm line was determined.
(5) Rearward field of view (and arm line shadow) was calculated and displayed.

Acknowledgement

The authors wish to express their appreciation to Maj. L.D. Maahs, TSgt. C.F. Carson and Mr. Noboru Horikoshi, Safety Department Yokota Air Base, U.S. Air Force for their great help; to Mr. Shiro Tomimoto, Mr. Hironao Adachi and Mr. Kazunari Ohara, Yamaha Motor Co., Ltd. for conducting the computer simulation and to all the motorcycle riders for their willing cooperation.

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Motorcycle Impact Simulation and Practical Verification

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Abstract

Experimental impact tests of a motorcycle into a flat rigid barrier at 90° to direction of travel have shown cast front wheels to have a marked pitching effect on the machine whereas wire spoked wheels do not have this effect. A mathematical model of the motorcycle and rider has been developed which can reproduce the dynamics of a motorcycle. The dynamic stiffness of front wheels has been experimentally related to static stiffness and impact velocity, and included in the simulation. The rider dynamics require further development on that part of the model.

Introduction

Motorcycle impact testing is inherently expensive and its results are not always conclusive. There is usually an inability to alter one major parameter, from test to test, without the inevitability of changing others in the process. A generalised overview of motorcycle and rider dynamics in an impact situation would require a vast number of practical tests before any reliable conclusions could be drawn. An experimental process was therefore devised whereby selected practical tests could be performed to verify a mathematical simulation of the process. This simulation can highlight the important parameters affecting the kinematics of motorcycle and rider, with sufficient accuracy for practical purposes.

Motorcycle and rider impact simulations have not, to date, taken full account of front and energy absorption characteristics. Recent impact tests at TRRL have shown that these parameters have a marked effect on rider kinematics. These tests involved identically impacting two heavy-weight motorcycles "head-on" into a massive rigid barrier. One of the machines had a cast aluminum front wheel and the other a conventional steel wire spoked wheel.

Film analysis of these impacts has shown that for the cast wheeled motorcycle the peak deceleration of the centre of gravity was nearly twice that of the wire spoked version. The rider of the former motorcycle left contact with the machine at one and a quarter times the velocity of the latter. This increase was due to the cast wheel not crushing, thereby allowing more radial movement of the headstock (pitching) about the front axle before the headstock impacted the barrier. This radial acceleration for the cast wheeled machine was twice that of the one with a wire spoked front wheel, providing an increase in radial acceleration which would catapult the rider with one and a half times the kinetic energy of the wire spoked version on leaving the machine. The extent of crushing of the two types of wheels can be seen in Figs. 1 and 2.

Motorcycle and rider impact tests have repeatedly shown that the only items on the motorcycle that absorb energy during "head-on" impact are the front wheel and forks. The optimisation of these energy absorption characteristics would greatly aid the optimisation of other safety items, such as air-bags, to retard the rider at a safer level during impact thus reducing injuries in the process.

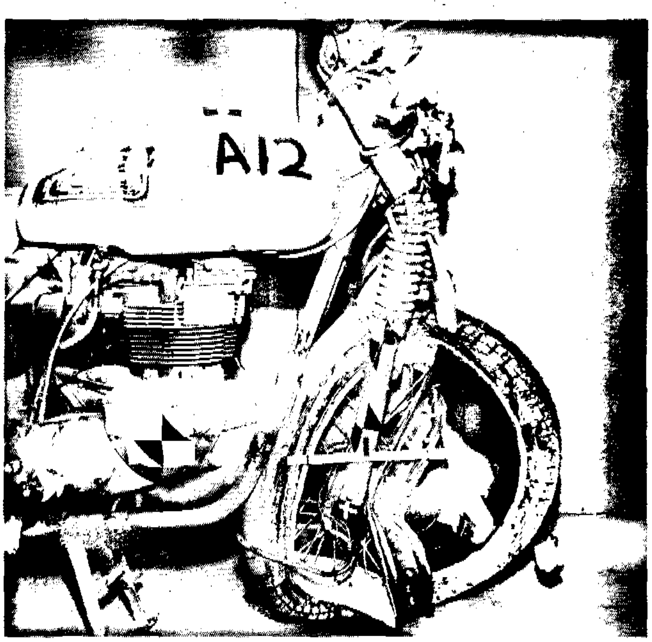

Figure 1. Heavyweight motorcycle wire spoked front wheel after a 13.4 m/s head-on impact

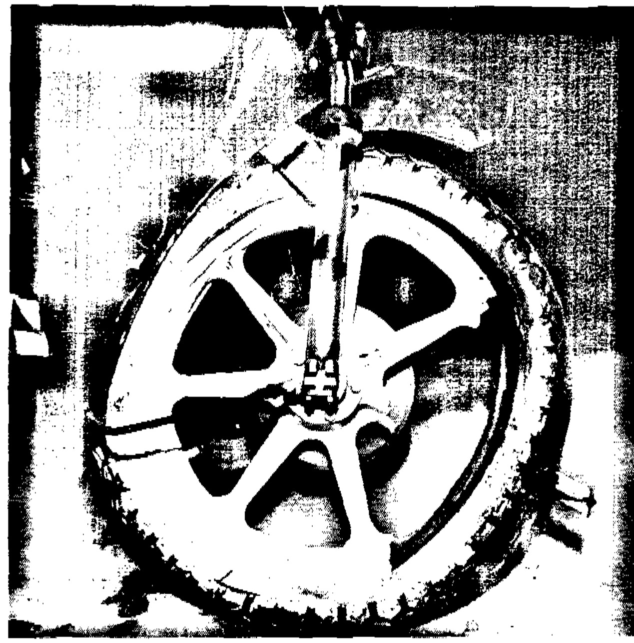

Figure 2. Heavyweight motorcycle cast front wheel after a 13.4 m/s head-on impact

Mathematical Simulation

Full Motorcycle

A mathematical simulation of the motorcycle and rider has been developed that is based on a three mass system, see Fig. 3. These masses are equivalent to the centres of gravity of the front wheel, the rest of the motorcycle and the rider's torso. The acceleration sustained by each of these masses was evaluated by the summation of the forces, acting in pertinent directions, in accordance with Newtonian mechanics.

The displacement of most points in the model was derived from absolute velocities, which were related to one of the main masses via translational and rota-

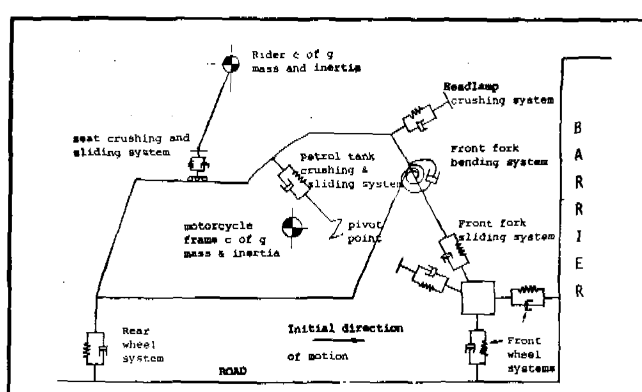

Figure 3. Diagrammatic view of mathematical simulation of a motorcycle and its rider

tional velocities. Angular velocities of two points relative to each other required triangulation via an auxiliary point, either dummy or real, and the use of the cosine rule. This method inherently provided velocities for damping forces and compression values for spring forces by integration.

The forces acting on the rider were from compression and friction against the seat and petrol tank as well as gravitational acceleration. The rider has initially been modelled as a point mass with rotational inertia at the centre of gravity of the torso with a mass-less beam connecting this mass to the rider's posterior.

The front forks were modelled as a sliding non-linear spring damper system, but also allowing for the forks to bend below the headstock. The bending of the front forks about the headstock is elastic, until the elastic limit is reached, after which the collapse is purely plastic. There is a small amount of structural damping applied to this motion.

The forces and moments acting on the main motorcycle centre of gravity were used to evaluate its translational and rotation motion. These forces were:

i. The gravitational force acting on the motorcycle.
ii. The front wheel when it impacts the lower front section of the frame.
iii. The front forks including the forces due to their rotation about the headstock.
iv. The action of the rear wheel on the road (the rear suspension system was initially considered to have a negligible affect on the global motion of the motorcycle).
v. The motion of the rider along the seat and petrol tank giving frictional and normal forces on the motorcycle. The seat and petrol tank were modelled as non-linear spring damper systems, with permanent deformation on the tank.

The inclusion of the front wheel and fork energy absorption characteristics in a simulation require an accurate knowledge of the dynamic load deflection properties of motorcycle wheels and front forks. Initially, the front forks have been modelled as an elastic-plastic system as suggested by Sherman(Ref. 1).

Front Wheel

The mathematical modelling of the front wheel was based on complete wheel spring stiffnesses obtained by static tests to destruction. An impact rig was used to obtain dynamic magnifying factors. The mathematical model is a non-linear spring with a damper in parallel. When the spring is unloaded there is an allowance for hysteresis and permanent deformation, based on the work of Fowler(Ref. 2). A more comprehensive third order system was not required as the relatively low tyre stiffness eliminated any initial velocity effects on impact, and damping levels were relatively low.

The forces acting on the front wheel mass during impact emanate from contact with rigid bodies, such as the road, the barrier or obstacle and the frame. The front forks bend at the headstock and trap the front wheel between the motorcycle frame and the barrier. The contact point of the wheel and frame will vary depending on the relative positions of the two bodies. It is assumed that the wheel stiffness characteristics are similar at all these contact points. The rotational motion of the front wheel was considered unimportant as it contained only a very small percentage of the total energy absorbed by the front wheel system but this motion may well have to be included in any three-dimensional motorcycle model.

Front Wheel Simulation Verification

A drop rig was built to test the behaviour under impact of motorcycle front wheels, front forks and possibly petrol tanks, at velocities up to 7 m/s, see Fig. 5. Characteristics for wheels have been extrapolated from a series of tests at differing velocities up to 7 m/s to give the required values for impact velocities up to 14 m/s. The rig results were in the form of energy/displacement characteristics, at selected velocities, for direct comparison with a mathematical simulation of the impact situation.

This simulation consisted of a mass falling a prescribed distance, under gravity, impacting a rigid mass, which was resting on top of, and independent of, a series pair of second order mass-spring-damper systems, see Fig. 5. The spring characteristics were

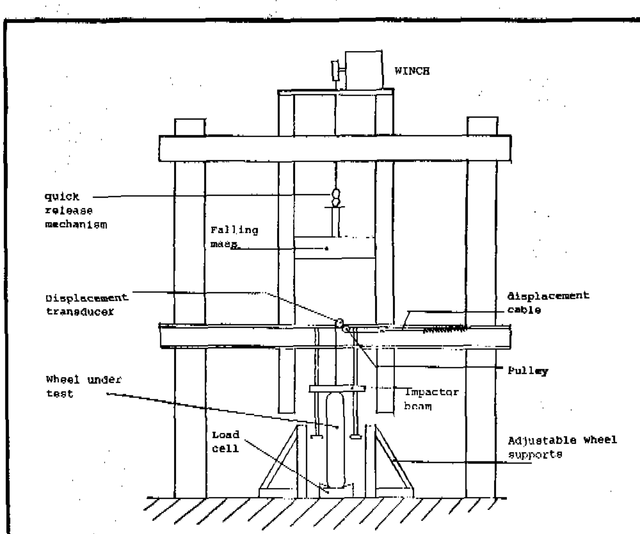

Figure 4. Diagrammatic view of the drop test rig used for dynamic analysis of motorcycle wheels

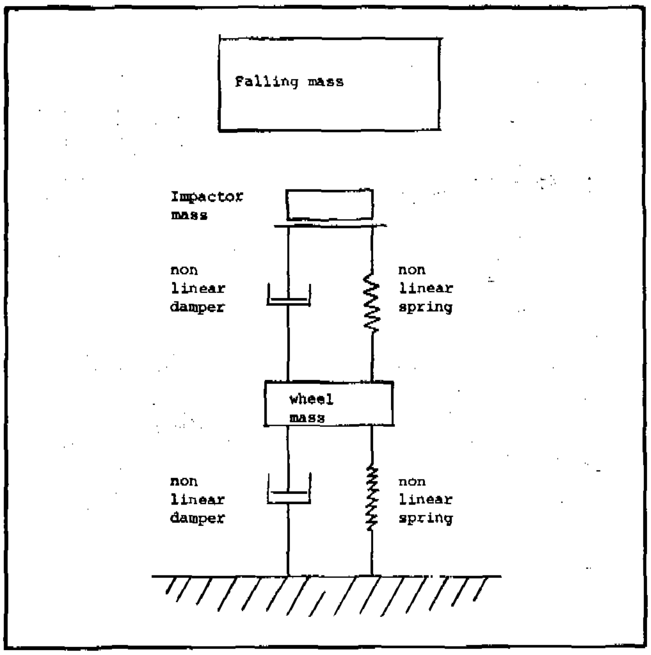

Figure 5. Diagram of mass-spring-damper model for front wheel drop test rig simulation

obtained by simple static crush tests with various velocity related factors, as on the full motorcycle model.

In practice, the struck rigid mass was used to obtain deflection/time characteristics. All the models have been written in A.C.S.L. which can be used for modelling continuous systems. The collision of the two rigid bodies was modelled by an instantaneous momentum balance relying on pre and post impact velocities. All models were designed to self-check using an energy based system.

The error in the experimental results was assessed by comparing the impact energy with the measured absorbed energy. The imbalance was used as a factor to weight the crush characteristics which were then averaged for each type of wheel and tabulated for use in the drop rig simulation. The velocity related factors in the simulation were adjusted to obtain an approximate fit to experimental results by achieving similar peak load and displacement values. A close fit was obtained by optimising the velocity factors to minimise the r.m.s. error between the simulation and experimental results. It has been found that damping significantly affects the system resonance and they relate non-linearly. This is particularly true for spoked wheels. Some drop rig tests have been performed on each type of wheel. When all the tests and simulations have been completed an impact on any wheel can be modelled up to an impact velocity of 15 m/s using only statically measured crush characteristics.

Drop tests at several different velocities need to be simulated for each type of wheel, but to date, only a few selected tests have been simulated. It can be seen

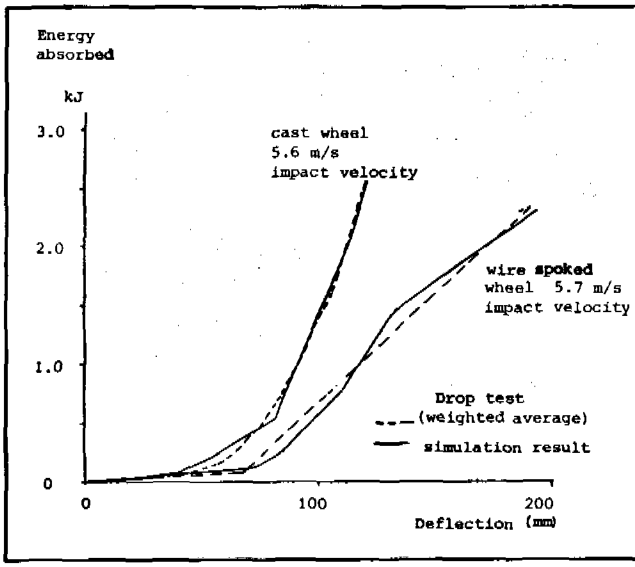

Figure 6. Comparison of results of drop rig mathematical simulation with weighted experimental results

from Fig. 6 that there is a good correlation for wire spoked and die cast wheels. The energy absorption can be separated into two sections, that absorbed by the tyre, which was never more than 10% of the total, and that absorbed by the wheel collapsing. Thus, there are distinct velocity related factors governing the behaviour of each section. Each half of the wheel model is simulated by a single non-linear spring and damper. When all the impacted wheels have been simulated then the variation of these velocity factors can be related to impact velocity and hence extrapolation can be performed to any impact velocity up to 15 m/s. A similar series of tests will be performed on front forks at a later date.

Wheel Test Results

Current production motorcycle wheels have been categorised, for test work, into three basic types: steel wire spoked, die-cast and a composite "comstar" type.

A comparison between the static and dynamic results highlights the following interesting phenomena. The wire spoked wheels showed a small increase in the peak load and a slight decrease in the energy absorbed for the dynamic tests compared with the static. During most of the impact, the dynamic load was significantly greater than the static load for both the cast and comstar wheels, see Figs. 7 and 8. However, the cast wheel failed prematurely in both tests and absorbed little energy although slightly more was absorbed in the static test. In contrast, the comstar wheel absorbed far more energy dynamically than statically, see Figs. 7 and 8. Whereas, the wire spoked and comstar wheels generally absorbed energy pro-

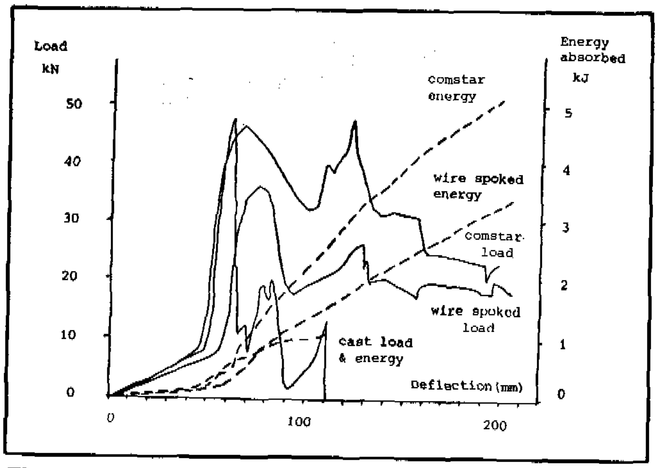

Figure 7. Comparison of static energy absorption characteristics of wire spoked, comstar and cast front wheels from medium weight motorcycles

gressively, the cast wheel did not. In Table 1 the energies absorbed and the peak loads are compared as a ratio using the cast wheel as a reference. This layout emphasises the phenomena mentioned above.

Results of Full Motorcycle Simulation

Two basic simulations of a medium-weight motorcycle and rider impacting a rigid barrier have been performed, one with a cast and the other with a wire spoked front wheel. The impact velocity has been restricted to 5.63 m/s (12.6 mile/h) because the wheel drop rig tests were not completed at the time thereby making extrapolation of velocity related factors difficult.

The cast wheel test induced a tendency for the motorcycle frame to pitch, once the front wheel has been trapped between the frame and barrier, see Fig. 9. The wire spoked wheel did not induce this tendency, see Fig. 10. Both these figures show the frame as a triangle with the front forks and the rider as a stick of 20 m/s intervals. The pitching tendency can be seen by following the rear portion of the motorcycle frame triangle.

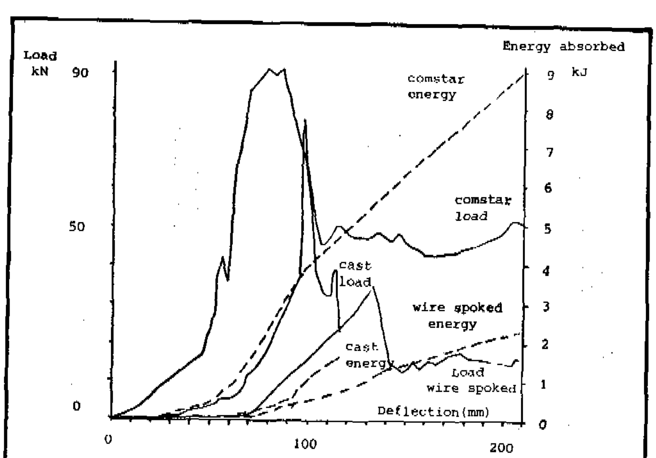

Figure 8. Comparison of dynamic energy absorption characteristics of wire spoked, comstar and cast front wheels from medium weight motorcycles. Average impact velocity was 5.41 m/s (12.1 mile/h)

Table 1. Table showing relative values for medium weight motorcycle front wheel types subjected to static and dynamic loading.

data type	factor considered	wheel type		
		cast	wire spoked	comstar
Static	energy absorbed for 112 mm displacement	1.0	0.71	1.65
	peak loads	1.0	1.32	1.33
Dynamic impact velocity 5.41 m/s	energy absorbed for 120 mm	1.0	0.7	3.86
	peak loads	1.0	2.26	2.65

Simulations have been tried at 13.4 m/s (30 mile/h) to gain an idea of the trend, without adjusting the velocity related factors from their value at 5.63 m/sec. The tendency for the cast front wheeled motorcycle frame to pitch was increased in these simulations. It is expected that inclusion of the correct velocity factors will exacerbate this tendency. This tendency to pitch was very evident from practical full scale impact tests on cast front wheeled motorcycles. Economy of computer use meant that the simulations were stopped at about 10 m/s after the rider had lost contact with the motorcycle.

The deceleration-time histories from mathematical simulations for both types of motorcycle are shown in Fig. 11. These curves show the peak deceleration of the cast wheeled machine to be twice that of the wire spoked version as in the practical tests. These curves also show the wire spoked machine to decelerate at a

Table 2. Table showing some results of mathematical simulations of medium weight motorcycle "head-on" impacts into a rigid massive barrier for differing types of front wheels.

	impact velocity 5.63 m/s (12.6 mile/h)		
	cast front wheel		wire spoked front wheel
Rider leaves motorcycle after	142 ms		175 ms
Period of rider contact with seat	93 ms		120 ms
Period of contact with petrol tank	52 ms		57 ms
Rider velocity on leaving petrol tank	forward	2.85 m/s	3.09 m/s
	vertical	2.11 m/s	1.55 m/s
	rotational	3.43 rad/s	3.14 rad/s
	Total translational	3.54 m/s	3.45 m/s

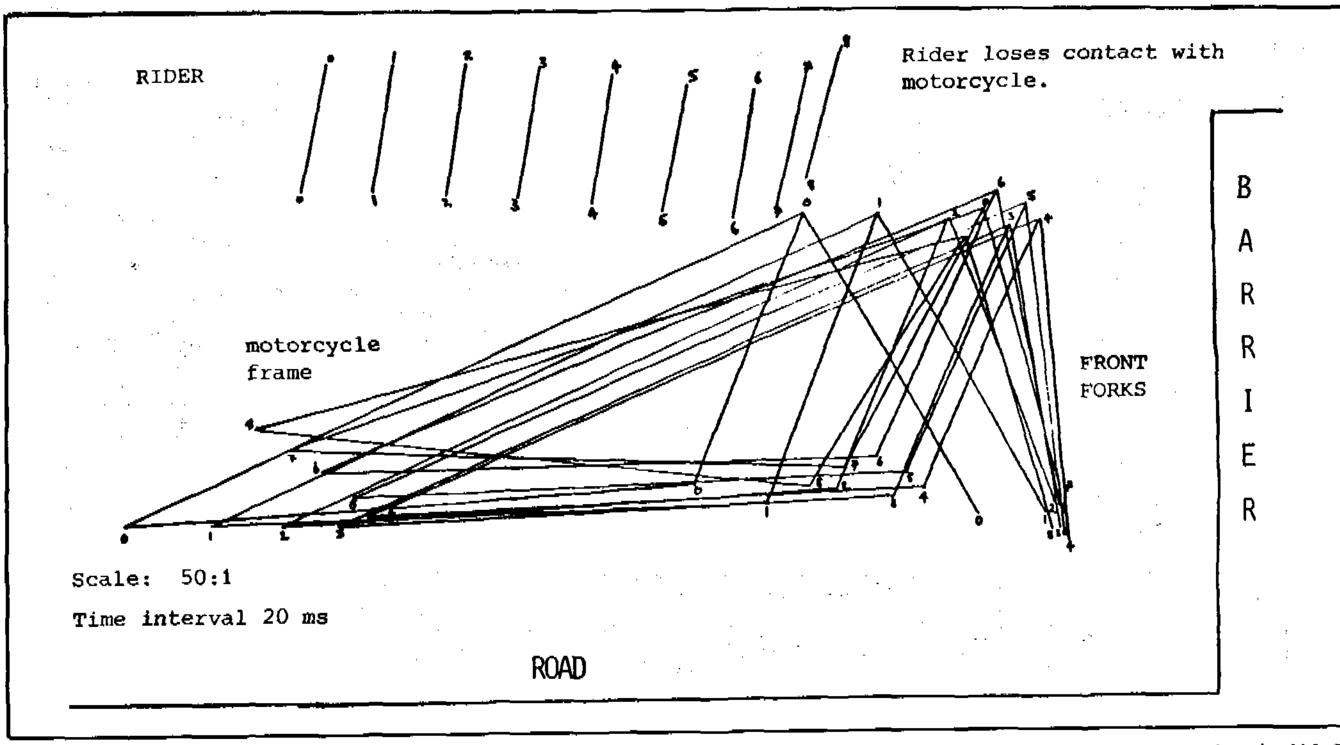

Figure 9. Simulation results for a medium weight motorcycle impacting a rigid barrier head on at 5.63 m/s (12.6 mile/h) with a cast front wheel

more consistent level than the cast machine, which would greatly aid the effectiveness of a restraining safety system.

The rider's vertical velocity on leaving the machine with a cast front wheel was $1\frac{1}{2}$ times that of the wire spoked version, see Table 2.

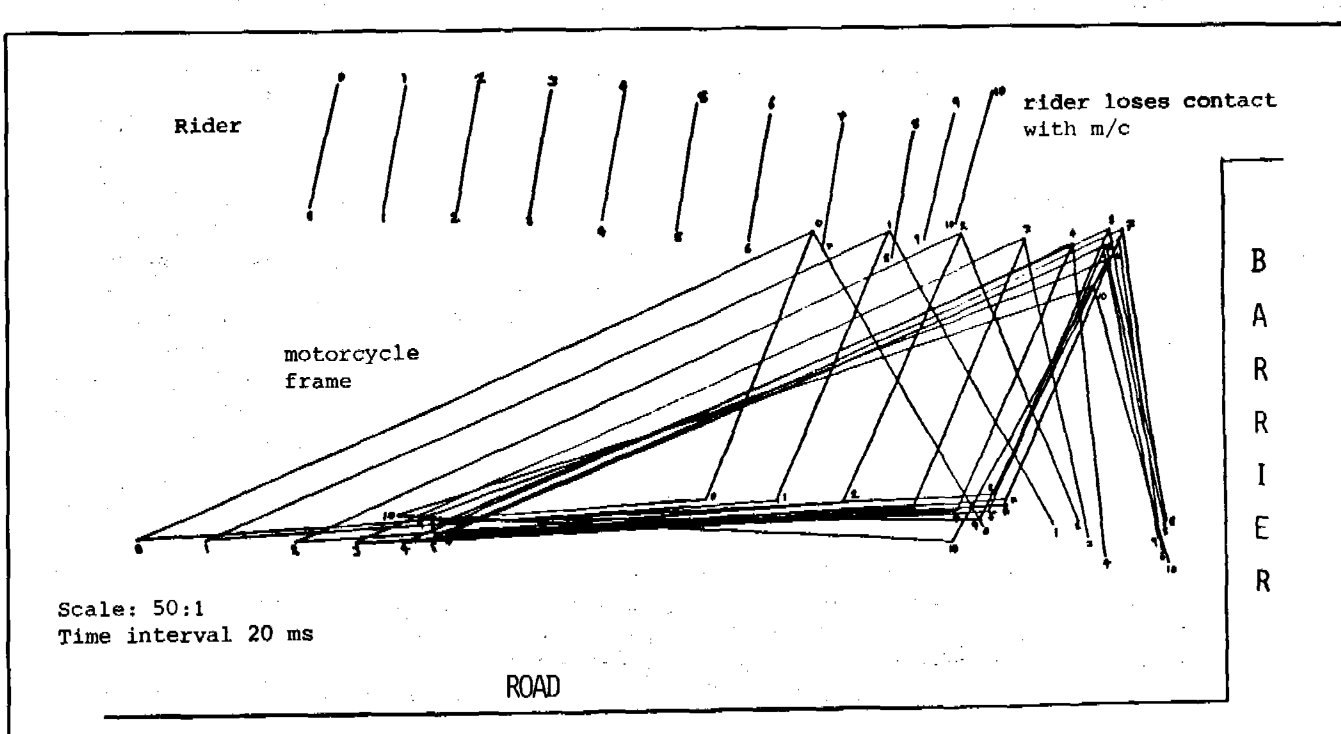

Figure 10. Simulation results for a medium weight motorcycle with rider impacting a rigid barrier head on at 5.63 m/s (12.6 mile/h) with a wire spoked front wheel

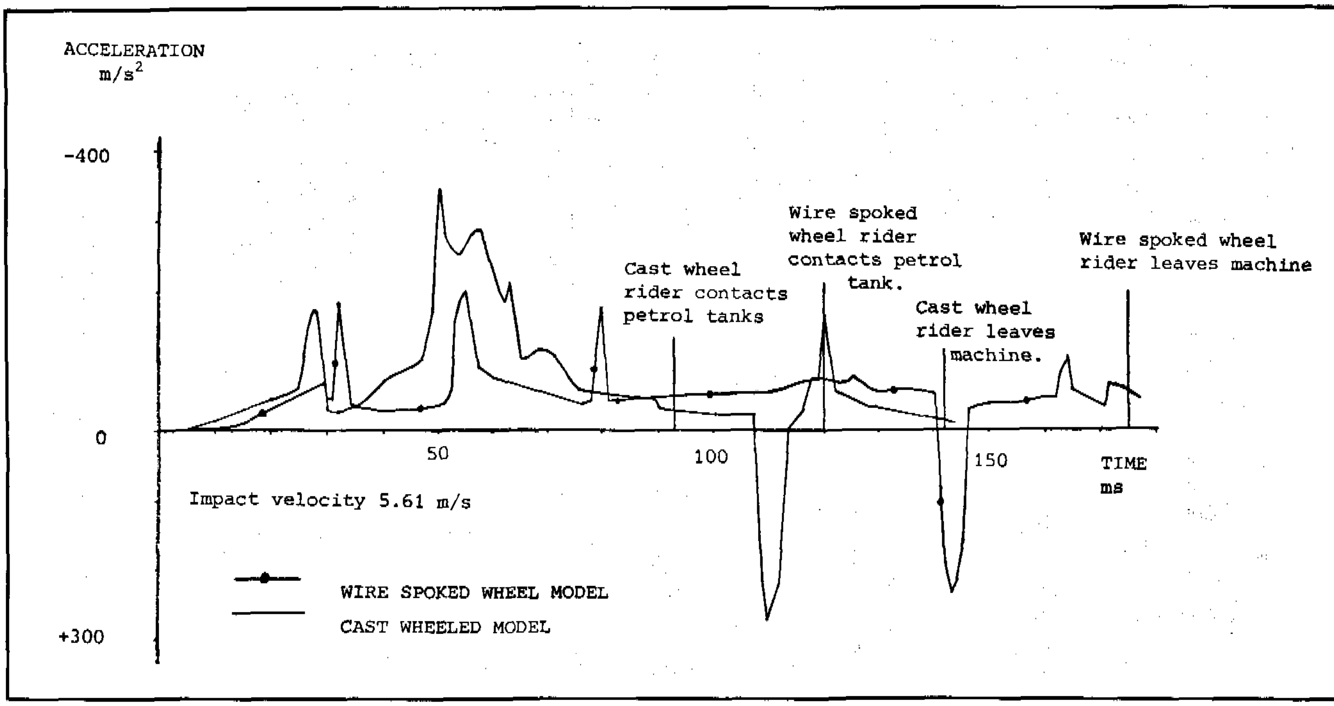

Figure 11. Comparison of motorcycle centre of gravity deceleration for cast and wire spoked front-wheeled medium weight motorcycles with time from mathematical simulations

However, both simulations predict that during the impact there will be an overall decrease in the rider's translational velocity of about 40% and a similar percentage increase in rotational velocity. This has not been observed in practical tests and indicates that a more sophisticated rider/machine contact model is required, possibly one which simulates all the possible contact points, such as both the seat and petrol tank simultaneously. It is considered that this will create more of an effect on the rider when the frame kicks up. The rider impacting the petrol tank appears to initiate the pitching effect, which is also responsible for launching the rider off the machine. The simulation of rider contact mechanics requires further work.

Rider-Restraint System

The computer programme is not yet fully developed. However, it indicates that a rider is retained on the motorcycle, following a frontal impact, for about 50 ms longer if spoked wheels are used than if cast wheels are fitted. In addition, the use of spoked wheels causes the motorcycle to pitch less. Both these factors are favourable to the effectiveness of an air-bag as a rider-restraint. An air-bag of 120 litre capacity (deployed with one inflator) has been assessed in impacts and it reduced the horizontal component of the rider's velocity to zero at the plane of impact. However, in these tests the motorcycle pitch was restricted to that expected if spoked wheels were used. Therefore, in practice, motorcycles would need to be designed with frontal energy-absorbing characteristics similar to those obtained with wheels of this type.

Although the horizontal component of velocity of the rider was reduced to zero by the presence of the 120 litre air-bag, some rotational energy was retained. This was also the case with the 60 litre air-bag used on ESM-2.

ESM-3 is fitted with a 120 litre air-bag similar to that used in the impact tests. The inflator and hence the bag retention is at the rear of the fuel tank. This arrangement has been found to be effective and does not need for any additional attachment of the bag. With development of the computer program, ideal restraint system characteristics should be predictable during impact.

Conclusions

A mathematical simulation of frontal impacts of motorcycles is being developed and shows promise of becoming a valuable research and design tool.

A method of analysing crushable structures has been developed whereby the dynamic crush behaviour for impact velocities up to 14 m/s can be predicted using statically measured characteristics. This type of analysis has been successfully performed on motorcycle front wheels and it is intended to treat front forks similarly. The characteristics predicted for the wheels were used in a mathematical model designed to simulate the motion of a motorcycle and rider when impacting a rigid barrier at 90°, which is known as "head-on". The predicted movements of the motorcycle correlate well with those seen in practical tests. In particular the tendency for a motorcycle to pitch (kick up at the rear) when fitted with a cast front wheel is apparent. Similarly the tendency not to do so when fitted with a wire spoked wheel, is accurately simulated by the model. However, the rider which is represented by a "stick", does not reproduce well, and is wrongly predicted to leave the motorcycle at approximately the same velocity regardless of the front wheel type. Track tests have shown that the velocity is greater with a cast wheel. A more sophisticated rider model is needed and it is intended to develop one.

The model predicts that a safety frontal restraint system would hold a rider on the machine for longer if a spoked rather than a cast front wheel is fitted. This is an example of how the model will be used and it is intended to create a database from which the head-on impact performance of any motorcycle can be simulated and hence its design to minimise rider injury can be readily determined.

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Lower Leg Injuries Resulting from Motorcycle Accidents*

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Lower leg injuries resulting from motorcycle accidents have been well documented over the years in the medical literature and recognized as one of the more frequent injuries resulting from an accident involving motorcycles on the roads worldwide. While many of the previous reports have studied these injuries in depth, few have carefully analyzed the exact mechanism by which the injuries occur. This study has carefully reviewed over 125 motorcycle accidents in which there was an injury to the lower leg. Of the cases reviewed, 58 were selected to do a static reconstruction of the accident, using exemplar vehicles and occupants in order to determine the vehicle dynamics and occupant kinematics of the operator/rider. The accident scenario for each case consisted of a car to motorcycle collision and all were less than 35 mph in speed. The predominant accident configuration was that of a left turning automobile in front of a motorcycle. The major injury was a fracture of the tibia and fibula and underlying soft tissue damage. Transverse fractures of the femur often result from loading of the distal end of the femur and rarely are the result of a direct impact. Fracture of the patella and dislocation of the hip are not a common occurrence in motorcycle accidents. It is quite apparent from the static reconstruction of the accidents that much of the soft tissue injury occurs after the initial impact with the opposing vehicle, and is not the result of the leg being crushed between the vehicles. In fact, the true crushing injury as is often described, is not in our opinion a correct description of the lower leg injuries in motorcycle accidents.

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Introduction

The medical literature has well documented the fact that lower leg injuries are frequently found in motor vehicle accidents involving pedestrians, bicyclists, and motorcyclists(1,2). Although some variation exists from study to study, the 14.1% lower leg injury frequency observed in Hurt's detailed analysis of 900 motorcycle accidents appears representative for motorcycling worldwide when allowance is made for the study data and local conditions. Surprisingly, while the medical literature reports on the frequency and characteristics of these injuries, only rarely has the actual mechanism involved in producing the injury been considered. The injury mechanism is the specific topic addressed in this paper.

All available accident and medical records were obtained for 127 motorcycle accidents involving injury to the lower leg. From this population, 58 accidents were selected for detailed evaluation by means of a static accident reconstruction using identical vehicles and people with similar body dimensions. This reconstruction greatly facilitated establishing the actual vehicle and rider/occupant dynamics during the collision and immediate post collision phases of the accident. All 58 of these accidents involved the motorcycle impacting with the front of a generally left turning automobile and with each vehicle traveling at 35 miles per hour or less. The resulting trauma frequently involved a comminuted fracture of the tibia and/or fibula with underlying soft tissue damage. The static accident reconstructions have established that the observed soft tissue damage was almost always a consequence of the initial impact of the leg with the automobile bumper and was not a consequence of the leg being crushed between opposing surfaces of the colliding vehicles. In effect, the sharp bone fragments themselves become agents of injury as they are propelled away from the impacting surface and into the underlying soft tissue. Furthermore, it was observed that transverse fractures of the femur often result from a distal loading of the femur without an accompanying fracture of the patella and without dislocation of the hip. This distal loading of the femur is generally associated with the knee impacting with the vehicle grill or fender.

Methods

This study was aimed at leg injuries, and therefore the type of accident cases we examined only addressed that area. The number of accident cases studied was 127 in which there was an injury to the lower extremity. For our purpose the lower extremity was defined as any part of the body from the head of the femur, or hip joint, to the foot. The vast majority of injuries were to the tibia/fibula region, which is often described as the lower leg. The next most often injured part of the lower extremity was the thigh region, in which the injury was a fracture of the femur. Injuries to the hip and foot were least often seen in this study, but again this was due to the type of accident studied.

The size of the motorcycle ranged from 90 cc up to the largest touring motorcycles on the roadway today. The presence of crash bars on the accident vehicles in this sample size was notably low, with only five cases in which the presence of a crash bar was noted. The crash bars that were present were the standard off-the shelf type or the smaller version that are considered engine guards.

The speeds for the motorcycle in the accident scenario ranged from zero (stopped to make a turn) to a high of 45 mph. The most prevalent speed was in the range of 25-35 mph. Speeds of the adverse vehicle ranged from 10-45 mph, with the most often speed at the low end of that range.

The usual type of accident seen in this study was the situation in which the car makes a turn in front of the motorcyclist, and strikes the left side of the individual riding the motorcycle. Obviously this results in an injury to the left side of the body. There were a limited number of cases in which there was a stopped motorcycle that was struck by a moving car. Also, there were a limited number of cases in which the accident was a single vehicle accident. In this situation it is usually a matter of the motorcyclist leaving the roadway and striking an object off the roadway.

In studying these accidents, the police report was obtained and reviewed for data concerning the nature of the accident, including size of vehicles, speeds, direction of travel, point of impact, point of rest for the vehicles and occupants, and type of damage and location. Where possible, photographs of the accident vehicles were studied to determine the extent of the damage from the accident. A complete review of the medical records was done to determine the extent and nature of the injury. This included the admitting report, operative report, radiology report, and nursing notes. In most cases, the x-rays were also reviewed. In many of the cases a complete examination of the motorcycle was done to determine and record the extent of the damage. This was useful in assisting with the understanding of the accident scenario. The type of damage to particular parts of the motorcycle would often provide useful data in determining the type of accident and the direction of the forces in the collision. There were a limited number of cases in which the adverse vehicle was also available for study and examination. In these situations we were able to study and document the extent of the damage to the opposing vehicle. Again, this provided significant data as to the type of collision that was involved, as well as helpful data as to the direction of force.

In cases in which one or both vehicles were available for inspection, they often provided valuable information concerning the points of contact of the body and thereby giving us data as to the mechanism by which the injury was produced. Frequently, it is possible to identify fabric transfer on one or both vehicles, location of material from clothing, and in some situations we were able to identify body imprints on one or both vehicles. These included dents in the fender and/or hood areas of the opposing vehicle, or a dent in the side of the gas tank.

All of the injuries sustained in the accident, were recorded onto a data sheet and then given an AIS number(3). In addition to the AIS scaling system, we devised our own system for further defining the type of fractures that occurred in the different accidents. This system allowed us to classify each type of fracture as to bone, location of fracture and nature of fracture (table 1).

In total 125 accidents were studied in depth where there was an injury to the lower extremity. In addition to the lower extremity injuries, a record was also made of any other injuries that were sustained as well in the accident. For each of the accidents a determination was made as to the mechanism by which the injury occurred. Of particular interest was the nature of the fractures of the long bones and the mechanism by which the injury occurred.

Of the 125 cases studied, 58 or 46% were selected for a static reconstruction of the accident. In these situations we used exemplar vehicles which were of the same make, model and year as the accident vehicle. We also would use people who were of the same physical size as those involved in the accident that was being studied. Using the information regarding the damage to the vehicle, we could then align the vehicles to determine the angle of the collision. This would be based not only upon the damage that resulted from the accident, but in addition we also considered the injuries that resulted from the accident. The purpose here was to determine both the vehicle dynamics in the collision, and the rider/occupant kinematics.

Table 1. UofL fracture classification.

ARM	FOREARM	FEMUR	TIBIA
1	2	3	4
PROXIMAL	MIDSHAFT	DISTAL	
1	2	3	

SPINE	PELVIS	HAND
5	6	7
ANKLE	CLAVICLE	OTHER
91	92A	10
SCAPULA	PATELLA	
92B	92C	

SHAFT FRACTURES

A. SIMPLE FRACTURES A1 SPIRAL	A2 OBLIQUE	A3 TRANSVERSE
	.1 PROXIMAL .2 MIDSHAFT .3 DISTAL	
B. WEDGE OR PIECE B1 SPIRAL WEDGE	B2 BENDING PIECE	B3 2 OR 3 PIECES
	.1 PROXIMAL .2 MIDSHAFT .3 DISTAL	
C. BITS & BROKEN PIECES C1 SEGMENTED FX.	C2 BROKEN PIECE	C3 FREE PIECES
	.1 PROXIMAL .2 MIDSHAFT .3 DISTAL	

Results

Tibia

In looking at the fractures of the long bones (i.e. tibia and femur) over half of the fractures were to the tibia, the number being 63% of the total fractures recorded. These ranged from simple non-displaced fractures to compound/comminuted fractures with significant soft tissue involvement. In studying the location of the fracture, the majority of the fractures were in the distal third of the tibia. Whenever there was a comminuted fracture of the middle and distal thirds of the tibia, there was an associated fracture of the fibula at the same location. Fractures of the tibial plateau were often associated with a fracture of the femoral condyles and significant involvement of the knee joint. Fractures at the tibial plateau that were displaced posteriorly often invaded the popliteal fossa, and the vessels and nerves within the fossa.

In examining the mechanism of injury through the use of exemplar vehicles and people, it is quite apparent that the injury to the middle and distal tibia is the result of the leg being impacted by the bumper of the adverse vehicle and then pushed in a rearward direction. This is typical of the situation where the automobile turns in front of the motorcyclist, and the latter then attempts an evasive maneuver to avoid the collision. The angle of collision between the two vehicles is usually less than 30 degrees. The leg is not pushed into the side of the motorcycle, but rather rearward along the side of the motorcycle.

In situations where fracture of the tibia occurs at the tibial plateau or the proximal one-third of the tibia, this is the result of the knee and upper tibia making contact with the fender region of the opposing vehicle. Again, the angle between the two vehicles is less than 30 degrees. When the impact to the leg is in this region of the body, there is often involvement of the peroneal nerve, which is just lateral and inferior to the knee. An injury to this nerve will affect the muscles of the anterior compartment of the lower leg, and the result will be foot drop and a numbness to the dorsum of the foot.

The type of fracture seen is usually a transverse or comminuted fracture in which there were many fragments of bone. A spiral or oblique fracture is seldom seen in accidents in which there are vehicle to vehicle collisions. We did observe a limited number of spiral fractures of the tibia, however, these were usually seen in situations of a single vehicle accident. In a single vehicle accident, the rider goes off the roadway and in an attempt to control himself and the vehicle puts his foot down and impacts the ground with sufficient force to cause a spiral fracture. As the foot impacts the ground, the force is transmitted through the foot and to the distal end of the tibia, often resulting in a tri-malleolar fracture or a spiral fracture of the tibial shaft.

Whenever there is a significant fracture involving the lower leg, with both the tibia and fibula involved, there is also soft tissue damage to the underlying tissue. This can be of particular concern when the blood vessels are damaged, and there is a loss of adequate blood supply. The main cause of the amputations is an inadequate blood supply to the tissue distal to the point of injury.

Femur

The incidence of fractures to the femur were approximately half the number of tibial fractures.

These usually occurred in the distal third, and were transverse in nature with little or no soft tissue involvement. The limited number of fractures at the head of the femur usually were associated with a dislocation of the head of the femur. Another problem seen with fractures of the head of the femur was also a fracture of the acetabulum.

The fracture of the distal third of the femur is almost always the result of an indirect impact, rather than a direct impact as is seen in the tibial fractures. The static reconstruction showed that as the knee would go into the fender or grill of the adverse vehicle, the force would be transmitted along the axis of the femur. While the distal portion of the femur is stronger than the shaft, the force is transmitted from the area of the femoral condyles to the shaft of the bone. The fracture then occurs at a point distal to the actual site of impact, and will usually be between the middle and distal third of the bone.

Fractures of the proximal third of the femur are usually the result of an impact to the ground, and not a direct impact from the opposing vehicle. In our study the limited number of cases where there was a fracture of the proximal third, it was determined for each of these that it was the result of an impact to the ground. When the neck of the femur is fractured, this is the result of the distal end of the femur being impacted, and then pushed rearward as the knee is held by the opposing vehicle. This is often seen in accidents where the knee goes into the compliant fender area of the car and is held there as the rider then slides forward.

Femoral fractures seldom have soft tissue involvement, and are usually transverse in nature. The lack of soft tissue injury is obviously due to the anatomy of the thigh region. The femur is surrounded by large groups of muscles. The notable exception to this is the accident where the neck is fractured and pushed rearward, and damages the muscles, nerves and vessels in the area.

Ankle & Foot

Injuries to the ankle and foot region are the result of the foot being caught by the bumper and pushed rearward. We often see the situation where the foot is caught by the underside of the bumper, and results in fractures to the tarsal and metatarsals. These types of impacts can also have involvement of the blood vessels as they are close to the surface of the skin in this region, and thus are vulnerable to trauma in this area. Impacts to the foot/ankle can and will often result in dislocations of the ankle.

Patella

The incidence of fracture to the patella is quite low. In the present study we recorded only 8 cases where there was a fracture of the patella. This fracture is usually seen where there is significant involvement with the distal femur and the femoral condyles. When there is an explosive fracture of the distal portion of the femur, it is indicative of a high impact, and there will be an associated fracture of the patella. However, from the reconstructions performed that demonstrate a loading of the knee region, with a fracture of the distal femur, there is rarely a fracture of the patella at the same time.

Discussion

In reviewing 127 motorcyle accidents in which there was a leg injury, it is quite apparent that the most frequently injured area of the leg is the region of the lower leg, with a fracture of the tibia and fibula. Whenever there was a comminution of the bone with soft tissue injury of the underlying tissue, the medical report would describe this as a crushing type of injury. While the injury may give this appearance to the attending physician, it becomes obvious when a careful analysis of the accident is made, that seldom is the injury mechanism a crushing injury. Using exemplar vehicles and people, and the information available concerning the speeds, and damages to the vehicles, we were able to reconstruct 63 of the accidents. In all but three of our cases this analysis showed the injury to be an impact type of injury, not unlike the situation in which the pedestrian is impacted by an automobile. The leg is not crushed between the opposing vehicles, but rather is pushed rearward along the side of the vehicle.

Much of the soft tissue injury is the direct result of the sharp bone fragments causing lacerations of the muscles and vessels. Once the bones have been broken by the impact of the bumper or fender of the car, the structural integrity of the leg is then lost and as the leg is moved the sharp bone fragments cause additional injury. This type of injury comes from the inside out, rather from the outside in.

The mechanism of femoral fractures that occur in the motorcycle accident is different from that seen in the automobile accident. The work of Nahum(4) reports on the incidence and type of lower extremity injuries that occur in automobile accidents. The report of States(5) clearly shows the mechanism by which a posterior hip dislocation occurs in an automobile accident. However, in the motorcycle accident, rather than a hip dislocation, the more frequent fracture is a transverse fracture of the distal third of the femur. The reason for this can be attributed to the seated posture. In the automobile, the occupant usually sits with the knees forward and close together. However, the motorcyle rider sits with his legs astride of the gas tank and therefore at approximately a 45 degree angle. If there is a passenger behind the rider, their legs are at even a greater angle. In this position, the head of the femur is rotated deep into the acetabulum and is held firmly. In the normal sitting posture as seen in an automobile, the head is not as deep into the acetabulum, and upon impact, the head is driven posteriorly and can often result in a fracture of the rim of the acetabulum.

In reviewing 127 motorcycle accidents in which there was an injury to the lower extremity, the mechanism by which these injuries occur is a high velocity impact, similar to that seen in pedestrian accidents. Static reconstruction of the accident clearly showed that the leg is not crushed between the two vehicles, but rather it is impacted and then pushed rearward along the side of the motorcycle. In looking at the types of leg injuries that result from motorcycle accidents, the type of injury is very similar to that seen in pedestrian accidents.

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Load Measuring Method of Occupant's Leg on Motorcycle Collision

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Abstract

In the past, researchers have studied the leg protection devices. We can say there is no effective device which protects motorcycle occupant's legs without negative side effect.

In the development of effective leg protection devices, it has become necessary to analyze leg injury mechanism.

In this regard, advancements in the measuring method of leg load analysis are viewed as a significant contribution to the further research of leg protection device.

In this paper we have examined, tested and analized leg load measuring method.

Introduction

Researchers have been studying with the objective of developing leg protection devices for motorcycles. The leg protection devices investigated thus far, however, show a potential for increasing injuries to the other parts of the body. These result from the preservation of leg space which is a necessary premise to leg protection. This contradiction has not yet been solved.

Recent studies have focused on reducing leg injuries without increasing the injury potential to the other body regions. One of pontential approaches to achieve such objectives is to measure the severity of leg injuries quantitatively.

We believe that the leg load is one of factors affecting the injury severity, and that by learning the load characteristics on the leg, which have not fully been explored in the past studies, we will be able to contribute to the further study of the leg protection device.

In this regard, we considered the development of a leg load measuring method as a key factor, and have studied the methods for leg load measurement.

A Review of Leg Protection Devices for Motorcycles

Leg injuries resulting from contact with an opposing vehicle are considered to be significant due to the exposure of the motorcycle occupant's body to the environment.

Therefore studies for leg protection have been carried out over two decades.

A summary of the results on previous experimental leg protection devices is presented for an easier understanding of the situations (Table 1).

As mentioned in Table 1, countermeasures for achieving leg protection effect are accompanied by new problems. At present, effective leg protection

Table 1. Previous studies and experimental results regarding leg protection devices.

Period	Focus/Point of View	Experimental Results
The late 1960's 1971	A conventional bar was used to prevent the occurrence of severe injuries resulting from leg trapping between the motorcycle and an opposing vehicle.(1)*,(2)	The collision load being quite large, the conventional bar is weak enough to be bent thereby demonstrating the absence of any protective effect.
1972 1973	A reinforced bar was tested with the expectation of providing a leg protection effect by preserving leg space. (3), (4)	It preserves leg space under certain collision situations, however, it is necessary to investigate the adverse effects on the other parts of the body. The leg is fractured by hitting bare steel tube structure directly. A countermeasure to prevent the knee from hitting to the device is necessay.
1974 1976	The effect of reinforced leg protection devices was investigated through various collision tests.(5),(6)	It preserves leg space under certain collision conditions. It has potential for increasing head, chest,pelvic and upper leg injury,since the device makes rider ejection easier.
1975-1981	The effect of a knee cushion pad was studied as a countermeasure for protecting the leg from hitting the steel tube structure.(7)	As the knee intrudes into the pad and is trapped, pitching of the torso is increased and head hits the lower portion of the other vehicle's door. As a result, the occupant's neck is subjected to severe flexion and likely fracture.
1983 1985	In order to reduce the head impact velocity, the effect of energy absorbing materials placed on the sides of the motorcycles was investigated.(8),(9),(10),(11)	Energy absorbing materials contributes to a slight decrease of motorcycle impact acceleration. There are two sets of data regarding head velocity,one showing increased head velocity, the other decreased.

devices which do not increase injuries to the other part of the body, have not yet been developed.

The target of current efforts is to eliminate negative side effects while maintaining leg protection effect. Achieving this target has been quite difficult, since the adverse effect is due to the preservation of leg space, which is the very principle that has been advocated for leg protection.

A Review of Leg Load Measurement Methods

In order to evaluate leg protection devices of various researchers, various methodology were contrived and employed in the past, and they were satisfactory for the purpose of evaluating these leg protection devices.

We have come to recognize from our studies to date, however, that in order to develop an effective leg protection device, it is necessary that we understand the characteristics of the external force, i.e. leg load characteristics (direction, location, timing, mode etc.), exerted against the leg. The methodology employed in the past is hardly satisfactory for such needs. Therefore, we believe that it is necessary to develop a dummy which allows us to measure various load characteristics which may be relevant to the development of a leg protection device.

Viewed from this perspective, a dummy does not exist which can quantitatively evaluate the injury severity. In order to quantitatively evaluate lower extremity injuries during collisions, it is necessary to have:

- A dummy which approximates the human body, to accurately simulate injuries to the lower extremities.

Table 2. Comparisons between various methods for leg load measurement in terms of their merits and demerits.

Evaluation Item / Measurement Method	Load Direction	Load Timing	Load Mode	Quantitative Measurement	Measurable Area	Fidelity of the Rider Kinematics	Impact Point	Remarks
Leg Acceleration Measurement(1),(3)	N 1 axis	Y	N	Y Acceleration	Δ Narrow	N	N	Leg trapping load can not be measured.
Strain Gauge on a Metallic Bone (5)	N	Y	N	Y Bending Moment	Δ Sensor vicinity	N	N	If the point of impact misses the position of the gauge the value cannot be obtained accurately.
Knee and Ankle Load Measurement (6)	N	Y	N	Y Load	N quite narrow	N	N	Load Measurement is not possible if the load point misses the load sensor.
Breakable Resin Bone (6),(9)	Δ	N	Y	N Above or below threshold of fracture load	Δ Area between joints	Δ	Y	When fracture occurs leg tends to detach. Quantitative data cannot be obtained.
Metallic Plate and Aluminum Honeycomb(8),(10),(11)	Δ	N	N	Y Total amount of Energy	Δ Side face only	N	Δ Side face only	Effective measurement is limited to the right angle component of impact only. It is difficult to interpret the dent of honeycomb.

Y……measurement possible

Δ……measurement possible to a certain extent

N……measurement impossible

*Numbers in parentheses designate references at the end of this paper.

- A dummy capable of load measurements to enable accurate assessment of the injury severity and a correlation between injury and impact load to the lower extremities.

In the light of this, it was decided to first focus on and discuss methods for load measurement applied to the lower extremities. Table 2 summarizes the evaluation of the merits and demerits for various measurement methods proposed in the past in terms of the necessary parameters to be considered.

Despite the efforts that have been made to date by researchers, we regret that as of yet, there is no method which has gained universal acceptance by researchers in the load measurement field.

Examinations on Measurement Items and their Methods

Measurement items

As mentioned previously, researchers have made efforts to devise measurement methods. We submit this study with hopeful exception that it will contribute to progress in this area.

When conducting leg injury measurements, it is necessary to consider which region of the leg should be focused on. Thus, these examinations must be based on injury analyses of the actual accidents and dummy impact conditions observed during collision experiments. Here, measurement items to be focused on are chosen based on the dummy impact conditions observed during collision experiments. A summary of the results is presented in Table 3.

The Measurement Methods

Measurement of the Maximum Value, the Position and Direction for the Bending Moment Applied to the Femur and Tibia.

In the event that a load is applied as in Fig. 1-a, if the load point (bumper position) is always constant, attaching a strain gauge to the load point is sufficient for measuring maximum bending moment (Fig. 1-b).

Table 3. Impact conditions for dummy during collision experiments and required measurement items.

	Dummy Impact Condition during Collision Experiment	Required Measurement Items
Lower leg	Lower leg is impacted with the bumper of the other vehicle, while knee and ankle are supported by tank and engine of the motorcycle, respectively. As a result, the lower leg may be trapped. Pelvis is pushed up onto the hood of the opposing vehicle. Less possibility of the lower leg receiving a compression load between the ankle and the knee is observed.	To the tibia ● Bending moment ● Load point ● Load direction ● Torsional moment between the knee and the ankle
Upper leg	The femur hits the edge of the opposing vehicle's hood. *The knee penetrates into the* opposing vehicle's front grill. The lower leg will be trapped and the torso moves against the opposing vehicle	To the femur ● Bending moment ● Load point ● Load direction ● Compression load ● Torsional moment between the knee and the pelvic joint

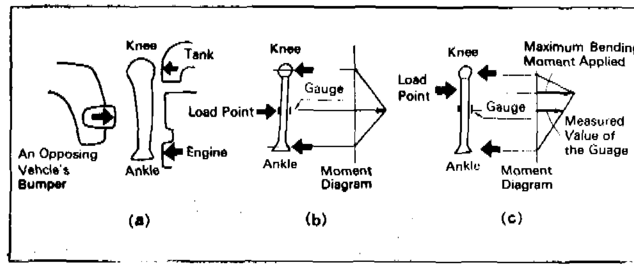


Figure 1. Differences in values measured by the load *point and gauge position*

If the load point varies and misses the strain gauge position, the strain gauge indicates a lower value than actual maximum load and can not measure maximum bending moment (Fig. 1-c).

Examinations were made as to assuming measurement methods to determine the maximum bending moment and load point under the condition where the load point changes. As a result, when the bending moment sensor is set between the supporting point and the load point, the bending moment at each point along the beam is shown with the line which links the bending moment of the supporting point (bending moment = 0) and that of sensor position.

On the other hand, if the same sensor is set near the other supporting point, another bending moment line can be drawn. The cross point is considered to indicate the value of the actual maximum bending moment and the load point position (Fig. 2).

Thus, when two bending moment sensors are placed near the knee and ankle respectively, the maximum bending moment and load point can be determined. The same analysis or approach applies to the femur.

The direction of the load applied can be determined from the measured bending moment around longitudinal and lateral axes and sensitivity curves of the sensors.

Therefore, to determine the direction, it is necessary to install bending moment sensors around the longitu-

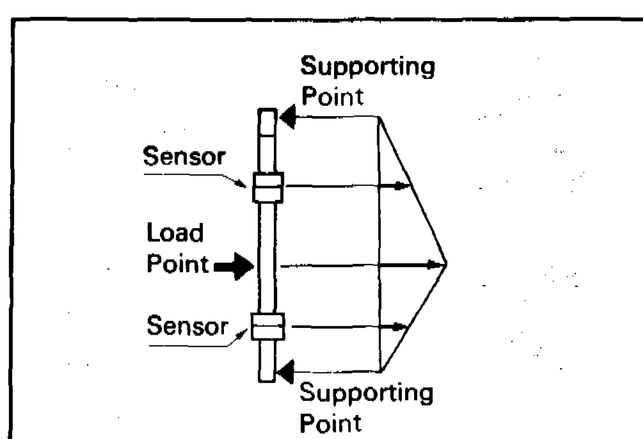


Figure 2. Determination of load point

dinal and lateral axes, and the obtaining sensitivity curves of those sensors.

Measurement of Torsional Moment Applied to the Tibia and Femur

It is reasonably assumed that uniform torsional moment exists between joints. Thus, it is possible to take measurements by installing a torsional moment sensor somewhere between joints.

Measurement of Compression Load Applied to the Femur

Since compression load also works uniformly between joints (as does torsional moment), it can be measured by placing a compression load sensor in one place between joints. A summary of required sensors is shown in Table 4.

Examinations on Various Factors Affecting Measurement Results

Factors effecting bending moment measurements. For the usage of this measuring procedure, factors which have an effect on the measured values are considered and discussed along with the items shown below.

- Joint tightening torque
- Elasticity of muscle around the bone
- Stiffness of bone itself
- Influence of bone fracture phenomenon

Joint tightening torque. Joint tightening torque adjustments for dummies in normal collision experiments are set on the order of one G. Since this level of tightening torque is small as compared to bone fracture level, the effect of the tightening torque is considered to be negligible.

Elasticity of the muscle around the bone. The elasticity of dummy muscle which is currently standardized is considered to be far below the bone fracture level and is also considered to be negligible.

Stiffness of bone itself In a simplified model where rigid mass (m) collides with an elastic body (elastic coefficient (k)) at the velocity V, the maximum force within a linear range can be represented by the formula $F = \sqrt{mk}\ V$.

This means that where the stiffness of the dummy bone is twice as high under the same conditions the resultant load becomes 1.4 times higher.

Table 4. Required sensors.

Tibia	• The bending moment sensors for X and Y directions of the upper part of the tibia • The bending moment sensors for X and Y directions of the lower part of the tibia • Torsional moment sensor between the knee and the ankle
Femur	• The bending moment sensors for X and Y directions of the lower part of the femur • The bending moment sensors for X and Y directions of the upper part of the femur • Torsional moment sensor between the knee and pelvic joints • Compression load sensor between the knee and pelvic joints

X,Y,Z : see Ref. (12)

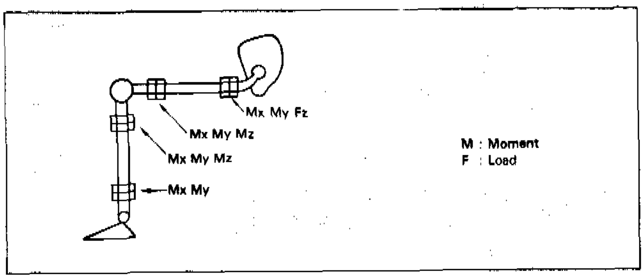


Figure 3. A schematic of sensor positions

Comparison between human and dummy leg bone characteristics from this perspective is shown in Fig. 4.

Judging from Fig. 4, the stiffness of current dummy leg is higher than that of human leg. By attachment of the load sensor to this excessively stiff dummy leg, the data as mentioned previously, will differ from the actual load values for human leg. In order to determine the correct leg load, it is first necessary to obtain the stiffness for dummy leg bones.

Factors effecting torsional moment measurements. The same considerations can be applied for the measurement of torsional moment as for bending moment.

This means that for the measurement of torsional moment, the combined effect of joint tightening torque and muscle elasticity is small and may, therefore, be ignored. On the contrary however, from the perspective of bone torsional stiffness, the maximum torsional moment as well as measurement of load, is proportional to the power of one half of the modulus of the elasticity in shear. Therefore, to measure the torsional moment applied to a human leg bone, it is necessary to obtain the torsional stiffness value for the dummy leg bone in advance.

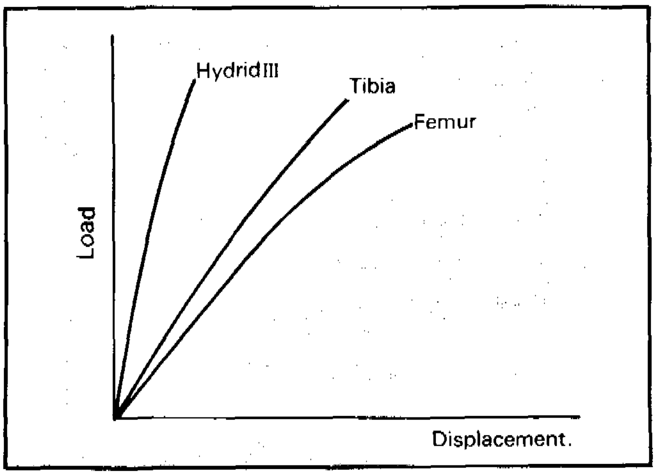


Figure 4. Comparison of human versus dummy bone characteristics

Table 5. Hybrid III dummy measuring system.

Tibia	Lower Tibia Sensor	Mx Fy Fz
	Upper Tibia Sensor	Mx My
	Knee Clevis Sensor	Fz
Femur	Lower Femur Sensor	Mx My Mz Fx Fy Fz
	Upper Femur Sensor	Mx My Fx

Verification of Measurement Procedures

Selection of Dummy

A verification has been conducted to determine whether the measurement methods discussed in this paper would be practical by using the Hybrid III dummy leg sensors which are considered to be nearly in conformance with our needs, although it does not have all of the sensors mentioned in Table 4.

Measurement parameters with the Hybrid III dummy used in this study are shown below.

Load Determination

The tibia of the Hybrid III dummy was used in impact experiments employing an impactor. A study was carried out to find out whether the load position and direction could be determined from measured data.

A photo is shown in Fig. 5.

Determination of Load Direction and Bending Moment at Sensor

In order to determine the load direction, sensitivity curves for Mx and My sensors were first obtained. Fig. 6 shows the sensitivity curve for the Mx sensor as an example. Sensitivity curves for all sensors are similar to a circle as well as the sensitivity curve for the Mx sensor.

Therefore, the load direction (θ) and actual moment (Mu) at the upper tibia sensors can be determined by applying the measured values Mxu, Myu of the Mx, My sensors to the following formulas (Fig. 7).

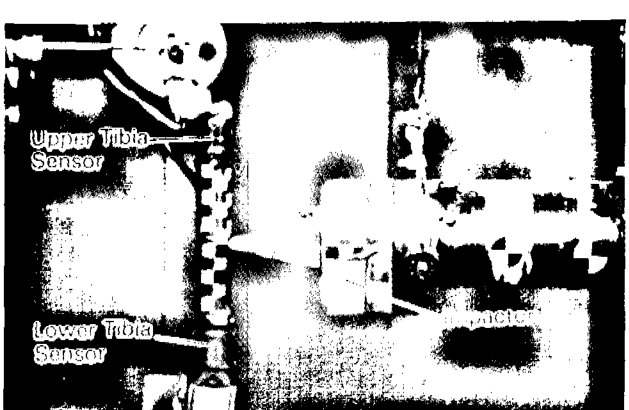


Figure 5. Impact apparatus

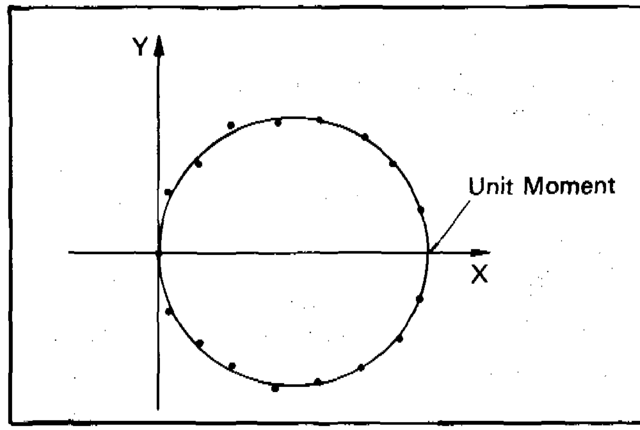


Figure 6. Mx sensitivity curve

On the other hand, the actual moment at the lower tibia sensor (M_L) can be obtained from the measured value M_{XL} of M_X sensor using the formula $M_L = M_{XL}/\cos\theta$

Determination of Load Point and Amount of Load

The load point (X) is determined by using Mu (refer to Fig. 7) and M_L (Fig. 8).

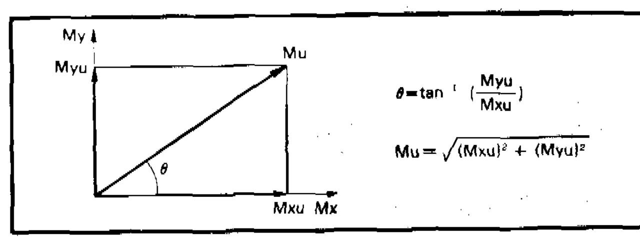


Figure 7. The relation between Mxu, Myu, θ and Mu

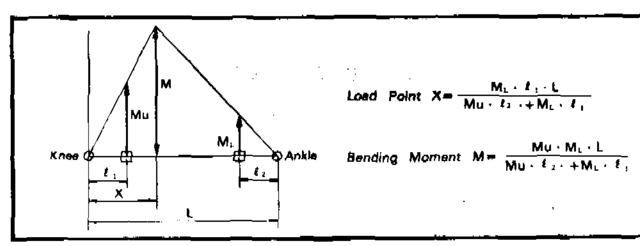


Figure 8. Determinations for load point and bending moment

The amount of load (W) is determined by using M in the formula below (Fig. 9).

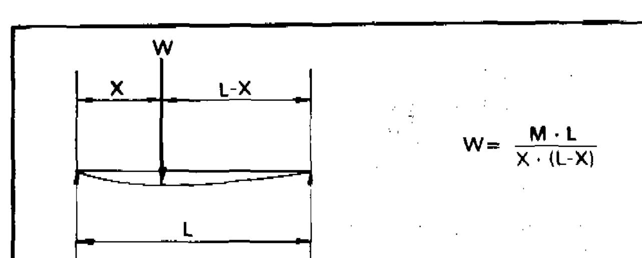


Figure 9. The determination for the amount of load

Table 6. Impact condition and results of analysis (N = 3).

	Load Direction (deg)	Load Point (mm)	Load Amount (kg)
Impact Condition by an Impactor	Oblique forward 45°	Below the knee 215	850±50
Results analyzed by the Proposed System	40°±5	220±10	610±50

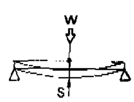
Table 6 shows the results of an analysis of a known impact condition by using the above procedure.

Effect of Leg Bone Bending Stiffness on the Measured Value

The square root of the bending stiffness*1 of the metallic leg bone employed in this dummy leg was compared with that of a human bone and was found to be 3.25 times higher. Therefore experiments were conducted employing a Bakelite bone which has a stiffness similar to that of human bone for comparison purposes. The results are shown in Table 7.

Table 7. Leg bone bending stiffness and impact load (N = 3).

	Bending Stiffness*1 (kg/mm)	√Stiffness ratio	Impact load*2 (kg)
Human tibia bone	29.6 (14)	1	-
Breakable Bakelite bone	26.8	0.95	270±25
Hybrid III dummy Tibia (Aluminum Bone)	313.5	3.25	850±50



Note:
*1 Bending Stiffness = W/S
*2 Impact Condition = Impactor Mass 30kg
Impact Velocity 2.0 m/s

Judging from Table 7, it can be seen that the impact load is influenced by the stiffness of the leg bone material. The Hybrid III leg bone shows a distinctly higher value due to its high rigidity.

In this impact experiment, however, a Hybrid III dummy original leg was employed, and so the value of the impact load was also influenced by the stiffness of the knee clevis and joint. As a result, the impact load of the aluminum bone from Table 7 indicated a slightly lower value than (the value for the impact load of the Bakelite bone) × $\sqrt{\text{stiffness ratio}}$.

The Effect of the Leg Load Measurement System on Rider Behavior

The current leg sensors for the Hybrid III dummy are attached to the metallic leg bone. As a result, fracture does not occur, as it did with the breakable Bakelite bone previously employed. Thus, an excessive load can be applied with no fracture and can influence dummy kinematics, especially, lean behavior of the dummy torso in the broadside collision. Therefore, dummy kinematics was observed by simulated collision experiments on sled tests. Fig. 10 shows the device used in the experiments.

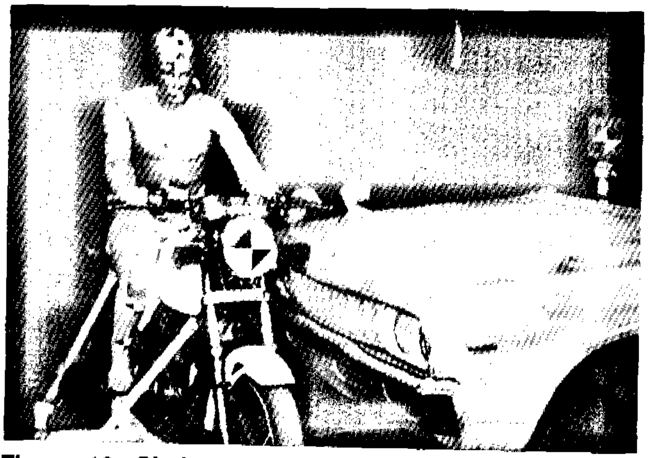


Figure 10. Sled tests set-up for simulated collision

With the dummy having the metalic bone, as opposed to the dummy having the breakable Bakelite bone which fractures upon impact, there will be no fracture even though a torsional moment is applied to the metalic bone when the inclination of the dummy pelvis exceeds the movable range of the pelvic joint, which tends to restrict the inclination of the pelvis. Fig. 11 shows the difference in the behavior of the pelvis and lumbar spine.

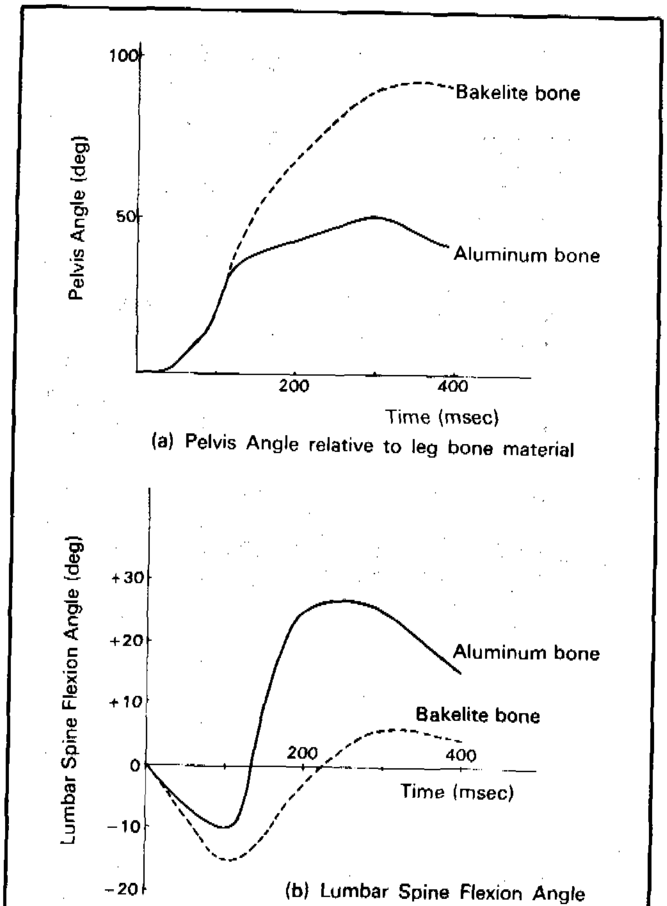


Figure 11. The difference in pelvis and lumbar spine behavior by leg bone materials

In observing aluminum leg bone, it was noted that along with the difference in pelvic behavior, the lumbar spine tended to be bent severely, and hip lift tended to be restricted. This is shown in Fig. 12.

Therefore, in comparing metallic bones to breakable Bakelite bones, behavioral differences were observed as follows:

- Pelvic inclination was restricted
- Lumbar spine was bent tremendously
- The amount of hip lift was lesser

We found that since the fracture phenomena cannot be simulated with a current metallic bone, the occupant's behavior was impaired. A consideration of fracture characteristics was found, therefore, to be necessary in order to properly simulate a occupant's behavior.

Discussion

Measurement Methods

The methodology in which sensors are placed in the leg was found to be useful in determining the load point, load direction, amount of the load and load timing from the experiment results.

Characteristics of Bone Stiffness and Fracture

The results of the tests verified that it is important for correct measurement, to obtain resultant stiffness of the leg system, including joint portions beforehand.

Furthermore it must be considered that a human leg bone is fractured if load exceeds a certain value. Therefore, excessive load can not be applied.

With metallic bones, however, fractures are not produced even after having reached the level at which human bones would fracture. In this case, the load continues to be applied. This has an effect on the primary kinematics of the dummy in the collision experiment.

Since it is usual to observe not only the measurement of applied load to the occupant's legs but also occupant's kinematics, it is necessary to take into consideration both fracture as well as stiffness characteristics.

Simulation of leg bone fracture characteristics leads to restricted measurement below the bone fracture level. It is important, therefore, to select an appropriate dummy leg bone for the purposes of particular experiments.

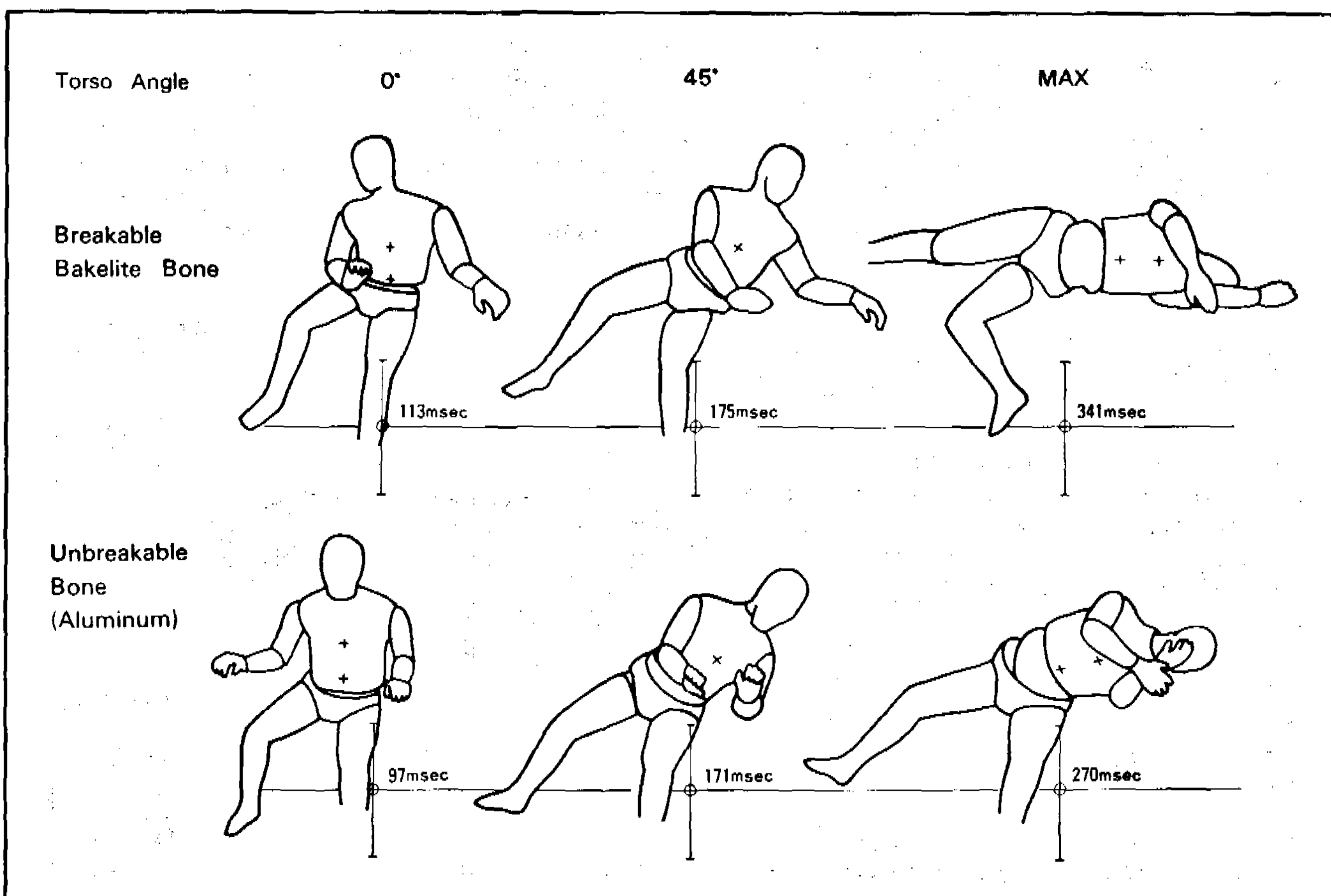


Figure 12. Difference in lumbar lean behavior depending on leg bone materials

Measurable Area

In the case of the measurement of the bending moment with the proposed measurement system, the measurable area is restricted to a leg bone portion which connects the sensors. Thus, the larger the joints and sensors are, the narrower the measurable area is.

Therefore, to widen the measurable area, it is necessary to devise sensors and joint portions as small as possible.

Cross Sensitivity

Cross sensitivity has two meanings. The first is to pick up the signal of the direction which crosses the main measurement axis. The second is those cases where undesired various items other than the target item are measured. The former becomes a cause of errors in determining the load direction, however, the upper tibia sensors employed in these experiments showed no significant error.

The lower femur sensor system, employed this time, unified several sensors, and was found to have unfavorable characteristics. For example, if a compression load is applied, the sensor indicates as though bending moments around X and Y axes are applied.

A sensor having this type of characteristic is not suitable for motorcycle collision analysis which requires strict distinction between compression and bending. Therefore, it is necessary to develop a sensor having minimal cross sensitivity.

Characteristics of Bone Stiffness and Fracture

Researchers in the past endeavored to measure injuries to the lower extremities for evaluation of leg protection devices. However, no measurement method has been accepted worldwide. Each method has its strong and weak points. As an example, the fracture simulated bone employed in JAMA studies (6), (9) indicates whether or not a fracture exists and also the fracture mode.

Those employed by G.W. Nyquist et al. (13) demonstrate the existance of bone fracture. With respect to those points they are considered to be superior but they do not measure quantitatively.

The method used by B.P. Chinn et al (8), (10), (11) whereby aluminum honeycomb is attached to a metallic bone can express the total amount of energy applied. An accuracy could be expected if the impact came from right angle to the honeycomb. In addition, it is also difficult to distinguish the load mode.

The strain gauge system utilized by Bartol et al (5), and JAMA study (6) is effective only with a definite load point.

Further improvements are required before the procedures which have been designed and proposed in this paper thus far can be useful. We believe, based on this study, that the system employed has the capability of measuring the time, location, mode, direction and amount of load.

Conclusion

The items below have become clear with regard to leg load measurements.

- The methodology for measuring leg load have their own strong and weak points, and they can not provide measurements on all the required items.
- There is no standardized method at present which is accepted by researchers for motorcycle collisions. Researchers have devised their own methods depending upon their particular needs at the time.
- The dummies developed for automobiles in the current state are not entirely suitable for the leg load measurements as we needed in this study, because the dummy receives different modes of load in the motorcycle collisions than in the automobile collisions.

Based on the observation of the collision experiments, it was found necessary to measure the following items:

- Bending moment and torsional moment applied to the tibia.
- Bending moment, torsional moment and compression load applied to the femur.

Regarding those items for which measurements are necessary, we examined the methodology to determine the impact point and direction, the load amount, load timing as well as mode of load.

As a result, placing sensors on the leg bone was proposed. With numerous sensors attached to the leg of the Hybrid III dummy, this leg measurement system was subjected to impact tests for verification.

The result indicated that following elements can possibly be determined.

- Load point
- Load amount
- Load direction

Through these discussions and tests, some points were noted which need to be improved. For example:

- To devise sensor and joint portion which are as small as possible.
- To develop a sensor having minimal cross sensitivity.

Although the measurement value and behavior of the dummy can be approximated to those of human being in the range short of bone fracture by making the characteristics of the dummy bone similar to the human bone, the usage of such bone will impair the measurement above that range. Therefore it is essential to select a dummy bone suitable for particular tests.

Further studies for the improvement of the methodology proposed here will be conducted in the future.

It is hoped that a more suitable dummy for load measurements will be developed after advancements in the field of the accident injury analyses. And it is also hoped that through the use of dummy above mentioned, a clue to the development of a practical leg protection device can be found.

Acknowledgments

The author wishes to express a special word of thanks to MR. K. Miyazaki and other members of Japan Automobile Research Institute for their expertise to conduct the experiments.

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Reduction of Injury Severity Involving Guardrails by the Use of Additional W-Beams, Impact Attenuators and 'Sigma-Posts' as a Contribution to the Passive Safety of Motorcyclists.

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Abstract

Motorcycle collisions with guardrails are a severe safety problem. Especially hitting the posts lead to severe injuries of riders and pillion riders. A total number of 150 fatalities out of 1,000 per year is estimated for the Federal Republic of Germany. To avoid fatalities and to reduce the severity of injuries these solutions are presented:

- fitting of the so-called "Sigma-Post" instead of the mentioned "IPE-100"
- fitting of an additional W-beam
- fitting of special impact attenuators to guardrail posts

Biomechanical tests prove the effectiveness of impact attenuators, of which approximately 20,000 have been fitted to guardrails in the Federal Republic of Germany since 1984/85.

Although not yet valid and reliable, field tests seem to prove the effectiveness of both the additional W-beam and the impact attenuators in terms of reducing the injury severity. Additional W-beams seem to reduce the number of accidents, too.

Finally the results of the cost-benefit studies are presented, which prove that under certain, realistic conditions the implementation of protective measures is to be considered positive.

Definition of the Problem

Motorcycle accidents of various configurations, falls or collisions with other road-users, can result in riders sliding along the road surface and hitting a section of guardrail after having been separated from their machines.

The Federal Highway Research Institute systematically analyzed motorcycle accidents in the Tuebingen area to find out whether they led to riders colliding with an obstacle beside the roadway. In 1984, 2793 accidents occurred in this region with 7 of the 44 deaths resulting from impact on guardrail (Domhan, 1987, page 205).

If taken as a basis for the whole Federal Republic of Germany, this and other regional surveys give us an approximate figure of 150 "guardrail deaths" from a total of about 1,000 (in 1986: 972) deaths per year. This is a share of 15%.

The fallen motorcyclists usually sustain their injuries from a collision with the guardrail posts (Schueler et al, 1984). Until 1985 nearly all posts to be fitted were the so-called "IPE-100-posts" which are particularly aggressive owing to their form and material.

The probability of hitting a guardrail after a fall is relatively high due to the fact that 10% of the 500,000 km of roads in the Federal Republic are equipped with such. Naturally there exists a higher density of guardrail on dangerous stretches of road than suggested by the statistic average (Motorrad, 9/87, p. 228).

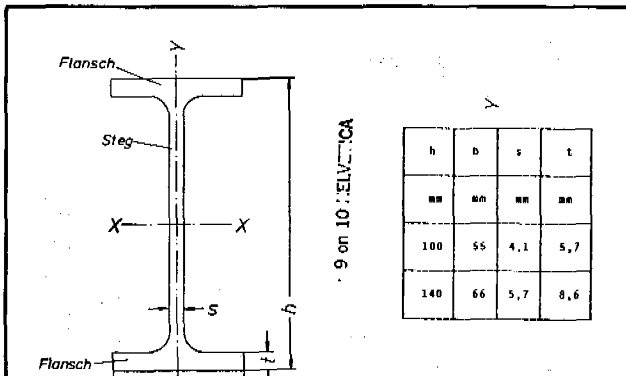
The results of an accident involving guardrail are grave. The injuries sustained by riders who are not killed are severe (Schueler et al, 1984)

The following description by the regional police authority is a typical example:

On June 21, 1985 an accident occurred in the area of Ludwigsburg, near the city of Rosswag. According to the Police the cause of the accident was speeding and lack of driving experience. The motorcyclist was thrown over the guardrail and suffered severe injuries. The 16-year-old female pillion rider slid over the road surface and crashed into a guardrail post. She was killed in this accident by fracture of spine. The deformation of the guardrail post showed the power of the impact.

Solution of the Problem

Because of the great statistical and traumatological significance of motorcycle accidents involving rider impact on guardrail, the Institut fuer Zweiradsicherheit (Institute for Motorcycle-Safety) commissioned a



h	b	s	t
mm	mm	mm	mm
100	55	4,1	5,7
140	66	5,7	8,6

Figure 1. "IPE-100" guardrail post, cross-section

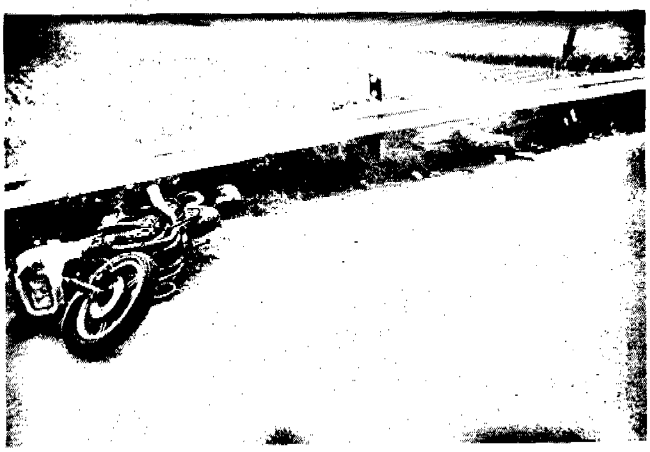


Figure 2. Scene of an accident, deformed guardrail post

research project the task of which was not merely to supply an exact definition of the problem, but also to develop possible solutions.

As a result the following possibilities for improvement were put forward:

- "Sigma-post"
  A "Sigma-post" differs from an "IPE-100 post" at least from a frontal view by being less aggressive owing to its form.

Figure 3. "Sigma-Post" (right) compared with "IPE-100-Post"

- Additional W-beams
  The lower, additional beam may be assembled in a fixed position and directly under the upper beam, or with a gap to the upper beam and springy. By this the lower beam is within given limits—able to compensate energy by replacing a point impact with an area impact.
- Enveloping of posts with special impact attenuators. These impact attenuators, which were specially developed for the protection of

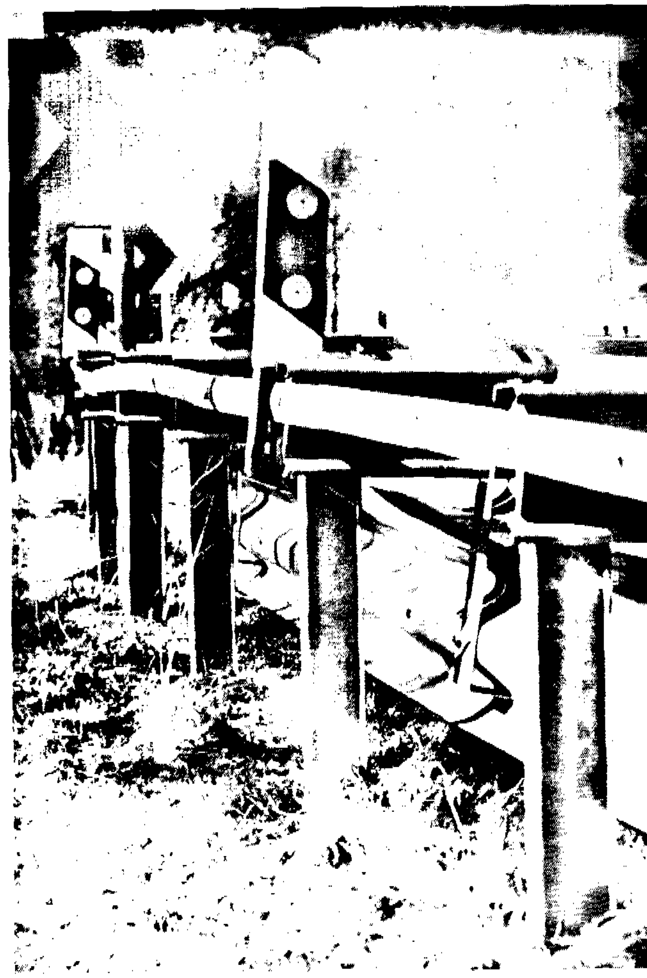
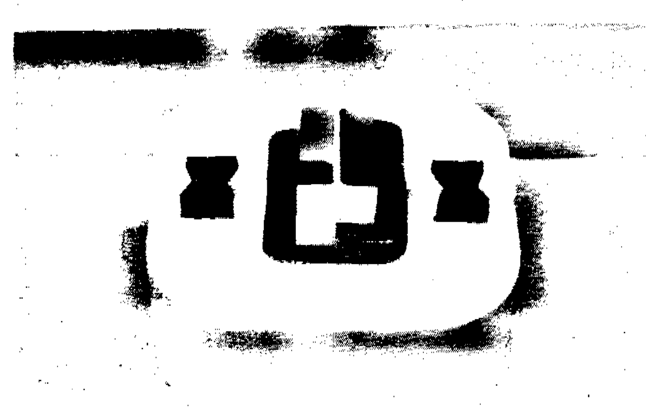


Figure 4. Additional W-beams

motorcyclists, consist of various synthetic materials. They have two tasks concerning the reduction of injury severity: first, to extend the impact surface and second, to absorb energy by distortion.



Picture 5. Cross-section view of impact attenuator fitted to post

Inspection of Effectiveness of Impact Attenuators

In order to ascertain the effectiveness of these impact attenuators guardrail crash tests were carried out in two projects by Schueler (1985) and Jessl (1985).

At the Institut fuer Rechtsmedizin, University of Heidelberg, an impact attenuator consisting of closed cell polyethylene foam with the brand name of "Neopolen" a 1 mm polyurethen outer coating was tested. The basic density of the polyethylene was 30 kg/cbm. Post mortem test objects were used to find out the reduction of injury severity. (Schueler 1985).

Jessl tested a polystyrene impact attenuator with a density of 22 g/1 and a 1 mm outer coating made of polyurethene based paint. He used a Sierra Hybrid II/Part 572 dummy as test object.

In both tests the test objects hit the "IPE-100" guardrail posts, which were fitted with the aforementioned impact attenuators with the inside of an extended arm. Corresponding tests were carried out with uncovered posts.

Jessl also carried out head crash tests.

In each case the impact velocity approximately was v = 32 km/h.

In the corresponding test with the uncovered "IPE-100-post", Schueler established a sub-total traumatic arm amputation (Maximum Abbreviated Injury Scale Value = 3) near the shoulder, whereas the collision with the covered post caused only minor injuries (MAIS = 1).

In the corresponding head crash test Jessl established an impact force of 9410 N and a maximum delay of 1214 m/sec2. The figures for the post with impact attenuator were 18080 N and 2500 m/sec2.

Schueler also carried out crash tests with "Sigma-posts" under the same conditions. These led to a reduced severity with the uncovered "IPE-100-post", but the results of injuries were worse than with the covered "IPE-100-post". According to the findings the injuries were MAIS = 2.

In summary, one can say that the effectiveness of the tested impact attenuators has been proved—both traumatologicaly and according to the recorded measurements. A considerable reduction in the severity of injuries sustained from impact on guardrail can be assumed.

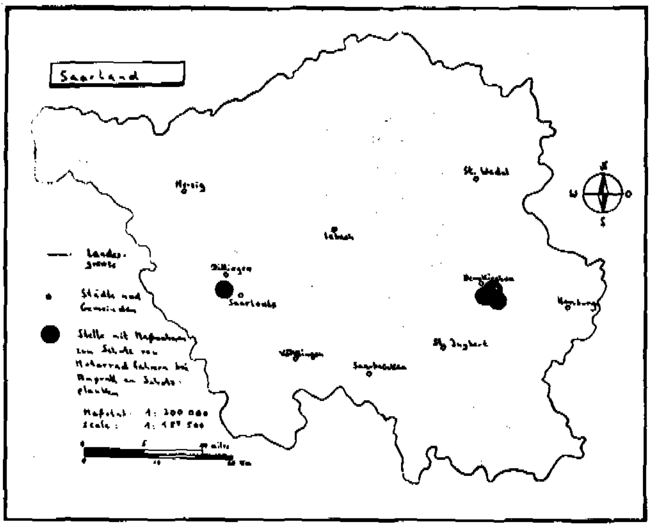
Implementation of Protective Measures

Based on these positive evaluations the authorities passed the impact attenuator and recommended its installation at accident black spots. (Administrative regulations concerning impact protection for motorcyclists issued by the Secretary of the Interior, Baden-Wuerttemberg, reference 7/4562/42, on November 17, 1986) In this respect petitions and other measures to raise public awareness employed by motorcycle associations and the Institut fuer Zweiradsicherheit were very helpful (Domhan, 1987 b).

Picture 6. X-ray

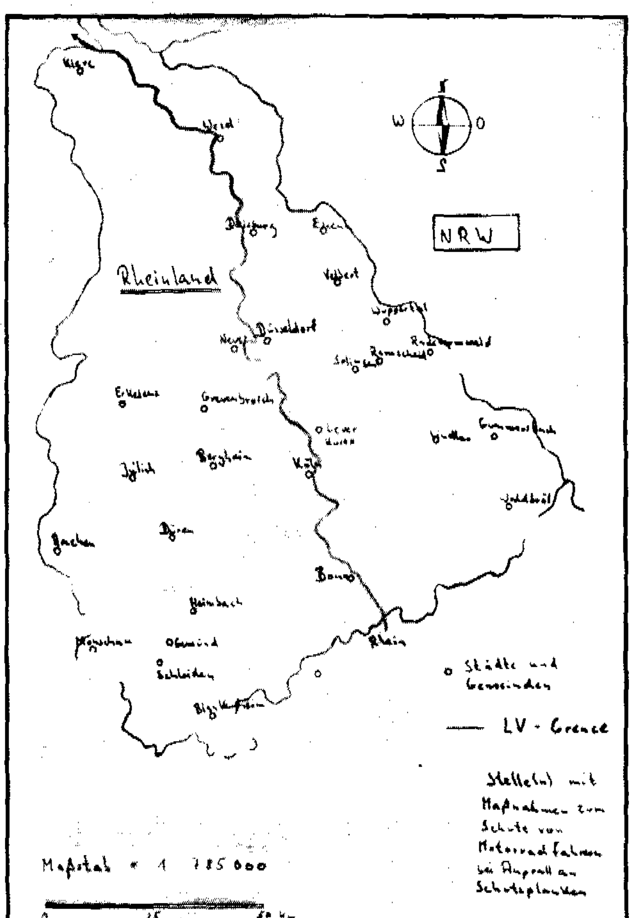
The finding of suitable road sections proved to be difficult. The criteria used by each regional administrative body vary. A widespread survey by the Institut fuer Zweiradsicherheit in 1987 showed that in most cases the initial step is to analyze the available accident statistics. The second step is to decide which accident figure per road section necessitates installing impact attenuators. This figure varies between one and more than two accidents per road section per year.

In some cases the authorities only became aware of problematic sections because motorcyclists themselves came forward and reported them. Not only are there differences in the process of selection, but also in the achieved density of implementation per road section. The differences between the various federal states can be seen in the following maps which were drawn up within the framework of our project. 7 of 11 federal

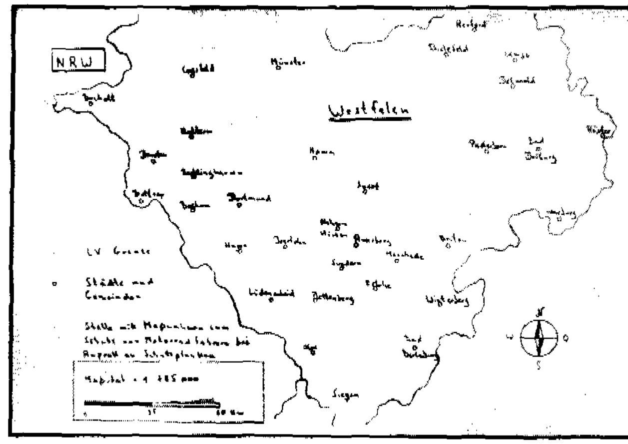


Picture 7. Federal state of the Saarland

states which received our questionaire actually replied. 6 federal states have installed impact attenuators and 2 of these have fitted additional W-beams. At present a total of 20,000 impact attenuators have been installed on West-German roads.



Picture 8. Federal state of North Rhine Westfalia I



Picture 9. Federal state of North Rhine Westfalia II

In some areas, for example in the federal state of Schleswig-Holstein, there was no above-average concentration of motorcycle accidents on guardrail road sections and therefore impact attenuators were not fitted. Pressure from the public did however lead to the decision to use the less aggressive "Sigma-posts" on all new road sections. This policy has also been adopted by all the other federal states which we interviewed!

Initial Examination of Protective Measures in Practice

The present findings of our investigation vary considerably concerning a reduction in the severity of injuries resulting from the implementation of protective measures.

Empirical results from an observation in the field on "Sigma-posts" (which have already been fitted) are not yet available. Therefore one can only assume that they are less dangerous, as established in the biomechanical tests. (Schueler 1985)

However the positive effect and success of the additional W-beam can be verified statistically. According to statements by the police authorities responsible a considerable reduction in both the number of accidents and the accident severity was achieved at 2 well-known accident black spots examined by us near the Nuerburgring. Whereas the reduction in accident severity is something which was expected from the modification, the drop in the number of accidents is a remarkable additional effect. The strong optical impression which a W-beam guardrail has on the motorcyclists obviously has the effect of a warning signal which influences their behaviour on the road positively.

A valid and reliable evaluation of the effectiveness of impact attenuators fitted at accident black spots since 1984/85 cannot yet be achieved due to this short period and the consequently small number of cases.

However, there are very strong indications in favour of these measures according to statements by the responsible police authorities.

Reports often show that the number of registered major accidents has in some cases dropped to zero. In several cases minor damage to the impact attenuators clearly resulting from crashes was registered although no accident had been reported. The police conclude from this that there must have been a collision without serious injuries which without the impact attenuator, would have led to major injuries and consequently to the accident being reported.

However, meaningful, empirically sound results cannot be expected within the next two to three years.

The fact that most departments expressed themselves positively and intend to increase the fitting of protective measures can also be seen as an encouraging sign.

Cost-Benefit Analysis of Guardrail Safety Measures

In order to specify the perspective for further installation of additional W-beams and/or impact attenuators the Federal Highway Research Institute has already carried out cost-benefit studies. (Domhan, 1984, p. 10-15) These studies revealed that modification by all guardrail sections is not sensible. The following table by Domhan shows the estimated cost-benefit factors for this proposition:

	Additional W-beam	Impact Attenuator
Motorways	0.2	0.3
Interstate Highways	0.5	0.7
State Highways	0.3	0.3
Country Roads	0.2	0.2

Alternatively he works on the assumption that 20%, 30% or 40% of all accidents involving the collision of riders with posts/guardrails occur on only 10% of the total guardrail sections. He arrives at the following cost-benefit relations:

	Additional W-beam			Impact Attenuator		
	20%	30%	40%	20%	30%	40%
Motorways	0.4	0.6	0.8	0.6	1.0	1.4
Interstate Highways	1.0	1.5	2.1	1.3	2.0	2.7
State Highways	0.6	0.9	1.2	0.7	1.0	1.3
Country Roads	0.4	0.6	0.8	0.4	0.6	0.8

From a cost-benefit point of view it follows that impact attenuators should have priority over additional W-beams. The valid conclusions reached by the Federal Research Institute for the Federal Republic of Germany are as follows:

- "Fitting all guardrails with protective devices is an uneconomical proposition;
- "On motorways, such additional protective devices can be justified only at accident black spots, representing considerably less than 10% of all guardrail sections. Median barriers can generally be neglected here;
- "On interstate highways, the use of additional protective devices may be justified in the case of a selected number of guardrail sections. This also applies to state highways, but for a still smaller number of guardrail sections.
- "On country roads and unclassified roads, additional protective devices are only justified at accident black spots."

Summary

Motorcycle accidents resulting in a collision of the rider or pillion rider with guardrail posts pose a serious safety problem. This is shown by the high number of major injuries and the fact that 15% of all motorcycle deaths in West Germany are in this category. There are 3 possibilities to solve or minimize the problem, namely the use of "Sigma-posts" instead of the conventional "IPE-100-posts" the installation of additional W-beams and finally, the envelopment of posts with impact attenuators.

Even though a final, empirically sound evaluation has not yet been possible owing to the limited period of practical experience, the effectiveness of additional W-beams has been established and the efficiency of impact attenuators is a justifiable assumption.

Moreover, under certain, realistic conditions the implementation of protective measures is definitely to be considered positive regarding the cost-benefit aspect. This means that the benefit gained is greater than the costs.

A direct transfer of the solutions developed by us to other countries is certainly not possible. But, on the other hand it does seem a reasonable proposition for people working in accident research to examine whether motorcycle accidents involving guardrails occur in statistically relevant numbers to justify and necessitate measures to increase motorcyclists' safety. Furthermore, accident researchers would face the task of monitoring these measures in the field and examining them critically regarding their effectiveness.

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ESM—A Motorcycle Demonstrating Progress for Safety

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Introduction

At the seventh International Technical Conference on Experimental Safety Vehicles in Paris, June 1979 the United Kingdom exhibited their first Experimental Safety Motorcycle ESM 1(1). This vehicle was based on a Triumph 750cc motorcycle and incorporated six features, which were in the prototype development stage, to provide solutions to the problems of motorcycle safety, derived from a number of studies since 1974.

For the occasion of the tenth International Conference on Experimental Safety Vehicles in Oxford, July 1985 the United Kingdom exhibited the second Experimental Safety Motorcycle ESM 2(2). This vehicle was based on a BMW 800cc twin cylinder motorcycle to Police specification. ESM 2 had seven safety features and showed the progress made to those originally fitted to ESM 1.

On the occasion of the eleventh International Safety Conference on Experimental Safety Vehicles, the United Kingdom now exhibits their third Experimental Safety Motorcycle ESM 3. (Figure 1.) This vehicle is based on the Norton Interpol II rotary engine motorcycle nominally of 600cc. ESM 3 has seven safety features and shows the progress of development from the prototype to the production stage for most of the features which can be incorporated on machines for daily use. ESM 3 is considered to be the last Experimental Safety Motorcycle in the present series which have been based on large machines.

Brakes

Earlier work at the Transport and Road Research Laboratory (TRRL) had provided a solution to the problem of inconsistent braking (3) in wet weather and in response to regulations requiring new motorcycles to be tested with the brake system both wet and dry the problem has largely been overcome. This is not the case with replacement pad linings where no such requirements exist and users may have inconsistent brake performance if they fit replacements of a lower standard. During the normal expected life of a motorcycle several sets of replacement pad linings will be fitted, which means that the braking performance could be significantly affected during a large part of the life of a vehicle. This situation can only be remedied by the legislative authorities introducing replacement lining controls.

Anti-lock brakes are another essential feature to improve the safety of motorcycles. The TRRL has been carrying out research work leading to the application of anti-lock brakes to motorcycles for over twenty years. This was summarized at the Tenth Conference on Experimental Safety Vehicles in 1985(4). The anti-lock system fitted to ESM 1 was based on a car system using electronic control which had been modified and adapted for motorcycle use by TRRL. ESM 2 was fitted with a mechanical system by Lucas Girling which was fully developed and tested. ESM 3 also has this system fitted. The three experimental safety motorcycles from the United Kingdom have all provided the rider with continuous information that the anti-lock system is functioning by driving the vehicle speedometer from the anti-lock sensing system. Failure of the speedometer indicates failure of an anti-lock unit and this can be backed up by either audible or visual warnings to the rider. The system used on ESM 3 results in zero reading of the electronic speedometer if either rear or front anti-lock systems fail. We feel that continuous monitoring of the anti-lock device either by this simple system or by some other method is an important feature of a total anti-lock device which will provide riders with increased confidence in these advanced braking systems.

Although those organizations who have been involved with the development of motorcycle anti-lock systems would have carried out their own in-house testing and evaluation, nowhere other than in the United Kingdom have these brakes undergone a field trial using members of the public. Our intention to carry out this trial was announced at Oxford in 1985 when the first motorcycle to go into Police service was included in the United Kingdom exhibition. The field trial consists of a number of motorcycles fitted with the Lucas Girling system in Police service together with a machine in use with a Courier company which is carrying out a high mileage in routine service. This is backed up by further machines for research and instructional purposes together with a single machine to cover short term loans outside the Police and Courier use.

The trial is now half way through the evaluation period and results are very encouraging. There have been some problems which were mostly due either to ancillary components or to the motorcycle itself, particularly in relation to suspension characteristics. The results to date show that the concept of introducing reliable anti-lock on motorcycles has been fully justified. The full report of the field trial appears in the proceedings of this conference (5).

Conspicuity

It is now accepted that a major factor in accidents involving motorcycles during daylight is the failure of road users to see motorcycles in time to avoid a collision. Research aimed at reducing the problem has resulted in suggestions being made to riders on how to improve their conspicuity by both rider-based and machine based features(6). As for the previous Safety motorcycles, ESM 3 is fitted with two daytime running lights as an effective machine based option to improve daytime conspicuity. These daytime running lights also have the advantage that their combined wattage is lower than that of the single headlamp. It has also been shown that this lamp itself is an effective conspicuity aid.

The evidence from accident studies suggests that, as in daylight, a significant proportion of motorcycle accidents in nighttime are associated with some kind of perceptual error on the part of the drivers of the other vehicles. But, unlike the daytime problem where it appears that drivers overlook the motorcycle, the difficulty of seeing motorcycles at night is complicated by errors of identification and interpretation of speed of approach as well as of simple detection.

The results of work by TRRL into overcoming the night time problem are given in "Safety Considerations of Motorcycle Lighting at Night" by Donne and Fulton(8) in the proceedings of this conference. In the United Kingdom all new vehicles, other than motorcycles, have been required to be fitted with dim/dip lighting if manufactured after 1 October 1986 and first registered after 1 April 1987. This may eventually have a benefit for improving motorcycle conspicuity at night. The findings in the TRRL paper should be regarded as a stimulus to the design of forms of lighting which can meet the nighttime requirements of motorcycles and be compatible with the needs of daytime conspicuity.

Leg Protection

Research on protection systems for the legs of riders has been carried out for five years at TRRL. The problems which were regarded as almost insoluble in terms of test techniques and remedial solutions are now approached optimistically as a full understanding of the various engineering features of protection devices has been reached. The work has progressed through a programme of accident and injury investigation, to experimental testing and analytical simulation studies. During the period of this research the TRRL has been keen to keep various organisations in touch with progress and for those interested in this aspect of motorcycle safety a summary of all the relevant documents are available at this conference(9).

The work has covered light, medium and heavy machines impacted into rigid barriers, stationary cars and more recently into moving cars. In all some 55 tests have been carried out and in all cases the resulting dummy injuries in terms of damage to dummy legs and high head velocities have been much reduced with motorcycles fitted with leg protection devices. The trajectory of both the rider and motorcycle are important and it has been found that leg damage increases as the angular velocity in pitch of the motorcycle goes up. The design of the leg protector is all important as this can increase or decrease angular velocity of the motorcycle to the disadvantage or advantage of leg injuries and head velocities.

The current position of the TRRL work on leg protection can be seen on ESM 3 in the form of a safety fairing constructed to TRRL criteria by Norton Motors. This is appropriate for large machines. The research has provided similar criteria for lightweight and medium weight motorcycles. A state-of-the-art has confidently been reached by which designers can use these criteria to produce fairings which should reduce many injuries to riders involved in accidents.

"Protecting Motorcyclists Legs" by Chinn and Hopes(10) reports on work since ESM 2 at Oxford and is available in the proceedings of this conference.

Safety Fairing

ESM 2 was fitted with a safety fairing which had been made from an extensively modified fairing that was available as a factory option. ESM 3 is also fitted with a safety fairing incorporating leg protection, which has been built by Norton Motors to specifications supplied by TRRL and will form the basis of fairings fitted to their machines in the future.

The sectioned fairing on display in the supporting exhibition shows both the energy absorbing cones inside the outer skin panels (removed) and the tubular structure carried forward to the headlamp aperture to provide the second load path which reduces the vehicle pitch on frontal impact. The inner skin panels also provide the crush zone immediately in front of the riders knees and legs.

Other Features

Speedometer

ESM 1 and ESM 2 were both fitted with digital speedometers as this type of instrument can be read quickly by riders. ESM 3 is provided with a conventional dial instrument as this machine represents a move towards a production model. The instrument is however electronic which also provides the continuous monitor to the rider that both anti-lock brake systems are functioning.

Fuel System

Reports on accidents show that 30 per cent of motorcycle accidents involve spillage of fuel from the machines. In one third of these accidents the spillage is reported to be excessive. ESM 2 was fitted with a modified fuel tank which prevents fuel being leaked down the fuel supply lines if the machine falls over on either side. ESM 3 is also fitted with a similar system but the installation has been considerably simplified by using the existing petrol taps and containing their feed pipes on the inside of the petrol tank. This feature is clearly seen on the sectioned components displayed in the supporting exhibition and the principle of operation of this non-spill fuel tank is shown in Figure 2. Designs for both gravity fed and pumped feed fuel systems are available.

Interlocked Stands

Like ESM 2, ESM 3 has ignition interlocks fitted to both stands. The system is now considerably simplified and also provides an override so that the engine can be run for servicing while the vehicle is on the centre stand.

Frontal Impacts

Following the experimental restraint system on ESM 1(1) using a chest pad, attention was given to the sensing and initiation system which could be used on a motorcycle to restrain the rider with an air-bag. Because of the ease of packaging, the air-bag would not have the problems of acceptability associated with the experimental chest pad restraint and the first successful inflatable bag system was shown with ESM 2(7).

Work has continued on this restraint system with both experimental testing and computer simulation. Although the simulation program is not yet fully developed, it indicates that a rider is retained on the motorcycle, following a frontal impact, for about

Table 1. Preliminary estimates of costs and savings for safety features.

	Number of accidents	Estimated cost of accidents £m/yr	Estimated number of casualties saved or with reduced injury severity	Estimated cost of injuries saved £m/yr	Estimated equipment cost £/motorcycle	Estimated cost to fit 250,000 new machines/yr £m/yr	Remarks
Daytime conspicuity	18.000	72 (2)	6.000	26	10	2.5	Original equipment or retro-fit
Anti-lock brakes	12.000	52 (2)	6.000	26	Large M/C 200 Small M/C 25	32.5	Treatment 150.000 Large 100.000 Small
Leg protection	38.000 (1)	90 (1)	(5282 serious converted to slight) (7778 slight)	37	75–300	19–75	Safety fairing cost Large machine £300 Medium machine £75(3)
Forward impact	42.000	183 (2)	8.500	37	15	3.75	Safety fairing would also have to be fitted

(1) 65% serious casualties 60% slight casualties
(2) Using average casualty cost

(3) quotation from commercial supplier producing from limited tooling.

Using 1983 Casualty Data (1)

Riders and Passengers of Two Wheeled Motor Vehicles			Cost £'s of Casualties		
	Fatal	963		Fatal	150.045
	Serious	20.317		Serious	6.950
	Slight	43.214		Slight	170
	All severities	64.494		Average all severities	4.370

50ms longer when spoked wheels are used than when cast wheels are fitted. In addition, the use of spoked wheels causes the motorcycle to pitch less. Both these factors are favorable to the effectiveness of an air-bag as a rider-restraint. An air-bag of 120 litre capacity (deployed with one inflator) has been assessed in impacts. It reduced the horizontal component of the rider's velocity to zero at the plane of impact. However, in these tests the motorcycle pitch was restricted to that expected if spoked wheels where used. Therefore, in practice, motorcycles would need to be designed with frontal energy-absorbing characteristics similar to those obtained with wheels of this type.

Although the horizontal component of velocity of the rider was reduced to zero by the presence of the 120 litre air-bag, some rotational energy was retained. This was also the case with the 60 litre air-bag used on ESM 2.

ESM 3 is fitted with a 120 litre air-bag similar to that used in the impact tests. Both the inflator and the bag are located at the rear of the fuel tank. This arrangement has been found to be effective without the need for additional attachments of the bag. With development of the computer program, optional restraint-system characteristics should be predictable. Work will continue with these restraint systems tested on both faired and unfaired motorcycles.

Simulation

Experimental impact testing to assess the effects of changes in features is a necessary part of this type of

Figure 1. E.S

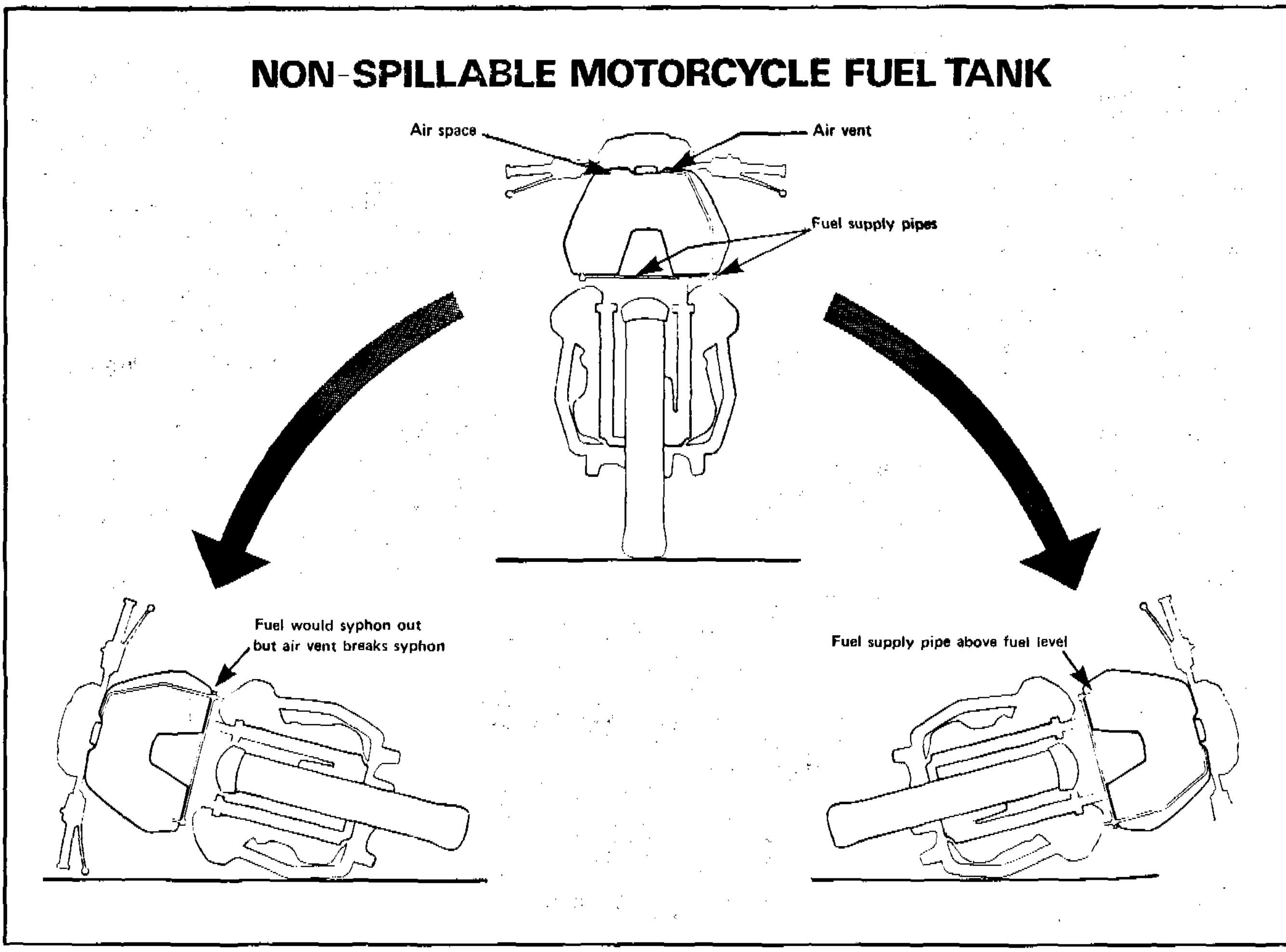

Figure 2

work and is an aid to the preparation of legislative requirements. For research purposes this in itself is too narrow and at best only results in a pass or fail situation for the set of conditions of each test. The work at TRRL now includes mathematical simulation which, when verified by practical tests, produces a design aid. This provides information that would not be available from experimental work alone. ESM 3 is the first of the three safety motorcycles which has benefited from information derived from the simulation technique.

The simulation studies have developed in two ways. For frontal impacts the two-dimensional model looks at the side elevation of the motorcycle and rider. Details and progress on this work are given in the paper "Motorcycle Impact Simulation and Practical Verification"(11) which appears in the proceedings of this conference. A two-dimensional model also exists for studies in plan view(12)(13).

Assessment

Accident and casualty data in Great Britain have shown that motorcycles are ten times more likely to be involved in a casualty accident per mile travelled than are cars (not allowing for rider and driver age differences). This will probably continue unless improvements are made to the roads and vehicles and to the skills of riders. Although the trend of reducing motorcycle mileage continues and this has produced fewer casualties, fluctuations in motorcycle mileage have been seen before and when the motorcycle mileage increases again the increase will contain a larger proportion of inexperienced riders. This will tend to increase the accident rate thus producing a disproportionate rise in casualties. Some preliminary estimates of costs and savings for safety features were made for the Oxford conferences on four of the safety features of the ESM 2 motorcycle. These are still relevant to ESM 3 and are reproduced in Table 1.

It is worth reflecting on the progress of the three safety motorcycles and the benefits which have arisen from exhibiting them at the International Technical Conferences for Experimental Safety Vehicles. The response and interest which has been shown in all three of these safety motorcycles both at the conferences and afterwards indicate that the ESV conferences are the proper forum to exhibit the vehicles and discuss their safety aspects. The progress being made towards incorporating new safety features in production machines reinforces this view.

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Investigation Into Motorcycle, Driver and Passenger Safety in Motorcycle Accidents With Two Motorcycle Riders

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Abstract

Investigations into motorcycle accidents with motorcycle carrying not only driver but also pillion passenger have so far been unknown. However, qualitative observations of accidents indicate that, owing to the mutual influencing of the motorcycle riders, this accident type follows a different sequence from one in which the motorcycle is carrying only a driver.

In experimental accident simulations, motorcycles, carrying two riders, impacted laterally at 90 degrees and diagonally (45 degrees) against stationary passenger cars in the speed range between 50 and 60 km/h.

There is a description of the essential differences in the motion and impact characteristics as well as in head and body postures between driver-only and driver-plus-passenger accidents. Derived from this are safety-related considerations regarding design measures on the motorcycle in order to optimize the motion paths of the riders.

Bases for the reconstruction of this accident type are elaborated.

With regard to the safety of a passenger car and its occupants in the event of motorcycle impacts, the structure of the side assembly and the testing of its strength are discussed.

Introduction

Investigations into collisions between motorcycles and passenger cars with the motorcycle carrying not only a driver but also a pillion passenger have so far been unknown. Qualitative observations of real accidents indicate that, in this accident type, the motion of the pillion passenger differs from that of the driver and that the pillion passenger may cause changes in the collision sequence.

The following results from an initial rough evaluation of 130 accidents with pillion passengers/1/:

Pillion passengers have the same helmet-wearing rate as drivers, suffer less severe injuries and show a lower fatality rate.

As regards the kinematics of pillion passengers, it is found that they reach their final positions in free flight more frequently than the drivers and more frequently undergo the collision without changing direction.

As regards injuries, it may be said that in 35% of cases the driver was injured more severely than the pillion passenger and that in 31% of cases the injuries to driver and pillion passenger were of equal severity. In 30% of cases the pillion passenger was injured more severly than the driver.

As a continuation of joint series of tests of DEKRA Accident Research and the Vehicle Safety Department of Adam Opel AG, collisions were simulated for the first time in which motorcycles carrying two dummies impacted against the sides of stationary passenger cars, with head- and body-injury data being measured. Following on from earlier tests/2,3/and in order to evaluate the test results with pillion passenger, tests were also conducted in which the motorcycles had only a driver.

The determination of the impact events, the motion sequences of dummies and motorcycles as well as their decelerations in the course of the collisions contribute towards indicating motion paths and collision protection of the riders for a given standard of design and towards discussing possible improvements.

With regard to car-occupant protection in the event of the impact of motorcycles and riders, there is a discussion of the structure and strength of the door-side assembly on passenger cars.

Finally, new findings can be gained regarding the reconstruction of this type of accident.

Test Setup and Procedure

The tests took place in the Safety Center of Adam Opel AG, Rüsselsheim. In a total of eight tests, Figure 1, motorcycles impacted in the collision-speed range between 50 and 60 km/h against stationary passenger cars of the latest Opel Kadett range in the saloon version with four doors and in the hatchback version with three or five doors. Six tests, of which five were with driver and pillion passenger on the respective motorcycle, served to simulate ninety-degree motorcycle impacts against the driver-side or front-passenger-side door of the passenger car. The equivalent accident type with a 45-degree motorcycle impact was performed once with and once without pillion passenger.

An already repeatedly described acceleration sled/2,3/was used to accelerate and guide the motorcycles together with the riders represented by 50% hybrid II pedestrian dummies. The sled was braked just before the point of collision, whereafter, owing to the mass inertia, stabilized by the gyrostatic moments of the motorcycles, the motorcycle with the riders moves on at almost constant speed up to collision with the passenger car which has been positioned in accordance with the desired collision configuration.

Three high-speed cameras (frame rate 800 frames per second) were used to document the collision events. Two of these cameras with fixed recording directions, horizontal and at ninety degrees to the motion of the motorcycle before the collision and vertical onto the collision, provided film sequences suitable for in-depth motion analyses. The third camera was swung horizontally during the test procedure in order to provide additional observation of the collision events.

A digital clock (1 ms resolution) positioned in the recording areas of the horizontally directed cameras was started by an electric contact sensor on the passenger car precisely at the commencement of impact of the front wheel of the motorcycle and made it possible to allocate precise times to the individual film frames, Figure 2.

To measure the decelerations of the riders, in the case of motorcycles with two riders, the dummy representing the pillion passenger, and in the case of motorcycles with one rider, the dummy representing the driver was equipped with triaxial acceleration sensors in head, chest and pelvis. The associated measured signals were fed via cables into an evaluation computer, the output unit of which provided analog recordings of the respective deceleration components as well as the resulting decelerations up to 300 ms after the commencement of motorcycle impact and associated biomechanical data for head injury (HIC) and chest injury (SI).

After each test, the passenger-car and motorcycle damage was documented photographically and the vehicle final positions, motorcycle-wheelbase reductions and indentation depths on the passenger car were measured.

The dummies wore protective leather clothing and a new helmet for each test.

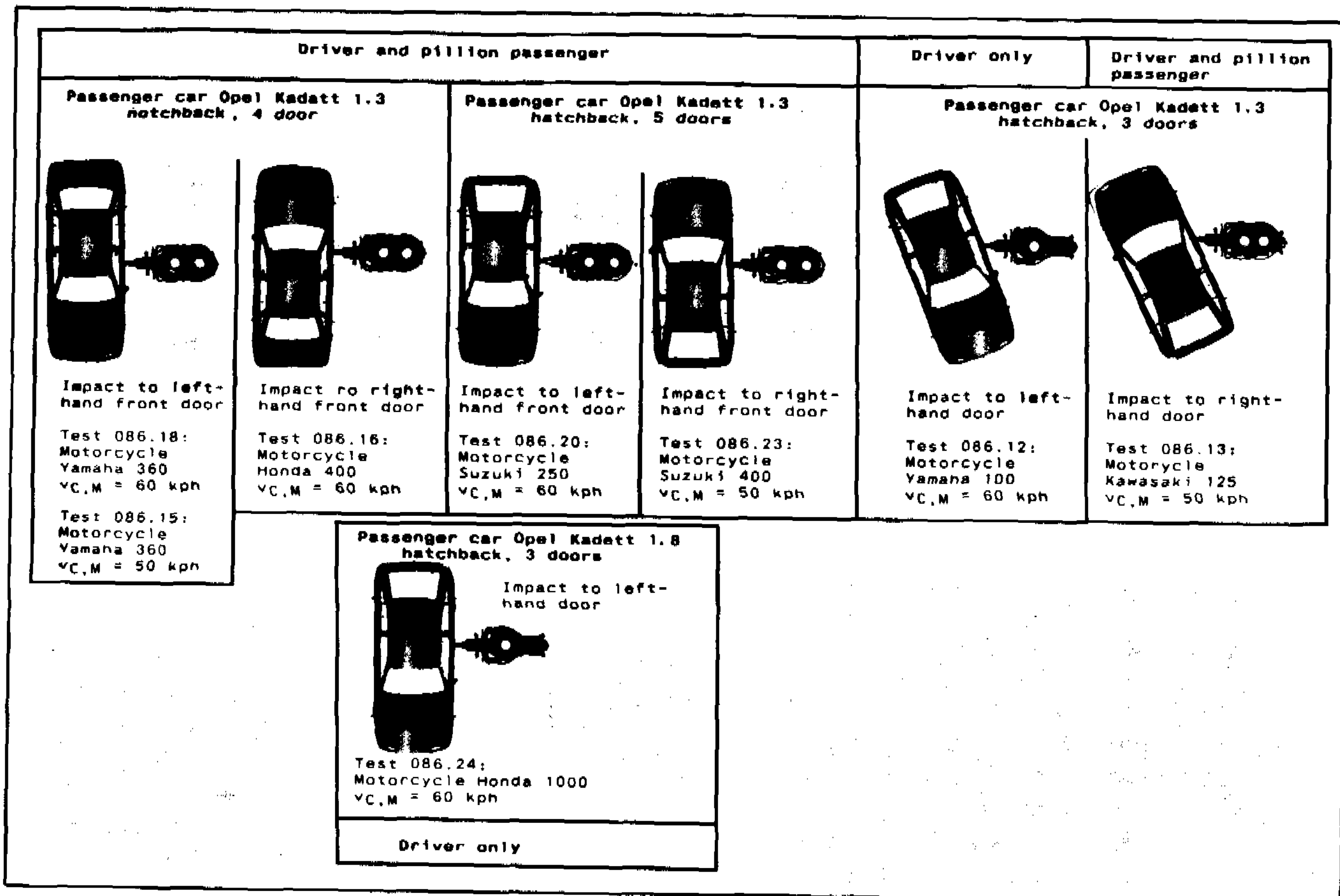

Figure 1. Summary of tests

Test Results

Events and Time Sequences of Motorcycle/ Rider Motions after Start of Collision

Typical events of motorcycle/rider motion after initial contact of the front wheel of the motorcycle with the passenger car and the time sequence of these events are shown in Figure 3. Shown also for comparison are the results from six earlier tests in which motorcycles with driver only impacted against the left-hand or right-hand doors of stationary passenger cars of the Opel Monza model/2,3/. For a total of 12 tests in which the motorcycles impacted at ninety degrees at collision speeds between 50 and 70 km/h against the doors of stationary passenger cars we can thus in all cases see very similar time sequences of the individual events with regard to the motions of motorcycle/rider as of the start of the collision:

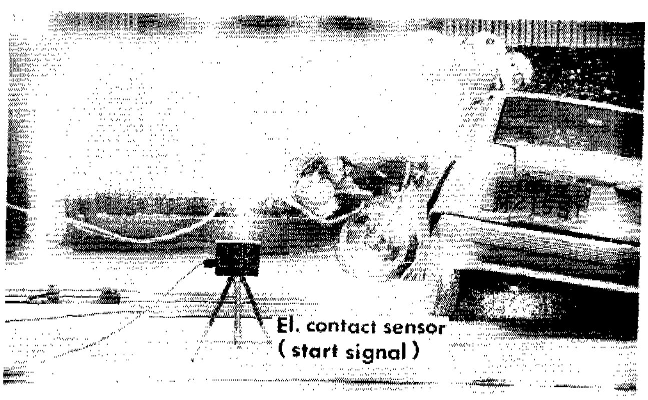

Figure 2. Digital clock for allocation of precise times to individual film frames

Start of front-wheel fork deformation, contact of front wheel with motorcycle engine block, contact of steering head/lamp of motorcycle with passenger car, upward motion of motorcycle rear wheel.

The major forward motion of the motorcycles during penetration into the passenger car is completed approximately 60 to 120 ms after the start of collision.

There are no clearly recognizable differences in the order or in the time sequence of these motion characteristics between motorcycles with and without a pillion passenger. Conversely, in the two 45-degree collisions, it was possible to establish a reversal of the order of events between contact of the motorcycle front wheel with the engine block and contact of the steering head/lamp with the passenger car. This is due to the fact that in these collisions—similar to 90-degree motorcycle collisions against the sides of mov-

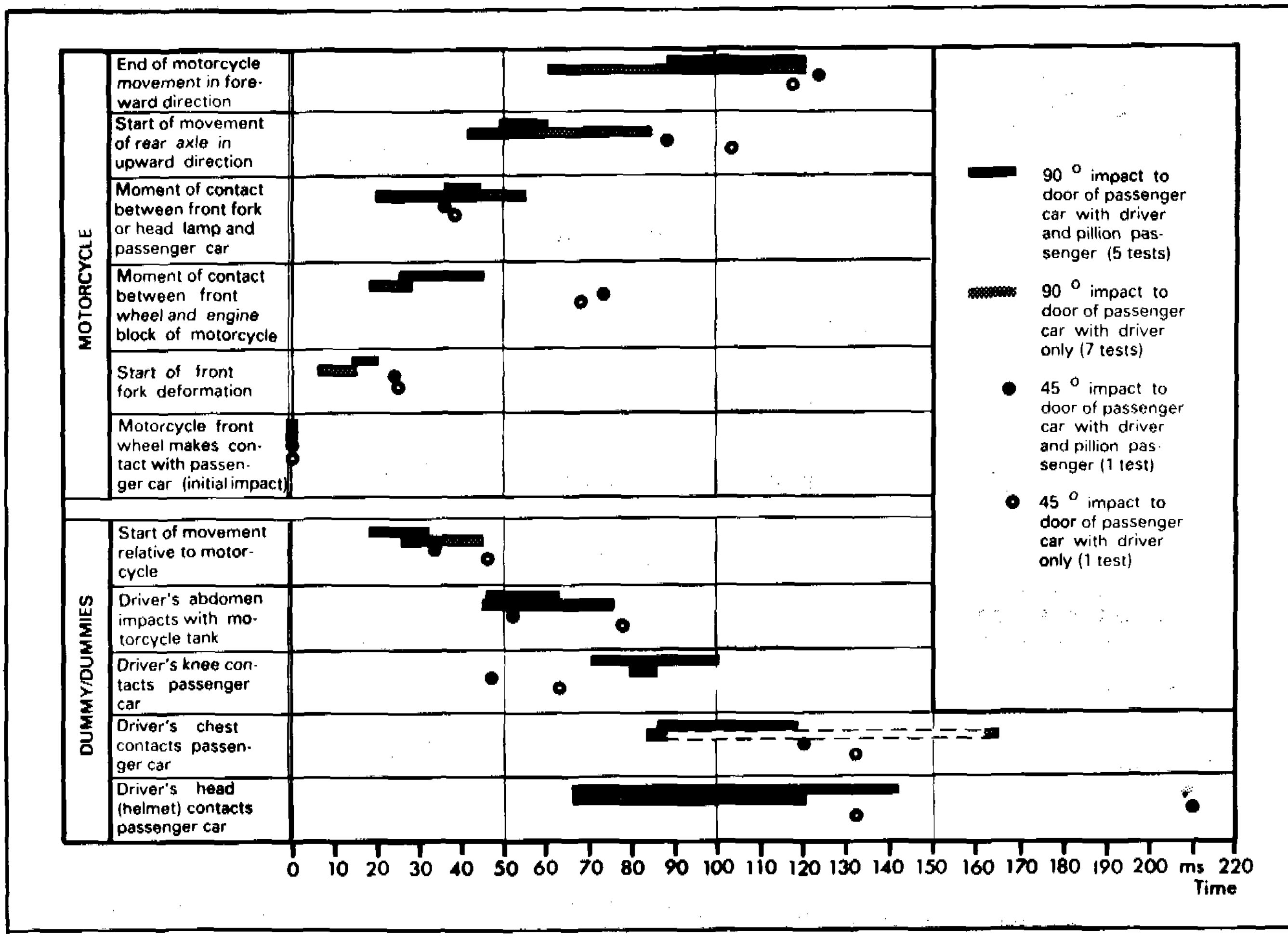

Figure 3. Events and time sequences of motorcycle and dummy motions for motorcycle impact at speeds between 50 and 70 km/h against stationary passenger cars (90-degree impact against passenger car without pillion passenger on motorcycle supplemented by the results from six tests from an earlier series of tests/2,3/)

ing passenger cars/4/—the front wheel is deflected after contact with the passenger car, so that the motorcycle engine block does not come into contact until later with the motorcycle front wheel.

The typical motion of the rider/riders is characterized initially by the start of a relative motion between riders and the already decelerated motorcycle with subsequent impact of the torso of the driver against the motorcycle tank. In the tests with pillion passenger and upright seating position of the driver, these two events were followed always by a knee impact and later by a chest impact of the driver against the passenger car. In one test with a pillion passenger and a forward-inclined seating position of the driver, it was possible to establish first of all the chest impact, then the knee impact of the driver against the passenger car.

In the tests in which the motorcycle had only a driver, there was not always a knee or chest impact, since, depending on the seating position of the driver and the shape of the motorcycle handlebar, the forward motion of the dummy was already so far diminished either on head impact or on impact of the thighs upon the motorcycle handlebar that knees or upper body did not come into contact with the passenger car in the direct sequence of collision events. With regard to knee impact in the two tests with 45-degree collision, it is striking that, owing to the shorter distance between the knee facing the side of the vehicle and the body of the passenger car, the impact of the driver's knee took place earlier, approximately simultaneously with the impact of the torso on the motorcycle tank.

In the tests shown, the helmeted head of the driver dummy impacted at the earliest approximately 65 ms after the start of motorcycle impact against the passenger car. Also in the tests with pillion passenger, the seating position of the driver was decisive with regard to the order in which chest and head impacted.

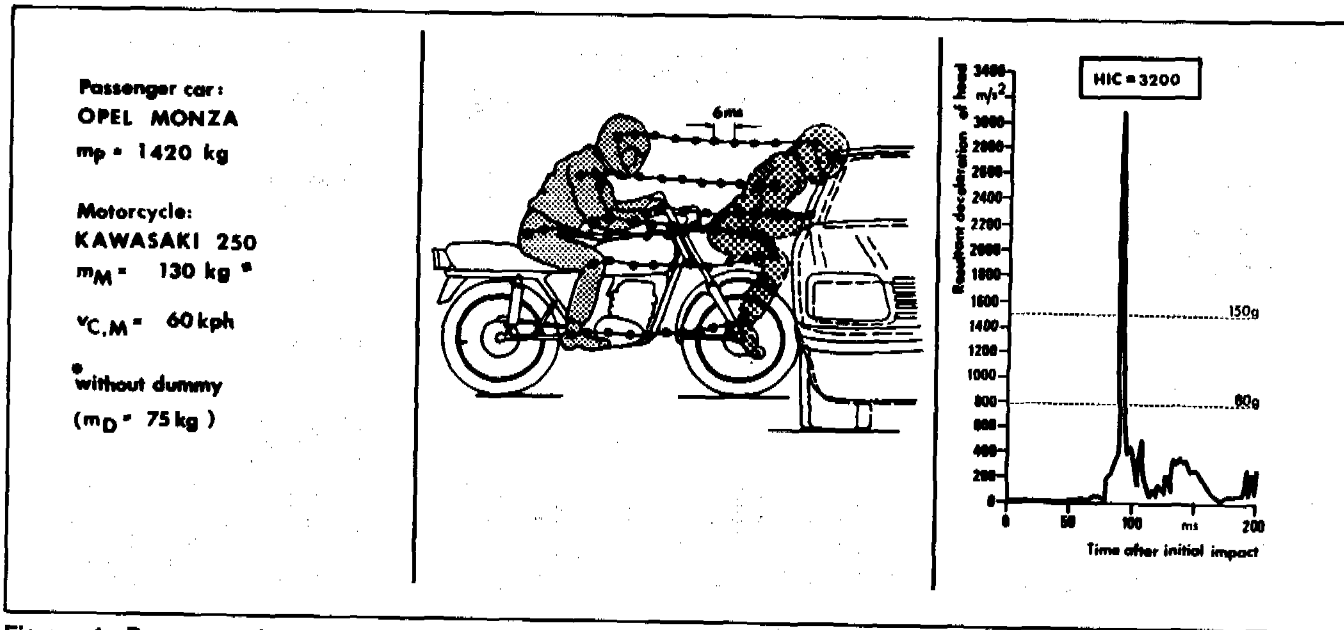

Figure 4. Dummy trajectories and resulting deceleration in the head of the dummy for 90-degree motorcycle impact against the door of a stationary passenger car (test from/1,2/)

Trajectories and Measured Decelerations of Rider Motions

Ninety-Degree Motorcycle Impacts in Passenger-Car Door Area, Motorcycle without Pillion Passenger. In the earlier tests with motorcycle without pillion passenger and with ninety-degree motorcycle impact in the door area of stationary passenger cars, hypercritical injuries to the helmeted head of the dummy were established during impact against stiff parts of the roof edges of the passenger cars/2,3/. Deceleration peaks between 2340 and 3400 m/s^2 and HICs in the range between 1837 and 3209 in the case of direct helmet impact against the roof edge of the passenger car, Opel Monza model, suggest that the main attention should be focussed on the further development of the potential of protective helmets. Figure 4 shows an example.

A test conducted for purposes of comparison in the current series of tests and involving a motorcycle with driver only, traveling at the same collision speed and with virtually identical head impact as in Figure 4, resulted in a considerably reduced head injury with an HIC = 561, Figure 5.

Subject to the exact reproducibility of head impacts in real accident simulations, this low HIC value is certainly also attributable to the less aggressive shape and greater flexibility of the roof edge of the latest version of the Opel Kadett in comparison with the Opel Monza. This points to the benefit of measures on the vehicle to protect two-wheeler riders in the event of a collision.

As already in the earlier tests, the decelerations shown for the chest and pelvis in Figure 5 are at a considerably lower level than that for the head and are to be classified as subcritical. Directional changes in trajectories and concentrations in the target positions shown at 6-ms intervals point to the fact that there are forces acting between the dummy and

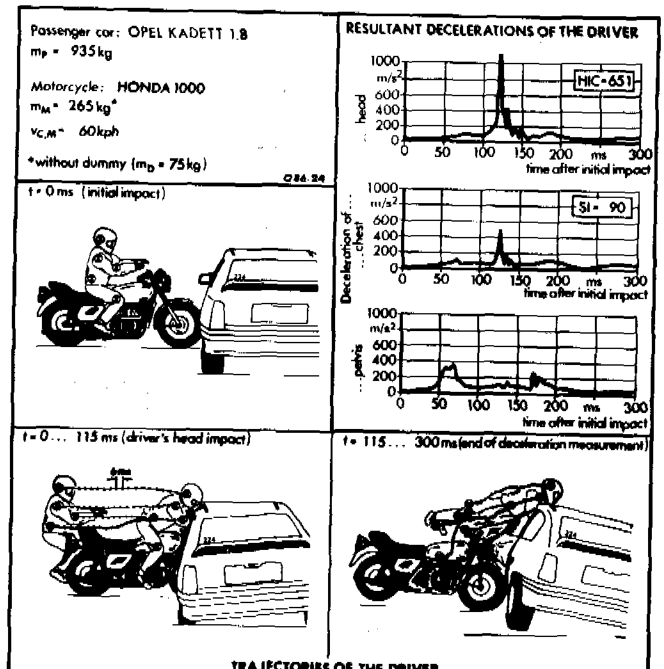

Figure 5. Dummy trajectories and measured decelerations in head, chest and pelvis of the dummy for 90-degree motorcycle impact against the door of a stationary passenger car (test from current series)

motorcycle that decelerate the dummy and/or change its direction of motion. The head of the driver impacts at virtually undiminished velocity.

Typical of the shape of the tank of the Honda 1000 is a raising of the center of gravity of the body with decelerations upon impact on the tank or with the driver's torso sliding over the tank, with the inclination of the upper body being shifted forwards and the trajectory of the head being given a downwards tendency. In a real accident, the supporting of the driver on the handlebar—insofar as this is possible by human muscle power—in conjunction with leg pads fitted directly in front of the driver's knees might compensate for the intensified downwards inclination of the upper body, and the upwards shifting of the center of gravity might also bring about an upwards tendency in the head trajectory, so that the head does not impact directly on the roof edge, but on the softer part of the roof behind the edge.

After the impact of the head, the chest of the dummy impacted on the passenger car in the test shown. In the further course of the collision, there was no knee impact on the passenger car, but a rotation of the upper body accompanied by further upwards motion with stretching of the legs. The velocity of the dummy, the hands of which had smashed through the side window of the passenger car with the result that upper arms and chest were entangled, was thus completely lost. The dummy reached its final position on the ground near the door of the passenger car that had been impacted.

Ninety-Degree Motorcycle Impacts in Passenger-Car Door Area, Motorcycle with Pillion Passenger. In four tests with ninety-degree motorcycle impact against the driver-side or front-passenger-side door of the Opel Kadett and with upright seating position of the driver, the driver's knees, the driver's chest and the helmeted head of the driver impacted one after the other on the passenger car, Figure 6. In a similar test with forward-inclined seating position of the driver, first of all the driver's head, then the driver's chest and finally the driver's knees impacted on the passenger car, Figure 7.

Common to all motion sequences shown in Figure 6 is that the trajectory of the driver's head before impact on the passenger car is not deflected downwards, but remains at least horizontal or is even given a predominantly upwards tendency after the impact of the driver's torso and after the driver has slid over the motorcycle tank. Consequently, the head does not impact directly on the roof edge, but behind it on the softer part of the roof of the passenger car in the region of the chin.

As will be shown, this positive tendency is attributable to the influence of the pillion passenger.

The measured decelerations in the pelvis of the pillion passenger show two more or less pronounced maxima and an initial rise approximately at the time at which the driver's torso impacted the tank or slid over the latter. The first maximum occurs on the impact of the driver's knees on the passenger car when the not-yet decelerated passenger impacts against the already decelerated driver. If the driver slides over the tank, the driver's body is subjected below its center of gravity to forces that in themselves ought to cause an intensification of the inclination of the upper body. This is counteracted by small supporting forces of the arms of the driver dummy, which, in themselves, are not able to compensate for the intensification of the inclination of the upper body.

The upward shifting of the driver's center of gravity and also head trajectory is essentially attributable to the influence of the passenger. Firstly, the pushing action of the pillion passenger's torso reduces the deceleration of the driver's torso as it slides over the tank or as the driver's knees impact. Consequently, the relative speed between the driver's head and torso is not so pronounced and the upright seating position of the driver remains, so that the raising of the center of gravity causes a raising of the head, too. In addition, the pillion passenger slides with its thighs like a wedge under the driver, which has been decelerated as a result of its knee impact on the vehicle and is already slightly raised in the pelvic region. This supports the upward motion of the driver.

A further pointer to the pushing effect of the torso of the pillion passenger is that, in the tests with pillion passenger, there is always an impact of the driver's knee on the passenger car.

The second deceleration maximum of the passenger's pelvis is reached when the driver has impacted also with its upper body against the passenger car and the passenger begins to slide up on the virtually braked body of the driver.

Of interest in this connection are the positions of driver and passenger at the start of deceleration and at the start of the upward motion of the rear wheel of the motorcycle. Since it is intended to use the deceleration of the motorcycle to trigger an airbag, yet the deceleration occurs only at an advanced stage of the collision, the question is raised as to whether the airbag can still afford any protective effect. In addition, it must be clarified whether the observed upward motion of the motorcycle rear wheel and of the motorcycle seat bench in the course of the motorcycle impact can be used to support the upward motion of driver and passenger.

Shown in Figure 8 for all six ninety-degree motorcycle impacts in the door area of a passenger car is the

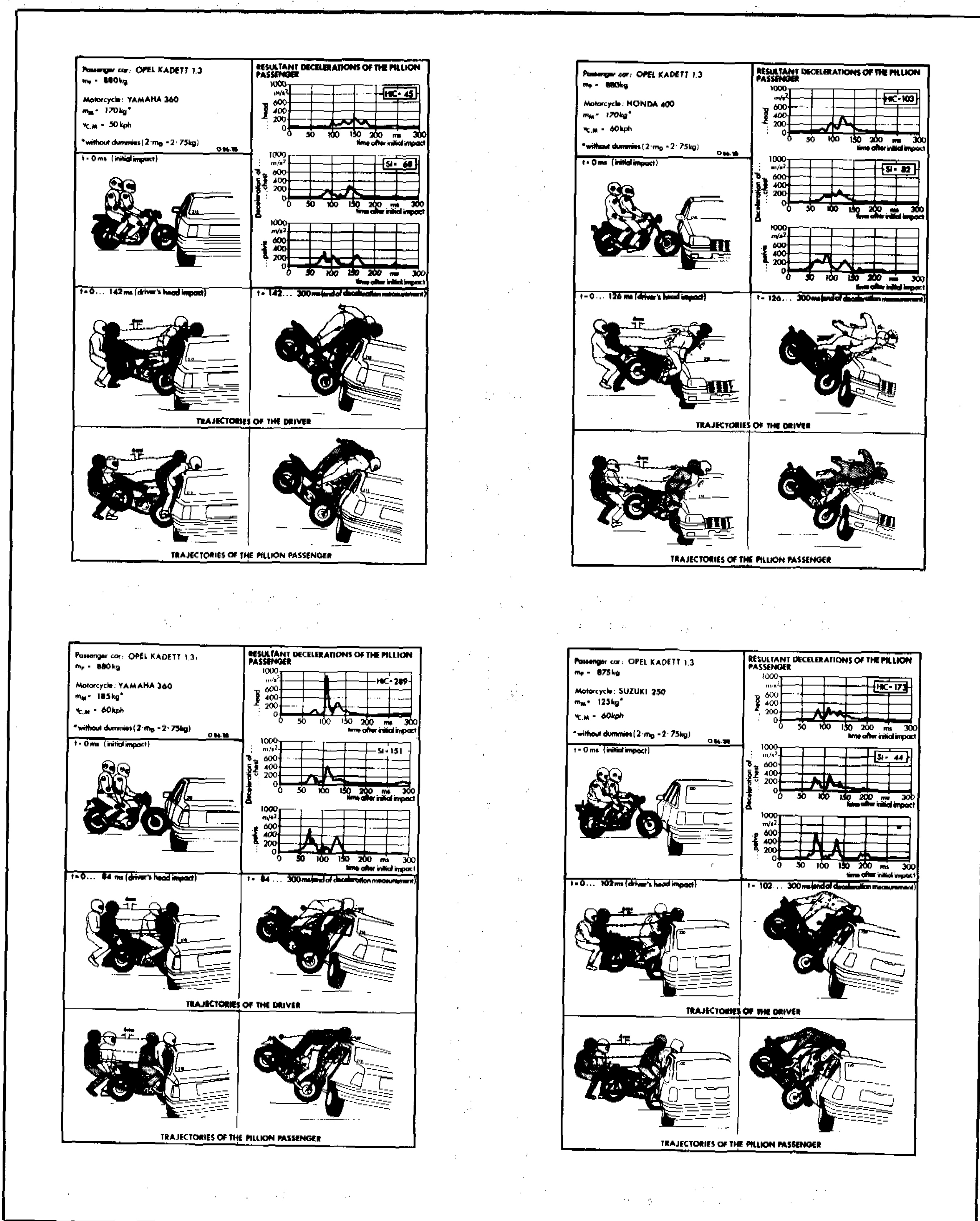

Figure 6. Dummy trajectories and measured decelerations in head, chest and pelvis of the dummy representing the pillion passenger for 90-degree motorcycle impacts against the driver-side or front-passenger-side door of stationary passenger car (driver's seating position upright)

situation at the start of the upward motion of the upper rear-wheel spring mounting of the motorcycle with the associated trajectory from initial impact to 120 ms thereafter.

The concentrations of the target positions, shown in each case simultaneously at 6-ms intervals, start approximately 12 to 18 ms before the start of this upward motion. Thus, in the tests performed, there would be a suitable degree of deceleration for the activation of sensors to trigger the airbag even before the torso of the driver impacts on the tank (at the earliest 45 ms after the start of impact of the motorcycle front wheel, see Figure 3), and, in addition to protection for head and chest of the driver, the impact of the abdomen on the tank could also at least be lessened.

As is also shown in Figure 8, the knees of the driver are still so far away from the passenger car that the effect of the airbag, starting in this situation, might—assisted by knee-pads—even prevent the impact of the driver's knees on the passenger car.

As already stated in/5/, the knee-pad, which is in close contact with the driver's knee, is intended, firstly, to at least greatly decelerate the relative motion between dummy and motorcycle—i.e. the early sliding-forward of the dummy towards the passenger car—and, secondly, to promote the upward motion of the dummy. In conjunction with the airbag, an even better protective effect can be expected for the collision configurations described here.

A rapid increase in the target concentrations can be seen after the start of the rebound of the rear wheel of the motorcycle. The upward motion of the rear sections of the motorcycle—as shown in Figures 5 and 6 for the head impact of the driver—is usually greatly pronounced, but has only very minor influence on the motion of the riders, because they have already slid away forwards out of the area of the seat bench that is effective as regards the upward motion.

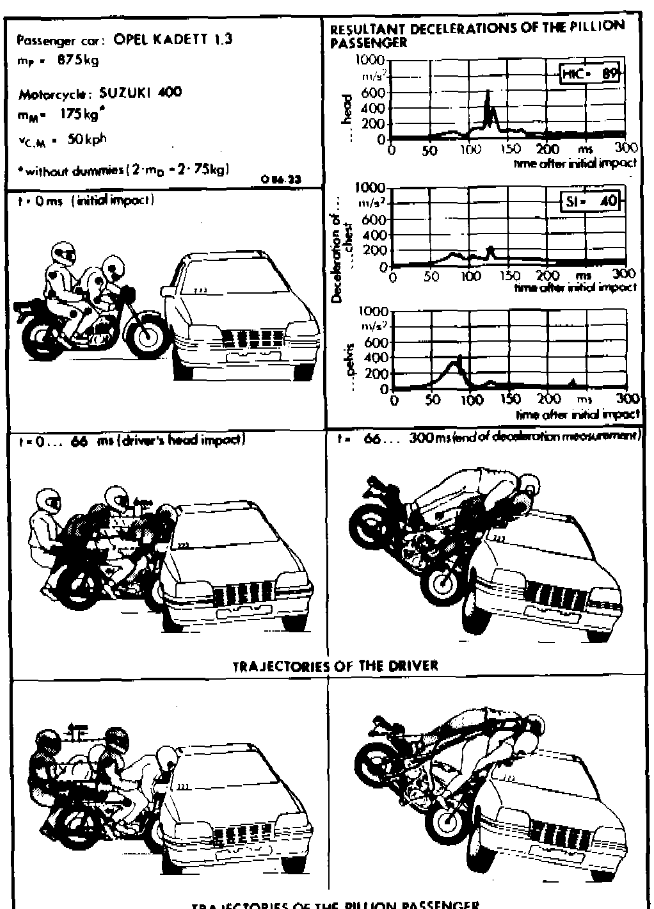

Figure 7. Dummy trajectories and measured decelerations in head, chest and pelvis of the dummy representing the pillion passenger for 90-degree motorcycle impacts against the front-passenger-side door of a stationary passenger car (driver's seating position forward-inclined)

45-Degree Collisions. Two collisions between motorcycles and passenger cars in which the collision angle between motorcycle and passenger car was 45 degrees were intended to provide initial findings on phase and motion sequences differing from those for

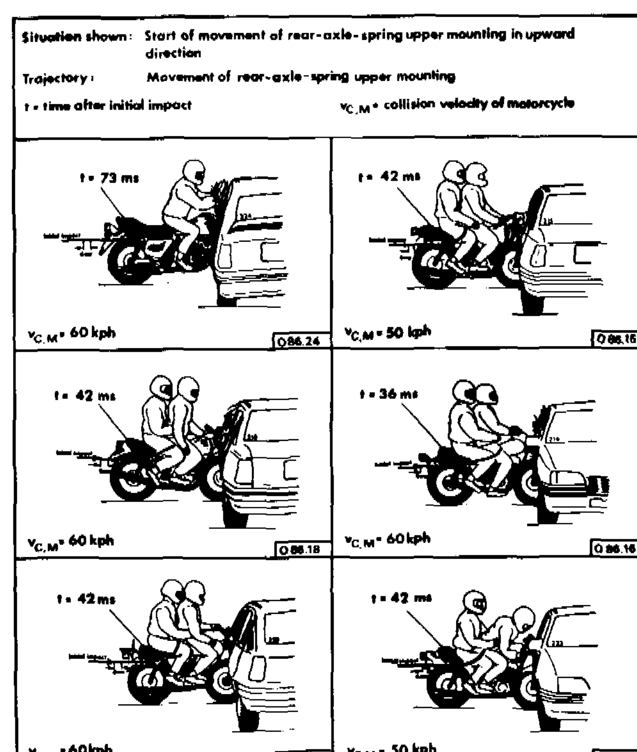

Figure 8. Trajectory of upper rear-wheel mounting on the motorcycle and situation at start of rebound of rear wheel of motorcycle (90-degree motorcycle impacts against the driver-side or front-passenger-side door of stationary passenger cars)

ninety-degree collisions, Figure 9. Approximately the same phase and time sequence applies to both versions of the test (driver and driver/passenger).

In the diagonal collision, after the start of contact, the front wheel of the motorcycle, sliding along the passenger car, is first of all turned until it is aligned parallel to the side contour of the passenger car. Approximately 20 ms after the start of the collision, the deformation of the fork is initiated, this being followed approximately 15 ms later by the contact between lamp/steering head and passenger-car door. Now, the motorcycle front wheel, which in the meantime is in broad-area contact with the passenger car, and the steering-head and lamp unit become entangled with the already deformed door, so that, as a result of the pushing action of the motorcycle, the virtually braked front wheel of the motorcycle comes into contact with the engine block. Approximately 120 ms after initial contact, the forward motion of the motorcycle is more or less completed and, while the rear axle is being raised slightly, the motorcycle folds also with the rear wheel against the passenger car.

The driver's knee facing the passenger car impacts on the vehicle door approximately 50 ms after the start of the collision. The impacts of pelvis and chest take place in the time phase between 50 and 140 ms.

Approximately 130 ms after the start of the collision, the head of the driver (only rider) impacts in a glancing manner on the comparatively soft vehicle roof, with the HIC being relatively low at 173.

The head impact of the passenger is against the back of the driver and is, therefore, heavily damped (HIC = 31). In this collision configuration, an airbag is certainly not able fully to develop its protective effect for the driver. As regards the knee impact of the driver, however, a protective effect can be expected if the knee-guard is so designed that it is also capable of protecting against direct lateral impacts.

Owing to the multiplicity of possible impact angles and passenger-car contours, more detailed findings can, of course, not be expected until after further tests.

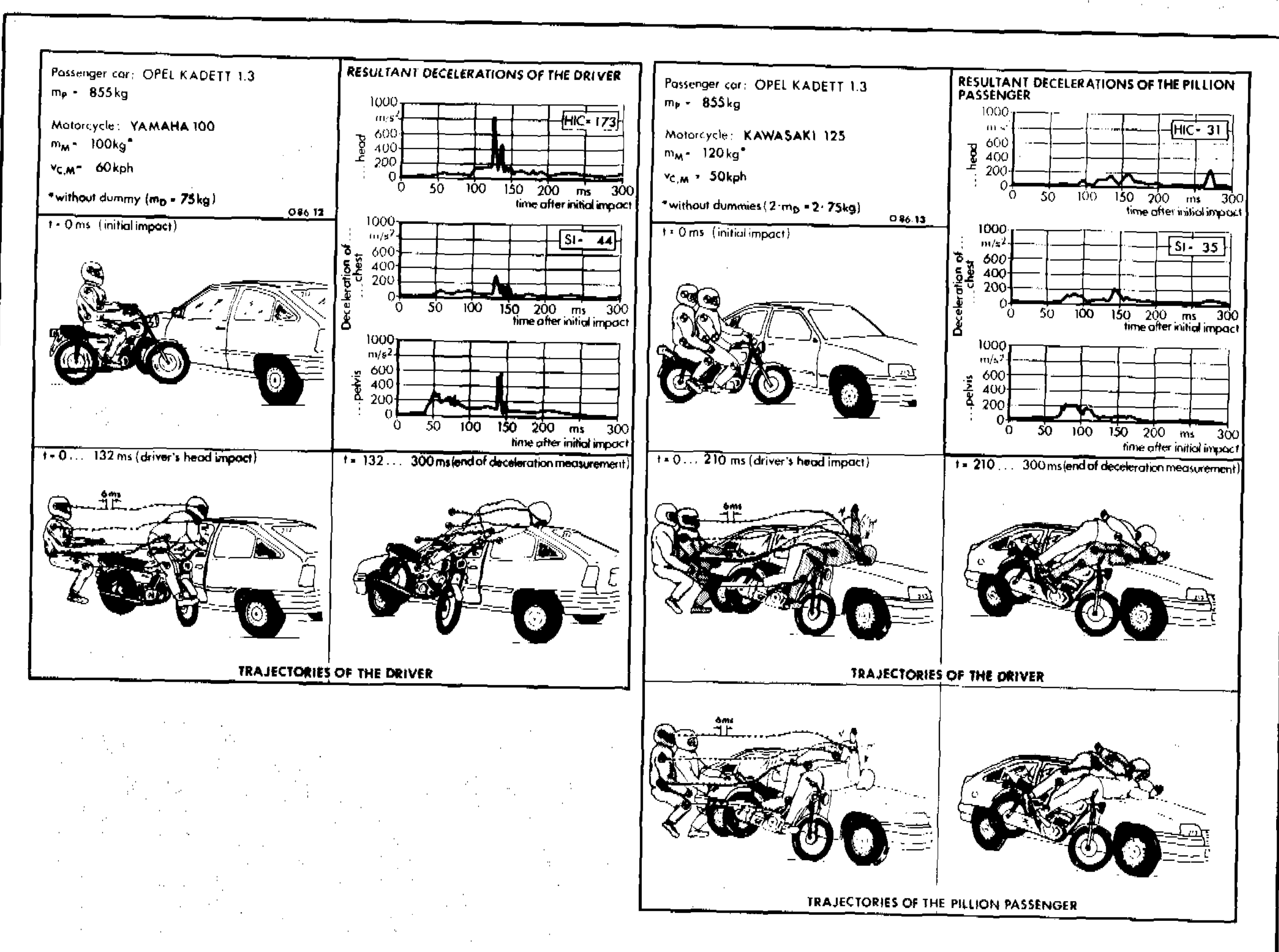

Figure 9. Dummy trajectories and measured decelerations in head, chest and pelvis of the dummies representing the driver and pillion passenger for 45-degree motorcycle impact against the driver-side or front-passenger-side door of stationary passenger cars

Strength of Door/Side Assembly

During the development phase, the side assembly of Opel passenger cars is dimensioned in tests for the impact of passenger cars. The main emphasis is placed on retaining the tensile assembly according to the principle of the chain. Therefore, A-, B- and C-pillars, doors as well as locks and hinges are matched to the loading.

In contrast to passenger cars, motorcycles, particularly very heavy ones (Honda 1000, m = 265 kg, Figure 5), apply concentrated forces to the side of the vehicle. Therefore, high penetration depths are expected.

In the tests presented here, the side assembly stopped the motorcycles in all cases from penetrating into the passenger compartment. A major contribution in this regard was played by the door sill. Owing to the heights of the front wheel of the motorcycle and of the door sill, there was a favorable overlap and thus a reduction in the load on the door. The penetration depths were of the order of magnitude of 300 mm, Figures 10 and 11. The car occupants are at risk as a result of the penetrating door, this being alleviated by the upholstered inside panel of the door. A further risk to the occupants is produced by the penetration of the motorcycle driver, assuming that the latter is in the appropriate (low) seating position.

Taking into account the vehicle class (lower mid-class) it can be said in this regard that there is a good protective effect.

Additional Findings with Regard to the Reconstruction of Accidents Between Motorcycles and Passenger Cars

Practical reconstruction methods often make use of the permanent shortening of the wheelbase on the motorcycle and—if the rider moved in flight—of the distance the driver was thrown. In addition, qualitative comparisons of degrees of damage on the vehicles provide pointers to the possible collision speeds.

All hitherto performed simulations of passenger-car/two-wheeler accidents make it clear that, given the multiplicity of possible motion sequences during the collision, the overall interpretation of degrees of damage cannot lead to the desired goal.

In the case of accidents involving the ninety-degree impact of a motorcycle against the door-side area of a passenger car of the Opel Monza model or of the

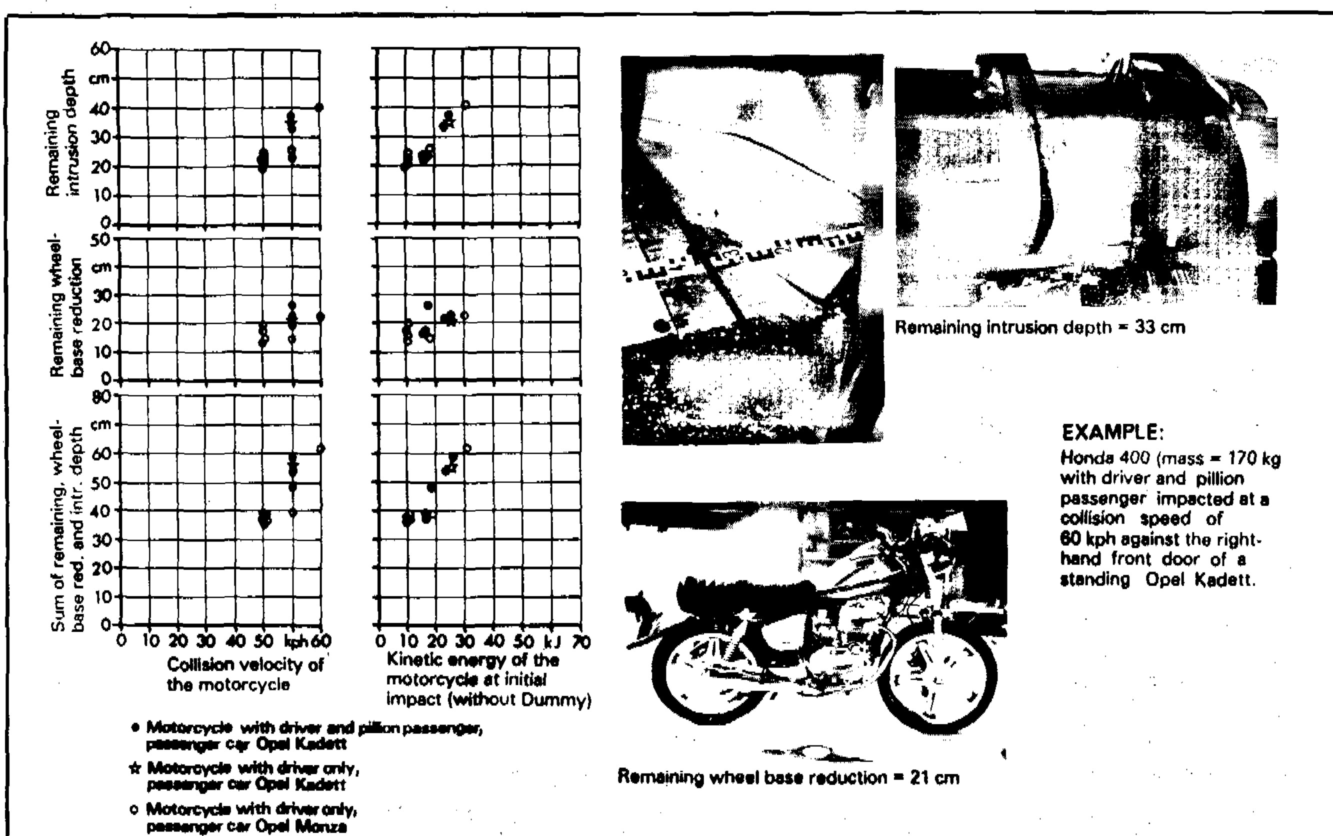

Figure 10. Penetration depth on passenger car and wheelbase shortening of motorcycle as a function of impact velocity and impact energy of motorcycle for 90-degree motorcycle impacts against the driver-side or front-passenger-side door of stationary passenger cars

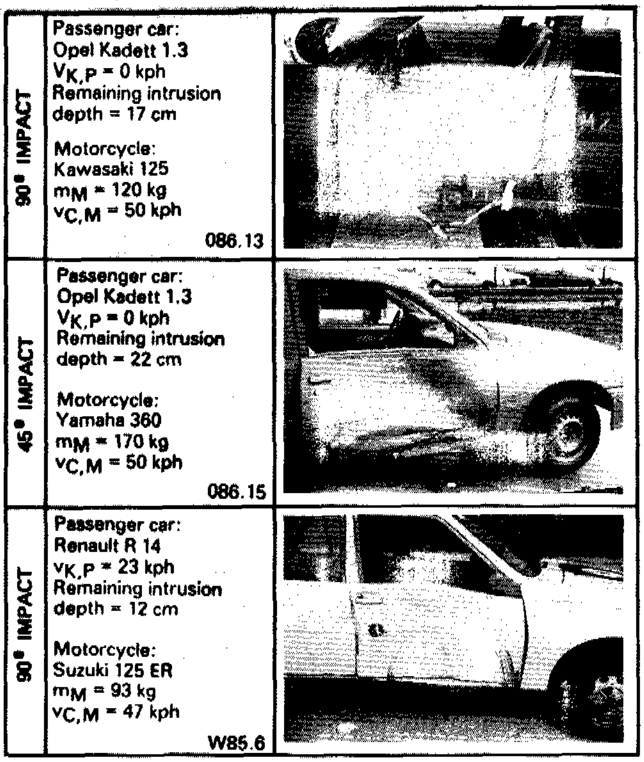

Figure 11. Different degrees of damage on passenger car after motorcycle impacts in the door area

latest version of the Opel Kadett, it was possible in the impact-speed range between 50 and 70 km/h to detect an approximately linear relationship between the maximum permanent penetration depth on the passenger car—arising from the impact of the motorcycle front wheel—and the impact speed/impact energy of the motorcycle. In contrast, less clear were the relationships between permanent wheelbase shortening of the motorcycle and the latter's impact speed/impact energy. The most favorable relationship for a rough delimitation of possible impact speeds of the motorcycle appears to be that between the kinetic impact energy of the motorcycle and the sum of permanent penetration depth on the passenger car and permanent wheelbase shortening of the motorcycle, Figure 10. In the reconstruction of real accidents of the type simulated, it might be possible in this manner to calculate, first of all with reference to the sum of penetration depth and wheelbase shortening, the kinetic impact energy of the motorcycle and, by means of the known mass of the motorcycle, then the impact speed. It does not appear worthwhile additionally to take account of the mass of the rider, because the deformation on the passenger car arising through the penetration of the motorcycle front wheel is already largely completed by the time the rider is decelerated or by the time of the major impact of the rider or the passenger car. Figure 11 shows, for comparison, three degrees of damage on passenger cars.

Finally, the tests are used also to derive pointers as to the flight tendency of the motorcycle riders. Figure 12 is a compilation of the center-of-gravity trajectories of driver and passenger in the case of ninety-degree impact against the doors of stationary passenger cars from the start of impact to 300 ms thereafter. It should be noted that unhindered flight is not possible in these cases.

It can be seen that the motion of the driver is deflected upwards within a relatively narrow range of between 15 and 20 degrees.

The angular range of the upward motion of the passenger extends from 18 to 45 degrees, i.e. it tends towards steeper lines of motion. This is expressed also in the qualitative observation that the passenger dummy always slides further onto or over the passenger car than the driver dummy, the latter usually after the collision coming to lie near the passenger-car side facing the impact.

The examples indicated here make it clear that, owing to the multiplicity of the possible impact configurations between two-wheeler and passenger car, considerable research remains to be conducted in order to solve these problems.

Summary

As a continuation of joint series of tests of DEKRA Accident Research and the Vehicle Safety Department of Adam Opel AG, collisions were simulated for the first time in which motorcycles carrying two dummies impacted at 90 degrees or 45 degrees against the sides of stationary passenger cars, with head- and body-injury data being measured. The collision speeds of the motorcycles were in the range between 50 and 60 km/h.

The 90 degree impact yielded no clear differences in the order or in the time sequence of the motion characteristics between motorcycles with and without pillion passengers. In the 45-degree collisions, the impacts on the passenger car were predominantly of the glancing type, with the result that there was a change in the degree of deformation.

Compared with earlier tests, lower HIC values were measured for the impact of the helmeted head of the dummy on the roof edge of the test vehicles, because the roof edges of the latest Opel Kadett range used in the tests have a less aggressive shape and are more flexible.

The measured decelerations of the pillion passenger in head, chest and pelvis were always subcritical, because the impact was diminished by the driver.

As a result of its pushing motion, the pillion passenger supports the favorable upward motion of the driver, with the result that the driver's head is

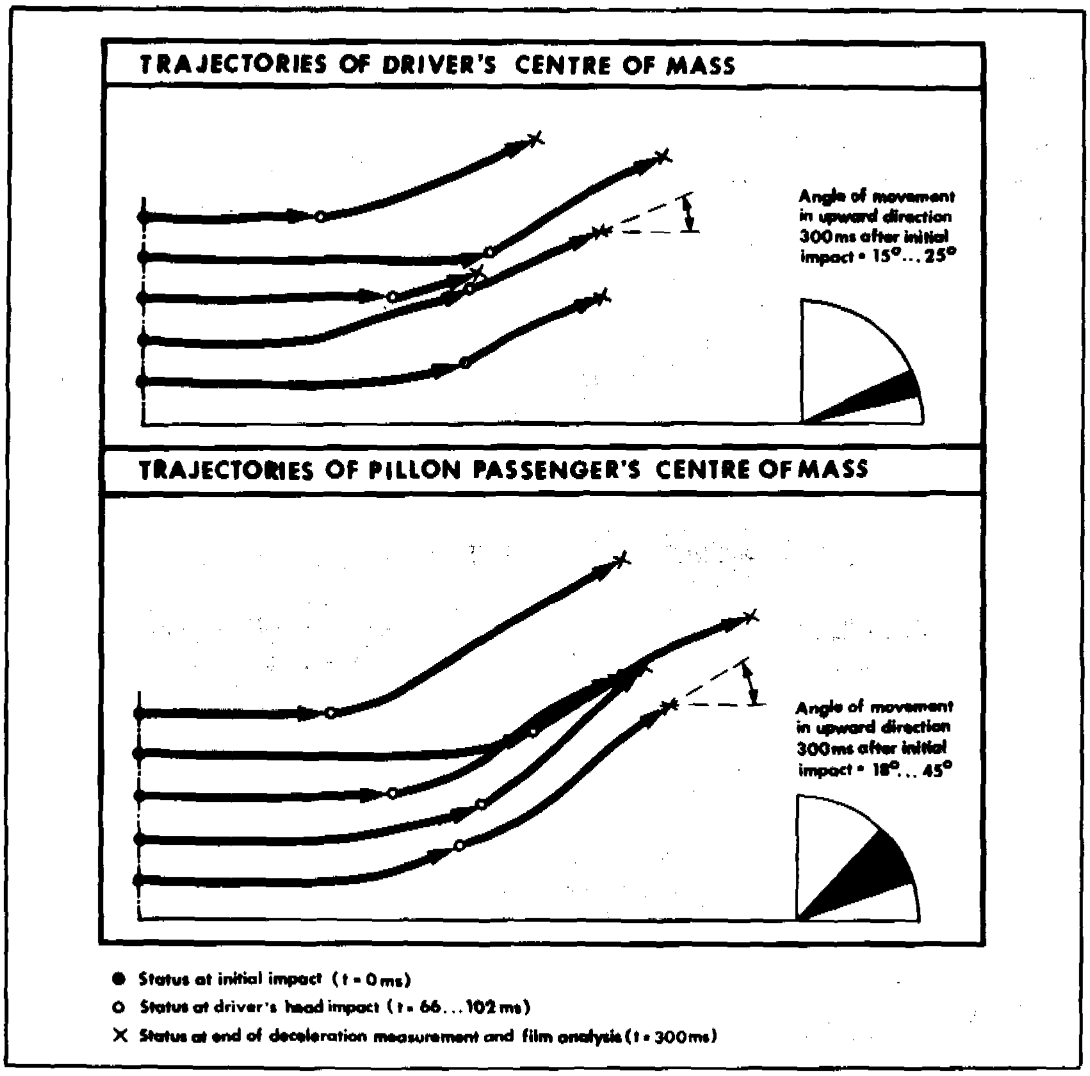

Figure 12. ***Center-of-gravity trajectories of dummies representing driver and pillion passenger for 90-degree motorcycle impacts against the driver-side or front-passenger-side door of stationary passenger cars***

lifted above the critical area of the roof edge. Additionally, the wedge effect of the thighs of the pillion passenger promotes the upwards tendency of the motion of the driver even before impact against the passenger car.

Motorcycle decelerations of sufficient magnitude to trigger an airbag via sensors were measured in the tests even before the driver's torso impacted on the motorcycle tank, with the result that the protective effect of the airbag can be taken into consideration also for the abdominal region of the driver. Closely fitting knee-pads, intended to prevent early sliding-forwards of the dummy on the motorcycle seat bench and to promote its upward motion, can be expected—in combination with a motorcycle airbag—to provide an increased protective effect both for the driver and for the pillion passenger.

In the case of diagonal collisions, the protective effect of the airbag is certainly not optimal, and the knee-pads should also afford lateral impact protection. Further tests may provide more reliable findings in this regard.

The strength of the door-side assembly on the passenger car has proved to be adequate in the case of a concentrated motorcycle impact.

With regard to the reconstruction of accidents involving ninety-degree motorcycle impact against stationary or slowly moving passenger cars, a relationship was established between kinetic impact energy and sum of permanent penetration depth on the passenger car and permanent wheelbase shortening of the motorcycle, with it being possible for this relationship to be used as a further basis for reconstruction.

The center-of-gravity trajectories of the riders showed a more pronounced upwards tendency in the pillion passenger than in the driver. In conformance with findings from real accidents, the tests showed that the pillion passenger is more likely to go over the roof of the passenger car, possibly flying further than the driver.

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Improvement of Conspicuity of Motorcycle Drivers by Passive Materials

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Abstract

Based on the measurements of the contrast of motorcycle drivers against the background, different features like protective clothing with retroreflective materials were investigated. Out of these partly dynamic tests improvements of the marking of motorcycle drivers are developed. Proposals of an optimal marking is derived from these experiments.

Introduction

Starting from the measured contrast of motorcycle drivers in the street, different markings were investigated. The tests of comparison were carried out dynamical and statical in the normal street situation and in a down scaled test set-up. The influence of the following parameters were investigated

size and shape of the marking
distance between marking.

As criterion a 9-rating scale was chosen.

Marking of the Driver

The motorcycle driver was marked in his vest-area, as shown in Figure 1. The geometry is layed down in Table 1.

Assessment of the Luminance of the Marking

In the experiments a 9-rating scale was used as summarized in Table 2.

The tests were carried out indoor and outdoor with 10 ennetropic test-persons. The marking of the motorcycle driver was illuminated by a typical European low-beam headlamp. In the 1 : 10 down scaled

Table 1. Geometry of the used markings.

Marking	"a"/cm	"b"/cm
1.1	3,5	3,5
1.2	5,0	5,0
1.3	7,0	7,0
2.1	3,5	3,5
2.2	5,0	5,0
2.3	7,0	7,0
3.1	3,5	7,0
3.2	5,0	10,0
3.3	7,0	14,0
4.1	5,0	5,0
4.3	7,0	7,0

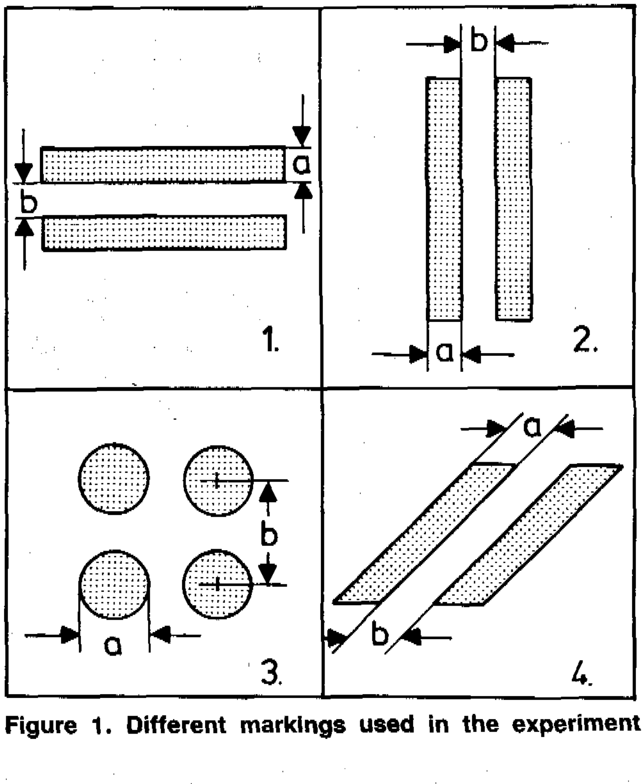

Figure 1. Different markings used in the experiment

Table 2. Assessment of the luminance of the markings.

grade	assessment
1	too glaring not recognicible
2	
3	bright recognicible
4	
5	optimal recognicible
6	
7	dark recognicible
8	
9	too dark not recognicible

experiment the illumination was changed by means of projectors.

Test-Results

Test-results are shown in Figure 2 ...5, for the different markings as described in Figure 1 and Table 2.

The results show the dependence of the optimal luminance L of a marking on the distance d in meter where this marking is shown to the test-person. All curves have a similar shape. Beginning at relative low luminances for short distances, the luminances increase rapidly for larger distances.

A comparison of these results is shown in Figure 6.

For certain viewing distances d the optimal luminance L is plotted for the 4 different markings. These curves are the results from calculation of the regression. For small distances the marking 1 (horizontal stripes) is optimal, for large distances the markings 2 and 3.

In Figure 7 one of the test results (marking 3) is compared with the luminances which can be reached with normal retroreflective materials.

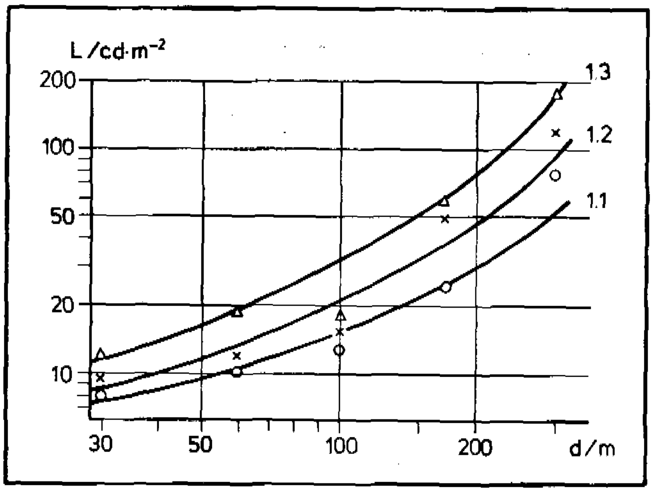

Figure 2. Luminance L and viewing distance d 1.1, 1.2, 1.3: marking with different geometric forms

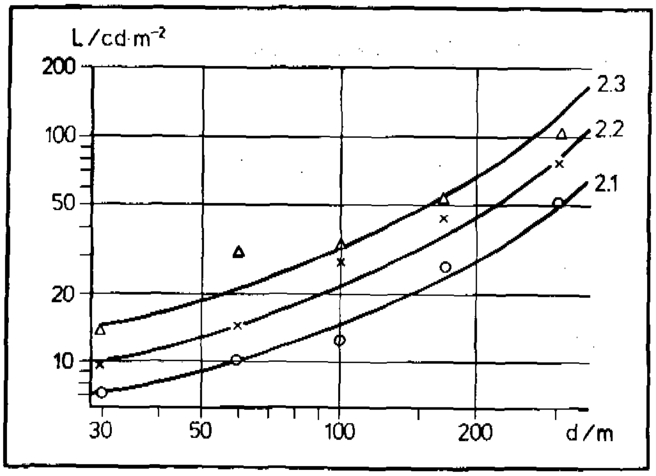

Figure 3. Luminance L and viewing distance d 2.1, 2.2, 2.3: marking with different geometric forms

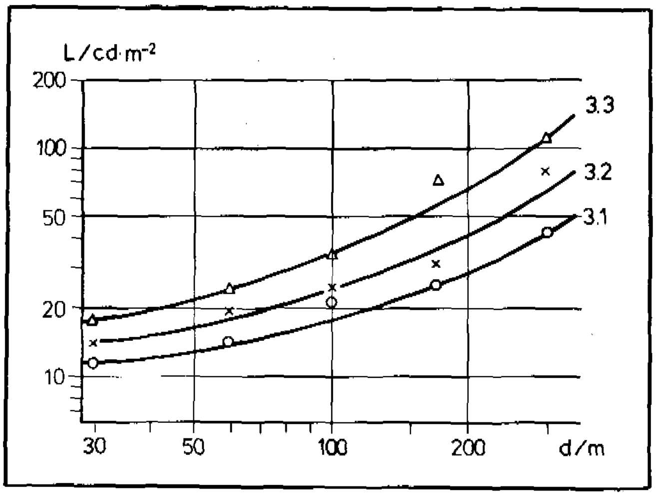

Figure 4. Luminance land viewing distance d 3.1, 3.2, 3.3: marking with different geometric forms

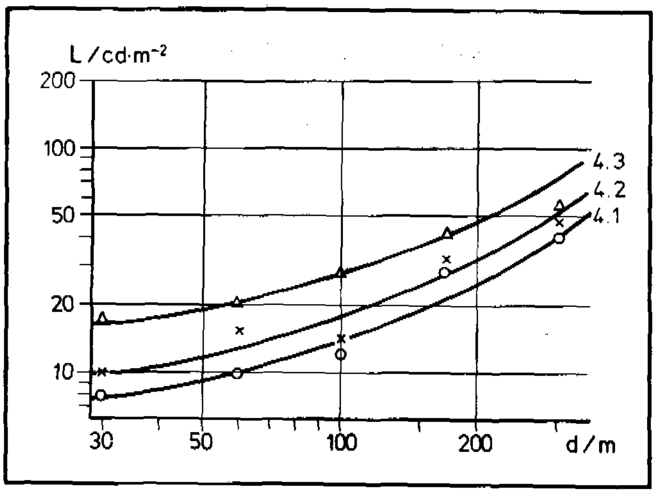

Figure 5. Luminance L and viewing distance d 4.1, 4.2, 4.3: marking with different geometric forms

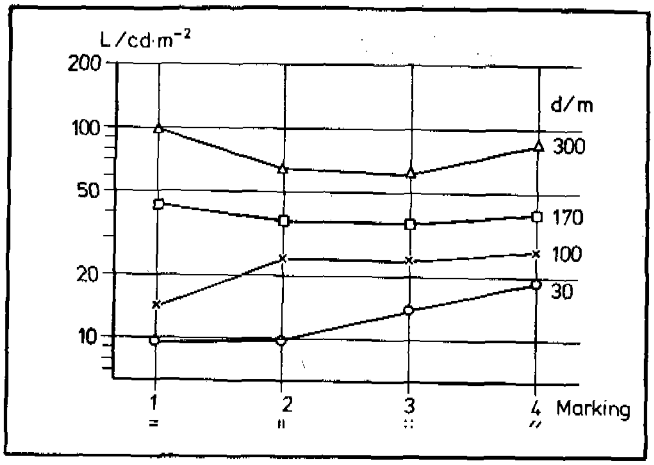

Figure 6. Luminance L for different markings
d : viewing distance

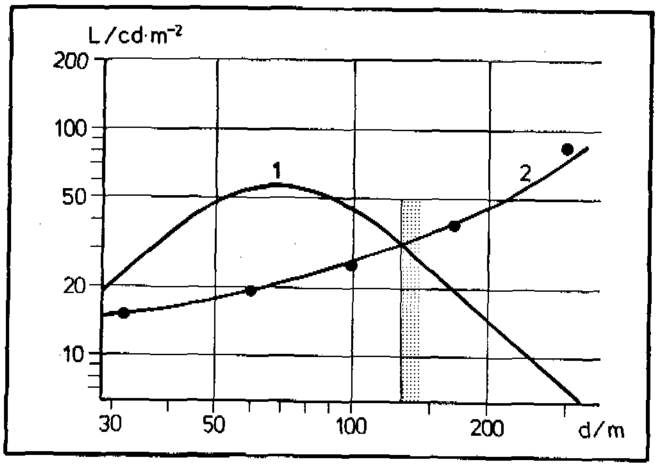

Figure 7. Luminance L and viewing distance d
1 : Luminance of white retroreflective material illuminated by low-beam-headlamps
2 : optimal luminance for marking with dots

Curve 1 shows the luminance of a retroreflective material illuminated by a low beam. Curve 2 is the result for the rating "optimal recognition" for the marking with dots. For distances d up to 130 m the requirement for "optimal recognition" can be fulfilled. Similar results can be reached with other markings.

Conclusions

The marking of motorcycle drivers can be improved by means of retroreflective materials. Up to distances of d ≈ 100 m the marking with horizontal stripes seems to be best. Up to d = 130 m an optimal marking is possible.

These results were gained without oncoming traffic and other glaring light sources. The results should be proved by a large scale experiment.

Protecting Motorcyclists' Legs (Written only paper)

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Protecting Motorcyclists' Legs

Introduction

An essential part of the development of leg protectors for motorcycles is the development of realistic test procedures to check whether they are satisfactory. This paper describes the test procedures which were set up for this work and then gives some test results which compare the performance of the currently preferred design of leg protection on motorcycles, with that of the unmodified machines. Performance is measured by recording head and chest accelerations on a dummy rider together with estimates of the energy absorbed in damage to its leg. This is the leg on the side of the motorcycle which is damaged on impact with the target car.

Test Procedure—Stationary Target Car

The essential features of the impact of a motorcycle into a car can be represented by tests with a stationary target car, and the leg protectors were developed using such a technique. The leg protectors consist of semi-conical leg guards just ahead of the lower legs of the rider, with knee padding to protect the knees. They are firmly attached to the frame of the motorcycle.

Four step-through and 4 BMW motorcycles were impacted at 48 km/h into a stationary car (Marina 4 door). Each set of tests comprised two impacts into the side and two into the front of the car. The impacts into the car side were aimed between the A and B post on the driver's side, and as though the car and motorcycle were travelling in the same direction at 30° to each other (see fig. 1). The impacts into the car front were aimed at the centre of the front. *All* the impacts were with the target face inclined at 30° to the motorcycle direction of travel, and each pair of impacts consisted of one with an unmodified machine and the other with leg-protectors. The tests of two

B.M.W.'s into the side of the car showed that the interaction of the horizontal cylinder head with the car induced a different and more violent impact than might otherwise be expected and one that is probably not typical of large machines. Therefore the remaining tests were with the cylinder heads removed and the equivalent mass replaced by lead weights inside the crankcase. In addition to these tests a B.M.W. with the leg-protecting fairing was impacted into the front corner of a car to provide more information on leg protection.

The leg-protection that was used is a foam filled metal semi-cone which is the one preferred from a previous series of tests into a rigid barrier(1)(2). In the barrier tests the protector absorbed about 5 percent of the total impact kinetic energy for the step-through motorcycles and 10 percent for the medium and large machines. It was assumed however that when impacted into a car that much of the energy would be absorbed by deforming the car body as well as the leg protector.

The foam filled energy absorber was built into a glass fibre fairing based on the B.M.W. R.T. type(3) and this was fitted to two of the large machines. The unmodified equivalents were tested without a fairing fitted.

The dummy rider is a fiftieth percentile OPAT fitted with the aluminium honeycomb injury indicating legs(1)(2) and with accelerometers in its head and chest. Accelerometers were also fitted to the motorcycle, and high speed film was used for the trajectory analysis.

Results

The results given below are for the tests into a stationary car and in some instances they are compared with those obtained previously from impacts into a rigid barrier. In this way differences between the two test procedures are highlighted.

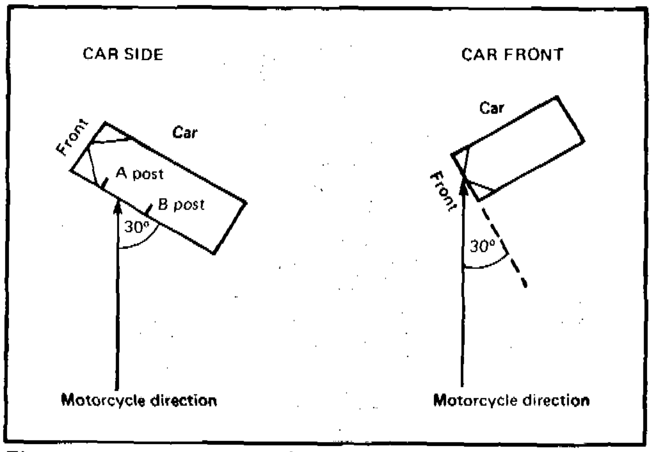

Figure 1. Orientation of motorcycle in impacts with the side and front of a car

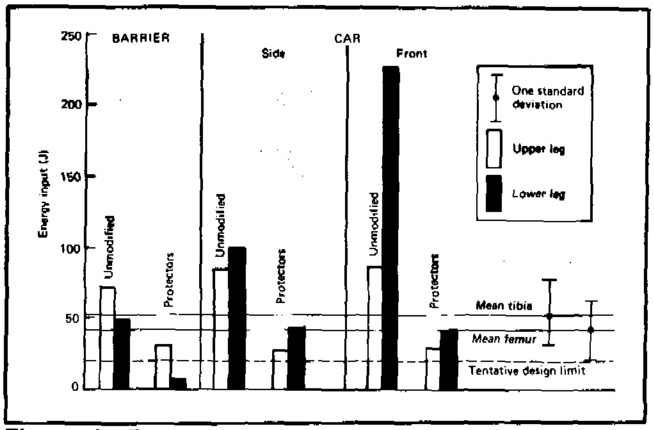

Figure 2. Energy absorbed by leg in impacts of small (step-through) motorcycles

Leg Injury

The energy absorbed by the leg of the dummy rider is given in figs. 2 and 3 and is expressed as previously(3). A tentative limit of 20J is suggested. Mean values which correspond to breaking the femur (upper leg bone) and tibia (lower leg bone) are shown in figs. 2 and 3 together with a range of ± one standard deviation. The values which are estimated using results given in references(4) and (5) are, for the femur (± one standard deviation) 24 to 62J with a mean of 43J and for the tibia (± one standard deviation) 30 to 78J with a mean of 54J.

Heavy Machines

As has been stated(2)(3) the results for the heavy machines into barriers are inconclusive because the trajectories of the motorcycles were severely affected by the horizontal cylinder heads and resembled that of a violent frontal impact. The leg damage was fairly low in all tests (see fig. 3), although the potential head injury was greatly reduced by the leg protectors.

The impacts into the side of the car were also affected by the cylinder heads but not to the same extent, because the car body panels deformed whereas the barrier could not. The cylinder head protected the lower leg but the impact energy sustained by the

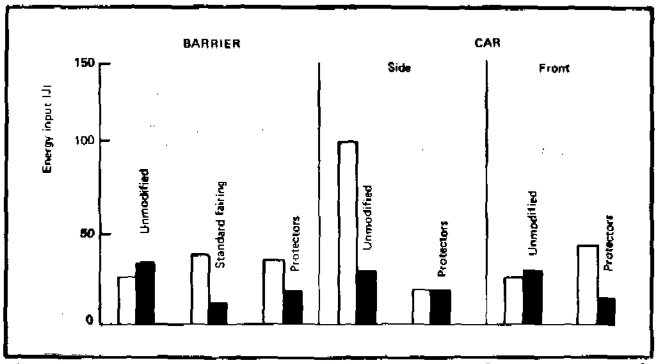

Figure 3. Energy absorbed by the leg in impacts of large (BMW R80) motorcycles

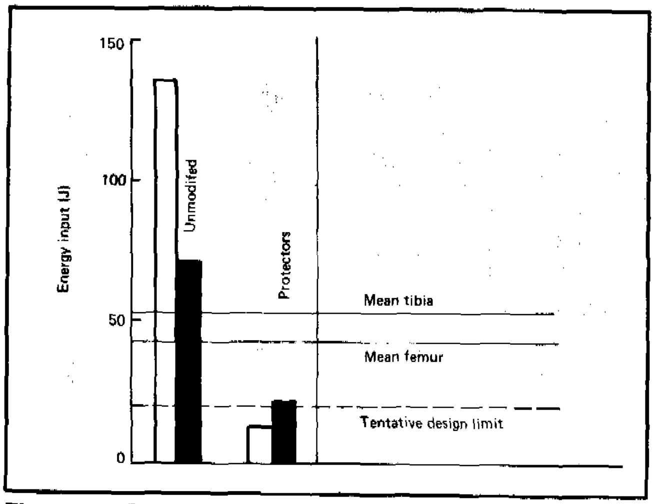

Figure 4. Energy absorbed by leg impacts of medium weight motorcycles into oblique barrier at 48 km/h

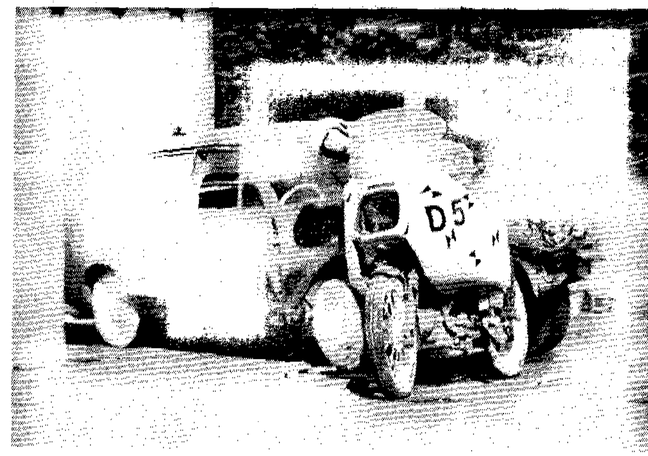

Figure 5. Motorcycle fitted with leg protecting fairing. (During impact)

upper leg was high and well above the tolerable level. The leg-protective fairing greatly reduced the energy sustained to below the design criteria of 20J, for each limb.

In the next set of tests the unmodified machine interacted violently with the front of the car (despite the lack of cylinder heads) and produced a typical frontal impact with the dummy being thrown off head first (fig. 6). The trajectory of the modified machine (fig. 5), was satisfactory as was expected. The leg impact energy sustained was similar for each test (see fig. 3). The result with the modified machine confirmed the need for an efficient knee energy absorber; earlier research(2)(3)(6) had shown this to be essential.

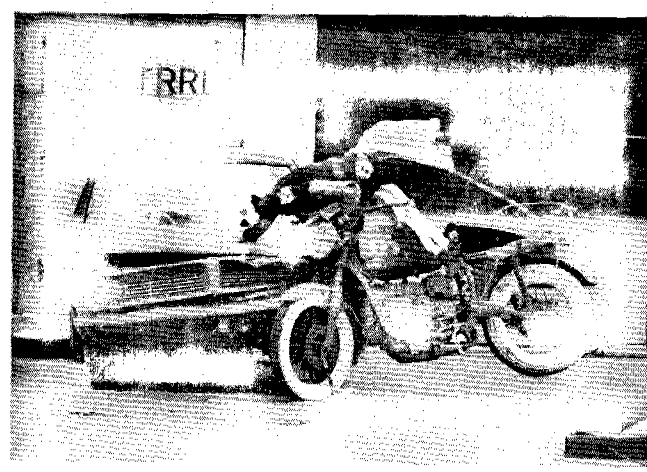

Figure 6. Unmodified motorcycle. (During impact)

Table 1. Dummy rider head & chest measurements—motorcycle car impacts.

MOTORCYLE LAYOUT	MEASUREMENT	STEP-THROUGH			LARGE		
		SIDE	FRONT	MOVING FRONT	SIDE	FRONT	CORNER
UNMODIFIED	HEAD HIC	400	*	1353	327	164	NA
WITH PROTECTORS		*	*	876	259	*	145
UNMODIFIED	HEAD PEAK g	109	*	144	93	32	NA
WITH PROTECTORS		*	*	115.0	67.9	*	54.2
UNMODIFIED	HEAD 80g EXCEEDED ms	1.8	*	8.3	3.3	0	NA
WITH PROTECTORS		*	*	3.3	0	*	0
UNMODIFIED	CHEST PEAK g	35	1	45	22	14	NA
WITH PROTECTORS		2	13	58	12	NA	23

* = NO CONTACT

NA = NOT AVAILABLE

Step-through Motorcycles

The results from this series of tests are given in fig. 2. The barrier tests suggested that leg protection could be effective, the car tests have reinforced this finding and also tend to agree with the accident studies, which show that the lower leg is more frequently and seriously injured than the upper leg.

The energy sustained by the upper leg is almost the same for all three tests and is caused by contact with the protector. Although energy absorbing foam was fitted ahead of the knee, it did not completely resist the solid metal substrate of the dummy leg and was fully crushed. A human knee would not have penetrated the foam so deeply, and would not have contacted the protector attachment struts, as happened in these tests. Careful observation of the high speed film shows that at no time did the leg make contact with the car.

Head and Chest Injury

In the first series of tests(1)(2)(3) horizontal head velocity measured at the barrier vertical plane was considered indicative of potential head injury. However in the impacts into cars the head invariably struck either the roof or bonnet while moving vertically downwards. It is considered therefore that vertical velocity might be more relevant, and where appropriate it is given in Table 1. Also given are H.I.C. (Head Injury Criterion) values, peak resultant acceleration, and times for which 80g was exceeded, all were evaluated from the head tri-axial accelerometer. Chest peak resultant acceleration is also given, and again this is evaluated from a tri-axial accelerometer.

These results should be considered as a set. For every pair of tests in which head contact occurred the H.I.C. was reduced when the machine was fitted with leg-protectors. In the tests into the car side no head contact occurred when leg protection was fitted, whereas with the unmodified machine the head struck the "A" post and the bonnet. The tests of the step-through machines into the car side showed that leg-protection prevented head contact. The chest accelerations are generally low and again leg-protection tends to effect a reduction.

It has been said that vertical velocity may be a good indication of potential head injury and a graph was plotted of vertical head velocity against H.I.C. (fig. 7). With the exception of one point the tendency is for HIC to increase with vertical head velocity. However more data is needed to confirm this.

Motorcycle Trajectory

The results from the research suggest that leg injuries tend to be potentially more severe when the motorcycle angular velocity is high during the first 100 m/s of the impact. This is illustrated by Fig. 8 which shows the average angular velocity during this period for the unmodified machine, and by Fig. 9 which gives the values for the motorcycles with leg protectors.

The results for the large machines are affected by the cylinder heads and so appear anomalous but they do illustrate that leg-protection can both increase and decrease the angular velocity to the advantage of the legs and the head. If however the linear forward velocity changes rapidly on impact, as with the large unmodified machine into the car front, then the rider will leave the motorcycle head first (see fig. 6). This is well before the rotation of the machine can have any effect. For leg protectors to be effective both linear and angular velocity must be controlled (see fig. 5).

The angular velocity of the unmodified step-throughs (mean for all tests is 5.2 rad/s) is consistently higher than for those with leg protection (mean 2.5 rad/s). This result supports the contention that leg injuries are related to angular velocity.

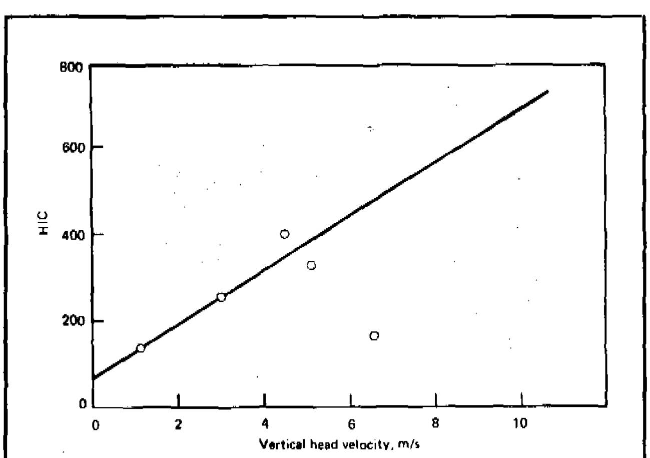

Figure 7. Vertical head velocity against HIC

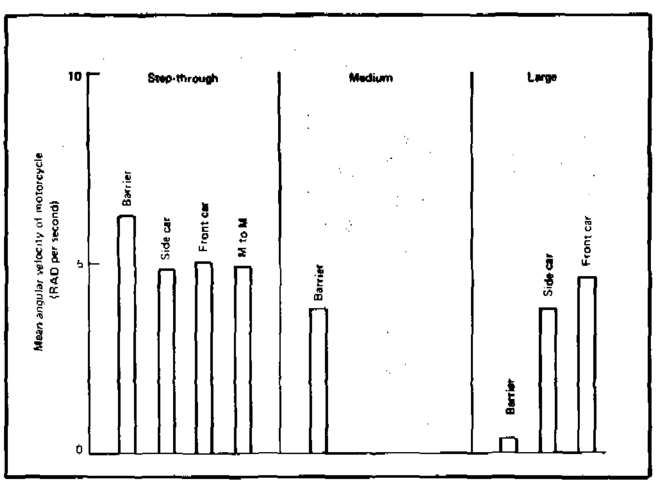

Figure 8. Mean angular velocity of unmodified motorcycle during first 100ms

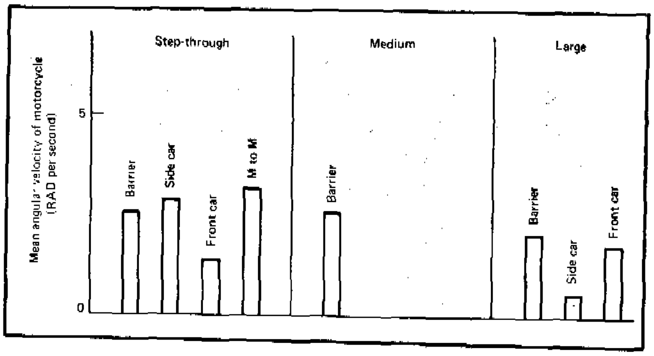

Figure 9. Mean angular velocity of modified motorcycle during first 100ms

Test Procedure—Moving Target Car

Doubts have been raised about the realism of impacts into stationary cars and so motorcycles were impacted into a moving target to check this. As well as this, a simple theoretical model is derived later to compare the two procedures. Two step-through motorcycles were impacted at 48 km/h (30 mile/h) into the front of a car moving at 24 km/h and at an impact angle of 30°. One motorcycle was unmodified the other was fitted with leg protectors.

The impact point was intended to be the centre of the car front but the first impact occurred at about a quarter of the distance across. No changes were made to the system and the second impact was identical. An adjustment will be made for future tests. The results of these impacts are described in a later section.

Apparatus

Fig. 10 shows the layout of the apparatus and fig. 11 shows the motorcycle launch trolley with its wheels in the guide rails. The car is similarly guided. The towing car (a large Oldsmobile) pulls the two vehicles together and when they are near the impact point the towing cables are automatically released as is the catch holding the motorcycle to the trolley. The trolley is brought to rest by an energy absorbing arrestor which causes the motorcycle to be launched. The mechanism by which it is launched is identical to that used previously when a launch frame was fitted to a Land Rover.

The speed ratio, motorcycle to car, can be 1:1, 2:1, or 3:1. The second two ratios are achieved by inserting the appropriate pulley blocks between the

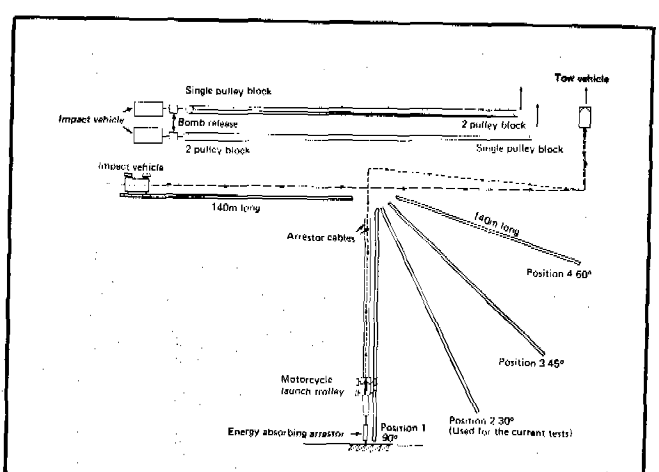

Figure 10. Impact apparatus for moving motorcycles to moving car tests

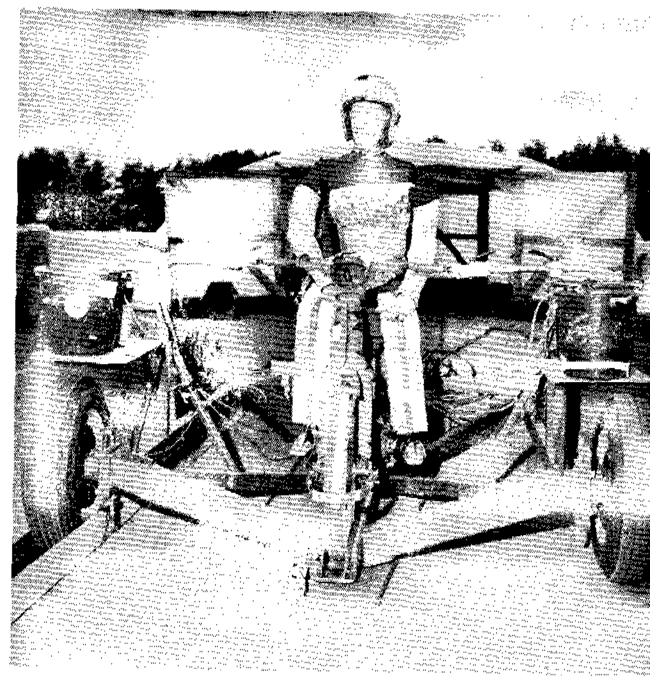

Figure 11. Motorcycle launch trolley for impacts with both vehicles moving

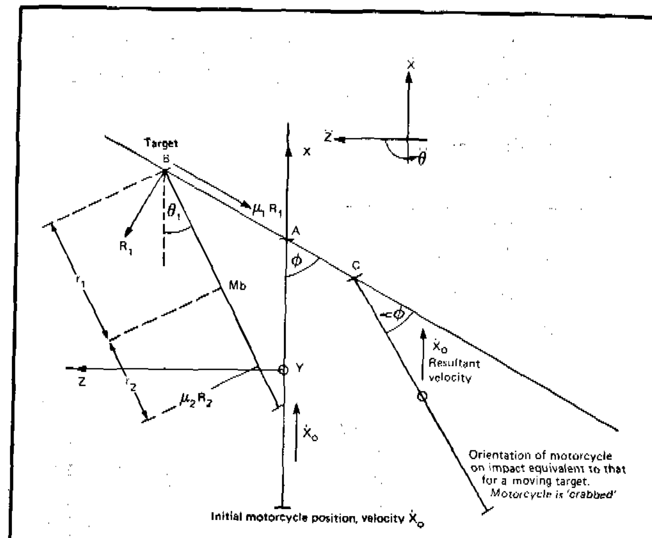

Figure 12. Simplified motorcycle, striking stationary target at A at t = 0 and slides to B at time t. Orientation of motorcycle at t = 0 for an impact equivalent to one with a moving target.

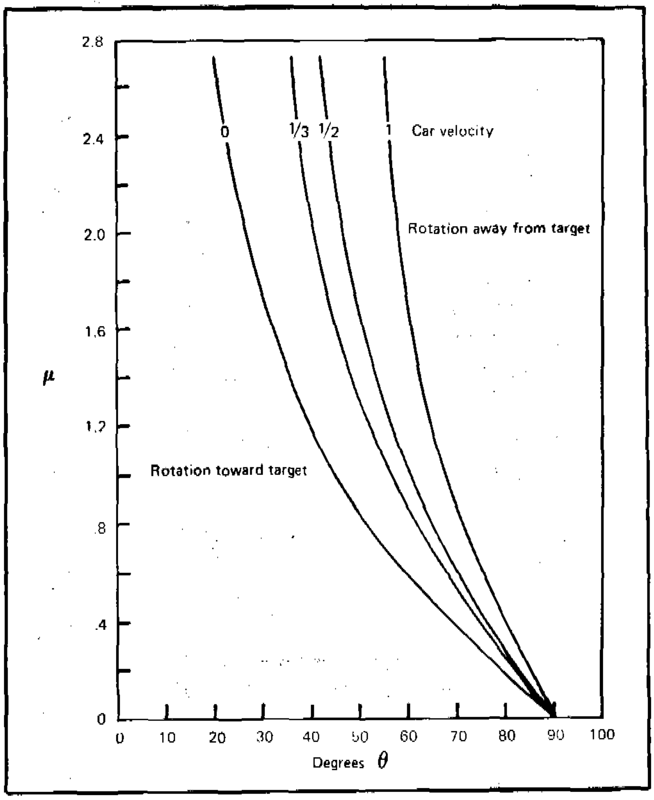

Figure 13. Graph to show the effect of friction on motorcycle rotation for angled impacts into stationary and moving targets.

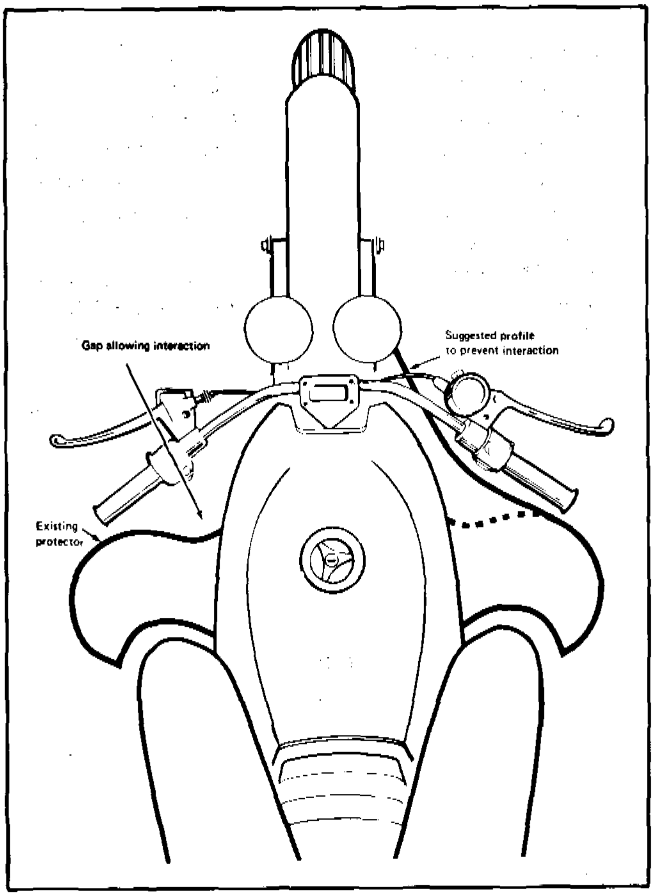

Figure 14. Diagram to show how existing protector can be modified to prevent interaction

towing vehicle and the car as shown in the two illustrations above the main diagram. The pulley block attached to the car is fitted with a metal "skid", which allows the pulley to slide easily along the ground after it has been released.

Simple Representation of a Motorcycle Impact

Previous work has shown that the coefficient of friction, which is generated on impact between a motorcycle and its target, greatly affects the subsequent motion. In order to study this a simple theoretical model was derived from which could be predicted some possible differences between the test procedure with a stationary and a moving target. The friction affects the findings.

Fig. 12 is a diagram of a simplified motorcycle during an oblique impact with a stationary target. The motorcycle is assumed to be equivalent to a blunt rod with a deformable front end which will crush during the contact period. μ_1 is the coefficient of friction between the motorcycle and the target and μ_2 the coefficient between the rear tyre and the road. R_1 is the reaction at the target face and R_2 the reaction between the rear wheel and the road. Mb is the mass of the bike at the centre of gravity and $r_1 r_2$ define its position relative to the front and rear tyre contact points. Ib is the moment of inertia of the motorcycle in yaw when it is assumed to rotate about the front forks. ϕ is the impact angle of the motorcycle relative to the target and the Θ angle moved through at a given time.

The motion most critical for leg injuries is rotation and using the equation of rotational motion (Inertia $\times$ angular acceleration = Torque) gives (i) below,

$$\text{Ib}\,\ddot{\Theta}_t = \big(R_1 \cos(\phi - \Theta)\big)\, r_1 - \mu_1 R_1 \operatorname{Sin}(\phi - \Theta)\, r_1 - \mu_2 R_2 r_2 \quad \ldots \quad (1)$$

(N.B. The front wheel is assumed to be parallel with the target face and rolling with zero friction.) If leg injuries are to occur the rotation on impact is towards the target face so that the motorcycle slides along it, i.e. anticlockwise in fig. 13 and this depends on μ_1

at impact $t = O$ and $\Theta_o = O$ and (1) becomes

$$I_b \Theta_o = R_1(\cos(\phi) r_1 - \mu_1 R_1 (\operatorname{Sin}\phi)\, r_1 - \mu_2 R_2 r_2$$

Rotation towards (turning parallel to) the target will occur if Ib Θ_o is positive. $\mu_2 R_2 r_2$ reacts only to oppose the motion and is zero when $t = O$, therefore IbΘ_o will be positive if $\mu_1 R_1 (\operatorname{Sin}\phi)\, r_1 < R_1 (\cos\phi)\, r_1$

$$\text{ie } \mu_1 < \cot\phi$$

Consider the motion of the motorcycle relative to a moving target. The resultant velocity of the motorcycle can no longer be considered to be acting along its longitudinal axis and if the resultant impact velocity is at the same angle ϕ relative to an equivalent stationary target then the motorcycle must be orientated at an angle less than ϕ i.e. "crabbed" as illustrated in fig. 13.

Fig. 13 shows graphs of the resultant impact velocity angle (relative to the target) against the friction coefficient critical to the direction of rotation, and illustrates that for a given coefficient, rotation toward and along the target (leg injurious) can occur over a greater range of impact angle if the target is moving. The extent of the range depends on the ratio of the motorcycle and target velocity, and the ratios available for the practical tests are (target car velocity-/motorcycle velocity) = 0 (car stationary), $\frac{1}{3}$, $\frac{1}{2}$, 1. The graphs in figure 13 correspond to these ratios and when compared indicate that a static target at 30° (test condition) provides the conditions for rotation equivalent to a moving target at 44° ($\frac{1}{3}$), 49° ($\frac{1}{2}$), and 60° ($\frac{1}{1}$) for a coefficient of friction less than 1.7. The rate of rotation depends on the resultant impact velocity, and for one of 53 km/h (33 miles/h) the motorcycle will be travelling at 40 km/h (25 miles/h) when the target is doing 20 km/h ($12\frac{1}{2}$ mph) and the relative angle is 30°. The resultant velocity for 45° is 48 km/h (30 miles/h). It can be said therefore that an impact into a stationary target at 48 km/h and a 30° angle is approximately the same as an impact at 40 km/h into a target moving at 20 km/h at a 45° angle if the friction generated is the same.

(It is interesting to note that an accident study (7) has shown that the mean speeds for motorcycle to car collisions are 39 km/h for the motorcycle and 23 km/h for the car. This is for an injury based sample.)

Figure 14 shows that a high value of friction greatly reduces the chance of rotation, and this is known from tests to be detrimental to the head. A low coefficient greatly increases the chance of rotation which is known to be detrimental to the legs.

An optimum is required and a correctly designed energy absorbing fairing will provide this.

Results—Moving Target Car

In both tests the step-through stopped rapidly, and although the impact with the modified machine was the less violent, it demonstrated a known design weakness in the current protector which allowed more interaction with the car than is desirable. This occurred because the curvature adjacent to the machine bends to the rear. This can be easily corrected as shown in fig. 14.

The leg damage is not fully analyzed but a subjective assessment indicates a similar result for both tests. However a substantial indent in the side of the car wing caused by the knee of the rider of the unmodified machine indicates that serious knee-femur-hip injury might have been sustained.

The head and chest accelerations are given in Table 1 and the motorcycle angular velocities in figs. 8 and 9. The H.I.C. indicates a fatal head injury for the rider of the unmodified machine whereas with leg-protectors fitted the value was well below 1000. The chest acceleration is slightly higher for the modified machine but is non-fatal. This is preferable to a fatal head injury.

The angular velocity is high for the unmodified machine, and had the impact occurred further across the front of the car the leg would probably have sustained extensive damage.

Conclusions

Tests with static and moving targets have shown that leg protection can affect a reduction in a motorcycle rider's potential leg and head injuries. The trajectory of the motorcycle during the impact is important as this has a marked effect on the trajectory and hence the potential injuries of the rider.

The potential for leg injuries increases as the yaw angular velocity increases. The potential for head injuries tends to increase as the yaw angular velocity decreases probably because this is related to pitching and high motorcycle deceleration. High friction and interaction cause this situation which can be readily predicted theoretically. Correctly designed energy absorbing leg-protection can control the trajectory of the motorcycle rider, induce an optimum motorcycle yaw angular acceleration and hence minimize a rider's injuries. Performance criteria for leg-protection can now be specified for all sizes of machine, and will be published as a separate paper.

It has been shown theoretically and practically that a test procedure using a stationary car can represent an impact into a moving target albeit of a different speed and angle.

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A Field Trial of Motorcycles Fitted With an Anti-Lock Brake System (Written only paper)

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Abstract

Although all types of vehicles are subject to skidding, particularly in adverse weather conditions, powered two-wheeled vehicles have the highest incidence of accidents in which it is a factor. The inherent instability of these vehicles makes capsize almost certain if a wheel is locked during braking, leading to risk or injury to the rider. There is a growing body of evidence, both from accident studies and observation of the behaviour of motorcyclists, that riders do not brake in a safe and effective manner. In particular, the front brake is used insufficiently or not at all; this is said by many riders to be because of their fear of the consequences of locking the wheel.

Research into the application of anti-lock brake systems for motorcycles has been conducted by TRRL during the last twenty years. This has demonstrated the possibility of reducing the incidence of skidding and improving braking performance generally by the widespread use of such systems. Research has reached the stage where reliable anti-lock systems are available but little is known about the way in which riders would use them and how they would react to their presence on a motorcycle. TRRL and Lucas Girling Limited have therefore undertaken a joint project to acquire data from a field trial of seven motorcycles equipped with an anti-lock system developed by Lucas Girling. The machines are in use with a number of Police forces and commercial organisations and are expected to cover relatively high mileages during the three year duration of the trial. This paper represents some of the information obtained at the half-way stage of the trial and gives details of reliability and riders' reaction and comments.

Introduction

Evidence of the difficulties faced by riders in the braking of motorcyles was presented at the 10th ESV Conference.(1) There seems to be little evidence that the part played in accidents by inadequate braking is decreasing to a significant extent. Indeed, recent studies(2)(3) of the behaviour of riders suggest that as far as braking technique is concerned there are serious problems. For example, it was observed that even during emergency braking, over 20 percent of riders used only one brake, predominately the rear. During "normal" braking only about half the riders observed by Sheppard et al. used both brakes. Clearly, if this pattern of braking behaviour is widespread, many motorcyclists are not even attempting to brake effectively. In particular, failure to use the front-brake limits the deceleration available to the vehicle. In an accident-study made in Australia(4) it was suggested that 30 percent of the accidents investigated could have been avoided if the available braking capability of the motorcycle had been used.

The reasons why riders brake "incorrectly" are not clear; training or the lack of it does not appear to be a factor according to Sheppard et al. However, many riders in his study expressed a fear of locking a wheel, particularly the front wheel. This is consistent with the fact that over 50 percent of motorcyclists who were interviewed said that they had skidded at some time during their riding career. Clearly the removal of the fear of locking a wheel would contribute to an improvement in the standards of braking of motorcycles in several ways. First, those accidents attributable directly to the locking of a wheel could be eliminated. Second, and perhaps more important, riders would gain confidence in using the braking-performance of their machines to the maximum. This could bring about a reduction in accidents by reducing stopping-distances.

The widespread use of effective anti-lock brake systems on motorcyles seems to be an obvious way of achieving the result discussed above. Such systems have been the subject of research for more than twenty years but little experience exists of their performance in the field. TRRL and Lucas Girling Limited are jointly conducting a field-trial with an anti-lock brake system developed by Lucas Girling. This has involved the fitting of the system to a number of motorcycles which have been distributed to Police forces and commercial organisations.

This is believed to be the first such trial of anti-lock systems on motorcycles, where the requirement for safe and reliable operation is critical because of the inherent instability of such machines.

History of the Trial

On the basis of experimental work which has taken place during the last twenty years(5)(6), it is believed that a wide-spread use of anti-lock brake systems on motorcycles would confer a number of benefits:

i) capsize or loss of control caused by over-braking produced by panic or misjudgment would be eliminated,
ii) steering-control would be retained during emergency braking,
iii) all riders could brake to the levels attained by the most skilled,
iv) removal of the fear of wheel-locking should encourage riders to employ the braking-performance of which their machines are capable.

However, no information exists about the use in the field of motorcycles fitted with anti-lock brake systems. It is possible that there could be problems related to factors such as reliability and rider-acceptance which are not apparent during research and development. At the outset it was clear that the reliable collection of data would be an essential part of the trial. This requires disciplined and methodical recording of vehicle maintenance, defects and mileage. As a result, the Police were approached with a view to taking part and agreed to do so. In addition, a company which uses motorcycles to deliver urgently-required mail agreed to participate.

At present six machines are in use by various Police forces in the United Kingdom, one by Cycle Courier Ltd. and one has toured a number of European countries for assessment by Government authorities. A ninth machine (R1) is based at TRRL for development and demonstration to participants in the trial. Two machines (ESM 2 and ESM 3) have the anti-lock system fitted as one of their safety features. These are exhibited nationally and internationally but have not to date been issued to external users.

Development has proceeded for a number of years and the first machine was issued to Gwent Constabulary in May 1985. Apart from R5, issued to Cycle Courier Ltd, each machine will be assessed by a number of users, each for a period of at least six months. R5 is intended as a high-mileage machine and will be used by Cycle Courier Ltd until it is life-expired.

The Trial Motorcycles

The motorcycles to be issued to external users were bought new, specifically for the field-trail. In the case of machines R1 to R5, it was necessary to fit cast-alloy wheels and convert the rear brake to disc operation, in order to accommodate the anti-lock system. In other respects all machines for use by the Police are to normal Police Specification, the remainder are standard "civilian" machines.

Three models of motorcycle are involved, all of which are in common use by Police authorities. The Cycle Courier Ltd. machine is similar to those normally used by the company. R1 to R5 are BMW R80/R100 machines; K1 to K5 are BMW K100 machines and N1 to N2 are Norton Interpol II machines.

The anti-lock systems were installed and tested by Lucas Girling Ltd. Although three types of motorcycle are involved, the fitting of the anti-lock units was straightforward. This is because prototype units were used which were designed to be applicable to a wide range of motorcycles.

Trial Procedure

After installation and testing of the anti-lock units, the motorcycle was handed over to the user, who was asked to treat the machine like any other in his fleet. (This was one of the reasons why three models of motorcycle are involved. Users have an "anti-lock" machine which is otherwise similar to the remainder of their vehicles).

It was considered that prospective riders of the trial machines would find it interesting to ride the TRRL-based motorcycle on a test-track, particularly as this machine is equipped with safety-skids which allow wheels to be locked without danger. Whenever possible, riders are given practical experience on a test track when each trial machine is handed over. This takes the form of making heavy applications of the brakes both with and without the anti-lock system operating. In this way riders are able to experience the effects of wheel-locking and the way in which an anti-lock system works to prevent it. Subsequently the value of this period of "tuition" became apparent and will be discussed later.

Information is obtained from the trial in several ways. Each rider is asked to complete an assessment form after having ridden the trial machine for a period of time. (Figure 1). This seeks subjective opinions about various aspects of the anti-lock system and its installation and also invites more general comments. In addition, each participant is visited periodically by a representative of Lucas-Girling Limited or TRRL to monitor progress. Problems or failures which are related to the anti-lock systems are rectified as they occur and a record made of their nature. In March 1987, an informal meeting of all past and current participants was held to discuss the progress of the trial. It is likely that this will be repeated at the conclusion of the trial. Figure 2 shows the history to date of each participating motorcycle.

Results

The rider-evaluation form seeks subjective ratings on a scale of one to ten of various features of the anti-lock brake installation. Figure 3 is a summary of these ratings based on the forms received to date. Figure 4 lists briefly the comments which riders added

Motor-cycle reg'n. no. ____________________

Motor-cycle Anti-Lock - Rider Evaluation sheet

Name .... Age ....

Riding Experience .... Current m/cycle (prior) ....

Test date .... Weather conditions ....

Test route summary ....

Assessment of Anti-Lock

Rating. (F=Front, R=Rear, if different)

Not acceptable. Satisfactory. Very good.

	1	2	3	4	5	6	7	8	9	10
1 Lever pulsing										
2 Fork vibration										
3 Vehicle drive										
4 Vehicle control										
5 Performance - dry road										
6 - wet road										
7 - slippery road										
8 - normal braking										
9 General brake feel										
10 Installation concept - packaging										

General comment:

e.g. Do you like this system? Does it have a future? Do you favour anti-lock for cars, and/or motor-cycles? Would you buy it? How much would you pay? Any comments from above rating chart? Critcisms ? (Attach sheet if necessary)

Figure 1. The rider evaluation sheet

to the assessment forms. These can be divided into "unfavourable" and "favourable." The most common unfavourable remark concerned excessive suspension "dive", particularly with one model of motorcycle. This, of course, is a feature of the design of the motorcycle itself. It is likely that the cyclic action which occurs when the anti-lock system functions will accentuate such characteristics of the vehicle suspension.

A number of riders criticized the appearance of the anti-lock units. At this stage of development it is an essential feature that the system should be applicable to a variety of motorcycles. For this reason the belt-drive arrangement was adopted; in a production version the system could be incorporated into the motorcycle as part of its overall design and styling.

One rider remarked that he was concerned that even though he felt that the system was excellent, it would lead to riders becoming "lazy" because they would not need to consider correct braking technique.

The final form of adverse comment concerned pulsation of the brake controls during anti-lock operation. This is, in fact, a deliberate feature, intended to make the rider aware of the fact that he is overbraking and its absence is an important indication of internal failure of the actuator. In addition, riders learn to assess the degree of slipperyness of road surfaces without risk, because the level pulsation provides an indication.

Favourable comments were less specific than the unfavourable ones. Fifty percent of riders (20) said specifically that they felt anti-lock systems should be a

MACHINE	DATE	MILEAGE	NOTES
R1	Jan. 84	600	Anti-lock installation complete. General development, system-tuning for optimum performance.
	Feb. 87	3000	Demonstrations, research for legislative tests, tuition of participants in field-trial.
R2	Mar. 85	-	Anti-lock installation complete. Experimental safety motorcycle, ESM2, exhibited nationally and internationally.
	Feb. 87		
R3	Nov. 85	160	Issued to Avon and Somerset Constabulary.
	Mar. 86) May 86)	1000- 2100	Loose steering-head bearings, run-out of front brake-disc (replaced).
	Aug. 86	4000	Issued to Devon and Cornwall Police - satisfactory.
R4	Nov. 85	230	Issued to Thames Valley Police. Loose steering-head bearings at 1000 miles.
	Dec. 86	7000	Issued to Northern Ireland Police Authority.
	Feb. 87	8300	Rear wheel lock at low speed caused by ingress of dirt into flywheel sensor - rectified, now satisfactory.
R5	Mar. 86	810	Issued to Cycle Courier Ltd. Loose steering-head bearings at 6000 miles.
	Dec. 86	28000	Rear anti-lock unit seized because of ingress of dirt into flywheel-shaft bearings - belt failed but normal braking retained.
	Feb. 87	40000	Satisfactory.
K1	Mar. 85	600	Anti-lock installation complete - General development and optimisation tests.
	Aug. 85) Feb. 87)	1500 6000	Evaluation by Government authorities in Holland, France, Germany and UK. - Dirt ingress to front unit sensing mechanism after steam-cleaning.
K2	May 85	150	Issued to Gwent Constabulary - Use restricted by problems with radio interfering with engine-management system.
	Aug. 85	3620	Modified rear anti-lock mounting-bracket fitted.
	Apr. 86	11000	Wear problem with drive pulleys - replaced by steel.
	Jan. 87	21000	Leak in flexible hose in rear brake - replaced. Performance satisfactory.
K3	Aug. 85	500	Issued to Lancashire Constabulary.
	Nov. 85	2700	O-ring leak in rear unit - replaced.
	Dec. 85	4800	Mounting bracket of rear unit redesigned after fixing-bolt became loose. - All similar motorcycles modified.
	May 86	9000	Vehicle destroyed in road-traffic accident - not related to braking.
K4	Aug. 85	180	Issued to Sussex Police - Satisfactory.
	Sept. 86	6000	Issued to Essex Police - Satisfactory.
K6	Feb. 87	100	Ready for issue to Thames Valley Police - replacement of K3.
N1	Mar. 86	1200	Issued to Gwent Constabulary.
	Jun. 86		Issued to Hampshire Constabulary - Satisfactory.
	Nov. 86		Issued to Strathclyde Police.
N2	Aug. 86	13000	Anti-lock installation complete. Vehicle to form basis of experimental safety motorcycle ESM-3.

Figure 2. History of participating motorcycles

standard fitting on motorcycles. Although cars were not involved in this trial, eight riders volunteered the comment that they too should be equipped with anti-lock brakes as standard. Seventeen riders stated that they would be prepared to pay for an anti-lock installation on a motorcycle. Five of these specified a price between £140 and £400, representing approximately 3 percent and 10 percent of the cost of the motorcycle itself. The remainder did not specify a price that they would pay. Several riders commented that they thought the widespread use of anti-lock brakes on motorcycles would be a major contribution to safety.

It is interesting to note that even of those riders who were not enthusiastic, none was wholly unfavourable in his comments.

Reliability

The motorcyles in the trial have, to date (March 1987), covered a total of 200,000 km (125,000 miles) without a failure causing a locked wheel incident. There have been several instances of difficulties caused by failures associated with standard components of the motorcycle and with the ancillary equipment of the anti-lock systems. Examples of the former are: distored brake discs, looseness of steering-head bearings, worn brake discs. Each of these caused symptoms which riders attributed wrongly to the operation of the anti-lock system.

The most serious problem with installation has concerned the security of the mounting bracket of the rear anti-lock unit on one model of motorcycle. A modification which incorporates additional fixing-screws was made and appears to be satisfactory. The second problem with the installation of the anti-lock units has been as a result of the ingress of water and grit. This is known to have occurred on two motorcycles; K1 while it was touring Europe, and R5, based with Cycle Courier Ltd. In the first case, dirt and water penetrated the flywheel cap of the front unit during cleaning of the machine and caused the flywheel mechanism to stick. It appeared that the cap had been removed and replaced, leading to poor sealing. In the case of R5, the bearing of the flywheel shaft of one unit seized as a result of water ingress and caused the drive-belt to fail, at 45,000 km (28,000 miles). It is known that this machine is steam-cleaned regularly; as a result road-wheel bearings are changed at 5,000 mile intervals by Cycle Courier Ltd. because of problems similar to that which affected the anti-lock unit.

It should be noted that none of the above faults resulted in loss of braking; at worst, the anti-lock capability was lost.

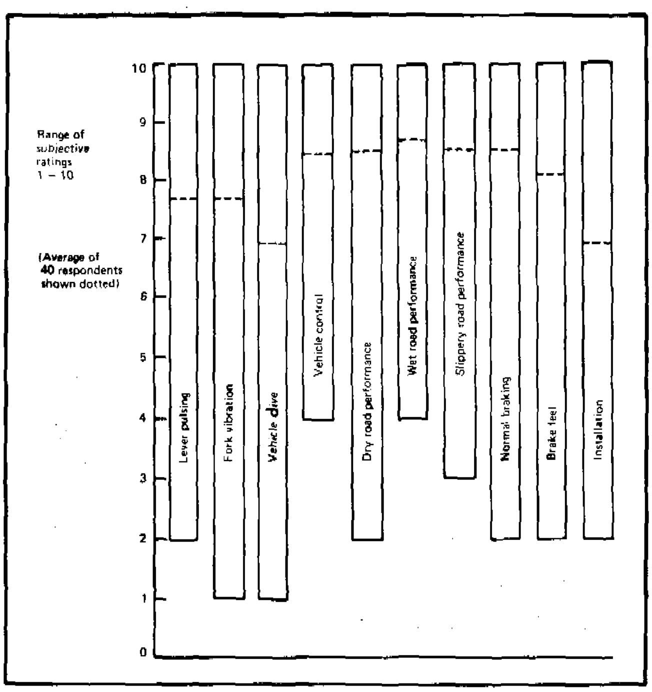

Figure 3. Summary of riders' subjective opinions of ten aspects of the anti-lock system

Assessment of use of anti-lock

A piece of useful information which could be obtained from a trial of this type is the extent to which an anti-lock system is called upon to operate, i.e. what is the proportion of brake-applications in which the system intervenes. Unfortunately it has not been possible to devise a simple and satisfactory means of recording, bearing in mind that the motorcycle provides a difficult environment for instrumentation and that the machines are not available to the trial managers on a day-to-day basis. This is recognised as a failure of the trial to date. Efforts are continuing to find a way of obtaining the information. Similarly, it is accepted that even if this information does become available later in the trial, it will not necessarily provide an indication of the level of anti-lock "use" to be expected of typical riders. This is because the riders involved in the trial are all highly- trained and have considerable experience.

A possible advantage of the delay in collecting use-data is that the "novelty effect" of riders initially experimenting with the system should be absent.

Discussion

The purpose of field-trials of novel equipment is to establish what problems arise as a result of failings of concept or reliability. In this trial the opportunity was taken to seek the subjective opinions of riders. It is accepted that the riders involved are all professional motorcyclists, mostly Police officers, and that their comments and riding-behaviour are not likely to be representative of the motorcyclist population. However, the methodical nature of the systems of maintenance and recording used by the police and similar organisations is invaluable in the collection of data, particularly when close supervision is not possible.

The problems associated with reliability have been discussed above. These have been of an innocuous nature generally and have involved a loss of anti-lock capability as a worst consequence.

Slight changes to some features of the anti-lock units and their associated mountings appears to be all that is necessary to overcome the problems which have arisen to date.

Riders have, in general, been favourable in their reaction to the advantages which anti-lock can confer. This is encouraging when the fact that these riders are trained professionals is considered. Many appeared to be set against the anti-lock system at the outset, expressing the view that "we don't need it," for example. This emphasizes the importance of educating potential riders regarding the working of the system and what it is intended to do. It is significant that riders from one Police force who had not been able to take part in a test track riding-session prior to riding the field trial machine were the most vehement in their condemnation of the system. It was unfortunate that their machine was one which had problems with distorted brake-discs. The effects of this were attrib-

1. System should be fitted to all new motorcycles. (20 riders)
2. System should be fitted to all new cars. (7 riders)
3. At all times the machine remained under control.
4. Would purchase an anti-lock system for own motorcycle. (17 riders)
5. A great advantage in rider safety. (7 riders)
6. Effectiveness for outweighs initial cost.
7. Excellent in the wet.
8. System prevented accident on wet road in London.
9. Would expect to see such a system as standard on large machines in future.
10. An advanced rider would never be in a position to need anti-lock.) made by
11. When the anti-lock system was caused to operate it did prevent a major rear-wheel skid.) same rider
12. I can find no criticism of the system at all.
13. To be able to retain full control on slippery road under heavy braking is reassuring.
14. Rear anti-lock operation is jerky.
15. If needed only once in a lifetime could be a life-saver.
16. Good apart from vehicle dive.
17. System needs to look less clumsy.
18. System looks unattractive and gave unacceptable "grab and notchiness" (Result of disc run-out)
19. System quite good but would have benefitted from fitment of anti-dive forks.
20. Steering-head bearings needed tightening 3 times in 1500 miles.
21. For Police use not really necessary because of high standard of training.
22. A good idea for members of the public but could give a false sense of security.
23. Light suspension of vehicle gave unacceptable effect with anti-lock.
24. Amazing to experience the difference after replacement of defective brake discs.
25. Gave the confidence to ride hard and brake hard.
26. System excellent but will make normal riders lazy.
27. Overall a good system worth improving with a package which is neater.
28. System allows full use of front brake and will give good deceleration.
29. Too easy to bring rear anti-lock system into operation because of load-transfer.

Figure 4. Summary of main comments made by riders

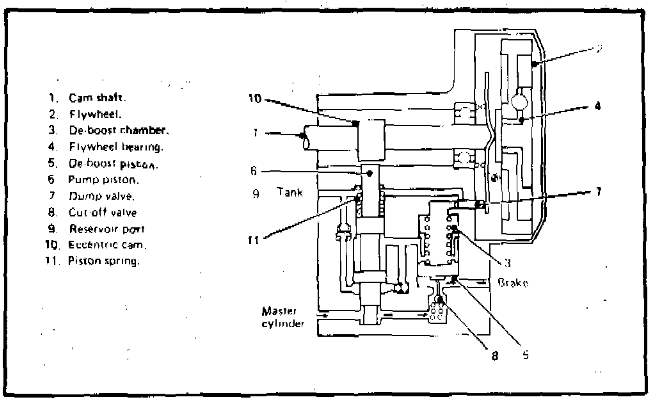

Figure 5. Sectional view of anti-lock brake unit

uted to the operation of the anti-lock system, probably because riders had not experienced the system working without these external influences. A retrospective test-track session was arranged for these riders, who then reversed their opinions. The need for particularly carefully-worded instruction material is apparent when such systems become available widely. Similarly problems and doubts have been expressed following a field trial with anti-lock fitted to passenger cars.(7)

Several problems and areas of adverse comment by riders have arisen as a result of defects in components of the motorcycle itself. Similarly, incompatibility between the operation of the anti-lock system and characteristics of the motorcycle has been a problem. These have arisen because the motorcycle and the anti-lock system have not been designed as an entity. This is inevitable at this stage; in a production form these failings would be eliminated by design.

Conclusions

1. The results to date of this trial have shown that the anti-lock system on the motorcycles has always worked correctly. Problems have concerned failings in ancillary components.
2. Some motorcycles seem to be more suitable than others for the installation of anti-lock. Careful choice of suspension characteristics to prevent exaggerated movement during cycling of the anti-lock system appears to be essential. Similarly the design of such components as steering-head bearings should be such that the cycling of anti-lock systems does not lead to the need for frequent adjustment. It was reported that with one model of motorcycle used in the trial, the use of police radio equipment interfered with vehicle electronic systems such as fuel-injection. This, perhaps, reinforces the decision to select mechanical rather than electronic anti-lock for motorcycle use.
3. It appeared to be essential to educate riders about what to expect of anti-lock systems. This has important implications when anti-lock becomes available commercially on a widespread basis.
4. The trial has been important in convincing interested parties of the viability of anti-lock under the arduous conditions of a motorcycle in the field. It has lead to interest being shown by major motorcycle-manufacturers and by potential users. For example, Essex Police have a policy of using anti-lock equipped vehicles throughout; the trial has convinced them that it is possible to extend this to their motorcycle fleet.

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Appendix

The Anti-Lock System

The system fitted to the motorcycle used in this trial was developed and manufactured by Lucas Girling Ltd. specifically for motorcycles. Although electronically-controlled systems were already manufactured by the company for use in cars and commercial vehicles, it was decided at the outset that the motorcycle system should be mechanically based. This was considered suitable for the following main reasons:

i) low cost,
ii) compact, self-contained unit,
iii) not affected by electrical system of vehicle or external electromagnetic interference,
iv) simple adjustment and servicing,
v) reliability in harsh environment of motorcycle.

A single hydro-mechanical assembly is interposed in the hydraulic line between the master cyclinder and the brake caliper, usually adjacent to the road-wheel (Figure 5). (An anti-lock unit is necessary for each road wheel which requires control.) A shaft within the unit is driven directly at a fixed ratio from the road wheel. In the case of the machines used in this trial, this drive is accomplished by means of a toothed belt. Two functions are performed by the rotating shaft:

i) to drive a cam-operated pump which provides hydraulic pressure for brake reapplication.
ii) to carry a small flywheel which senses road-wheel deceleration and acts as a speed reference.

Operation of the System

During braking which occurs at a level below the limit of tyre/road adhesion, brake-fluid passes uninterrupted through the anti-lock unit and applies pressure to the caliper in the normal way.

If braking is excessive, the flywheel overruns its shaft and causes the dump valve (7) to be opened, allowing fluid-pressure at (3) to fall. A pressure differential then exists between (5) and (3) and causes the deboost piston (5) to retract. The supply from the master cyclinder is isolated by the closure of the cut-off valve (8). These events result in a controlled reduction of brake-pressure and allow the road-wheel to return to a safe condition.

The fall in pressure at (3) causes the pump (6) to be forced into contact with a cam on the flywheel shaft. Fluid is circulated through (3), (7) and a reservoir port (9) back to the pump. When the road wheel has recovered, dump valve (7) closes and causes the pump (6) to re-pressurise the chamber (3) and move the piston (5) to reapply the brakes. This sequence of events continues until the vehicle comes to rest or the rider reduces the brake-force.

A more detailed description of the system has been published (CART 1985).

Safety Considerations of Motorcycle Lighting At Night (Written only paper)

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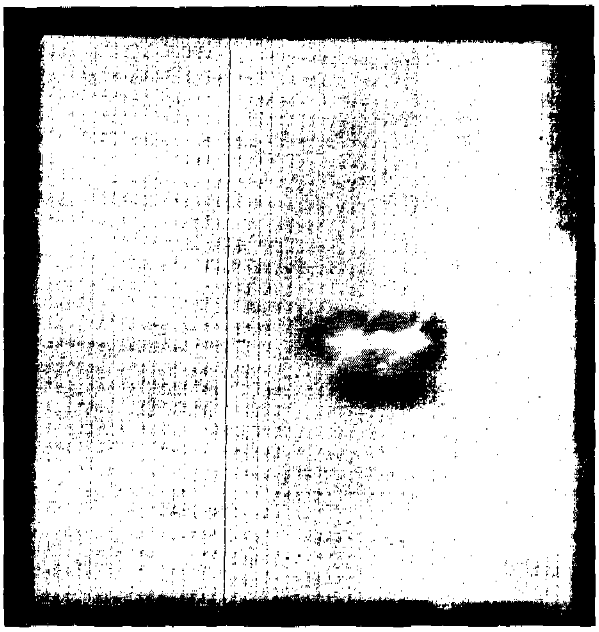
Abstract

Studies have shown that a large proportion of motorcycle accidents involve another road user's failure to see an approaching motorcycle. At night some of these accidents are associated with the misinterpretation of the visual cues given by motorcycles. These problems might be alleviated by the use of appropriate lighting displayed at the front of the motorcycle. Experiments have been conducted in darkness to discover what type of lighting-arrangements assist road users to see and make correct judgments about motorcycles in traffic conditions. Results showed that the detectability of motorcycles is related to the intensity and beam-pattern of the headlamp. Lighting which helped to define the form of the motorcycle, used in addition to the headlamp, aided identification in traffic. Although the use of daytime running lamps, in various forms, was found to be of no benefit at night it should not be inferred that specifications for improving lighting for day and night use are necessarily incompatible.

The functions of lighting on motorcycles

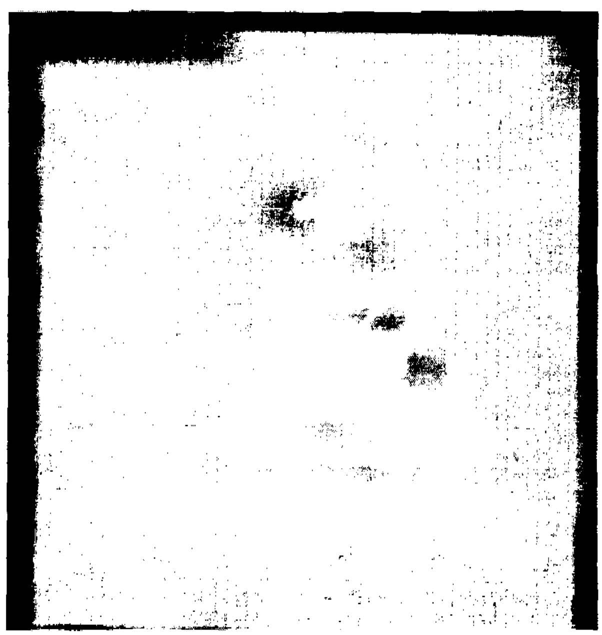
Lighting equipment on the front of motorcycles has two main purposes: to indicate the presence of the motorcycle to other road-users and, in darkness, as a source of illumination to enable riders to see their way and avoid obstacles.

The principle source of illumination at night is the headlamp. In well-lit streets at night and, of course,



Running lamps.

Illuminated legshields.



Striplights.

Figure 1. The special lighting arrangements

in daylight the role of the headlamp is primarily that of indicating the vehicle's presence.

Considerations of vehicle lighting as a means of providing illumination are well-documented, for example(1)(2)(3). This paper is concerned with those aspects of motorcycle lighting which contribute to the indication of the vehicle's presence at night. The relative advantages of standard and novel forms of lighting for motorcycles are discussed.

Nighttime accidents and lighting

It is now accepted that a major factor in accidents which occur in daylight is the failure of road-users to see motorcycles in time to avoid a collision. A similar problem exists at night. Evidence of this is provided by detailed studies of accidents(4)(5)(6).

These studies indicate that in about one third of all collisions between motorcycles and other vehicles, the driver of the other vehicle claimed to have not seen the motorcycle prior to the accident. Using 1985 data it is estimated that approximately 15,000 accidents are of this type each year in Britain. Of these, approximately 3,000 occur during the hours of darkness. The accidents occur mainly at junctions, in urban areas with well-lit streets and involve manoeuvres in which other vehicles infringe the motorcycle's right-of-way.

Even though the use of motorcycles is much less at night than it is during daylight, it was estimated in the studies mentioned above that about one third of all accidents which involved a motorcycle occurred during the hours of darkness.

The evidence from accident studies suggests that, as in daylight, a significant proportion of motorcycle accidents is associated with some kind of perceptual error on the part of another vehicle's driver. But, unlike the daytime problem where it appears that drivers overlook the motorcycle, the difficulty of seeing motorcycles at night is complicated by errors in identification and interpretation as well as in simple detection. This indicates that there are several different ways in which good motorcycle-lighting should assist other road-users at night.

i) detection—it should be easy for other road-users to detect motorcycle lights against the background of other lights at night, both those on vehicles and from other sources such as shop windows and signs.

ii) identification—it should be possible to recognise the light as signifying a motorcycle; by virtue of their size and performance, motorcycles behave differently from other vehicles. Hence, misinterpretation of a motorcycle light as belonging to another type of vehicle can have dangerous consequences.

iii) judgment of location and speed—these judgments are more difficult to make about all vehicles at night than in daylight because visual cues are more restricted. The design of lighting must not add to difficulties in interpretation; if anything it should aim to assist these judgments. Currently in Britain, and in most other countries, motorcycles are required to display only a single headlamp during darkness. This arrangement has a number of disadvantages with regard to the important functions described above:

in detection: most other vehicles have two headlamps, many of which are also larger and more powerful than those fitted to motorcycles. This makes motorcycles comparatively difficult to detect.

in identification: motorcycles have only one headlamp and are thus likely to suffer misinterpretation because of fewer visual cues.

in speed and location judgment: there are special problems for motorcycles because the major visual cue of changing angular-separation between fixed points is not provided by a single lamp.

Hence it appears that the existing front lighting arrangement for motorcycles is not performing its function of providing the information required by other road-users at night. As a consequence, attempts have been made to investigate how existing lighting

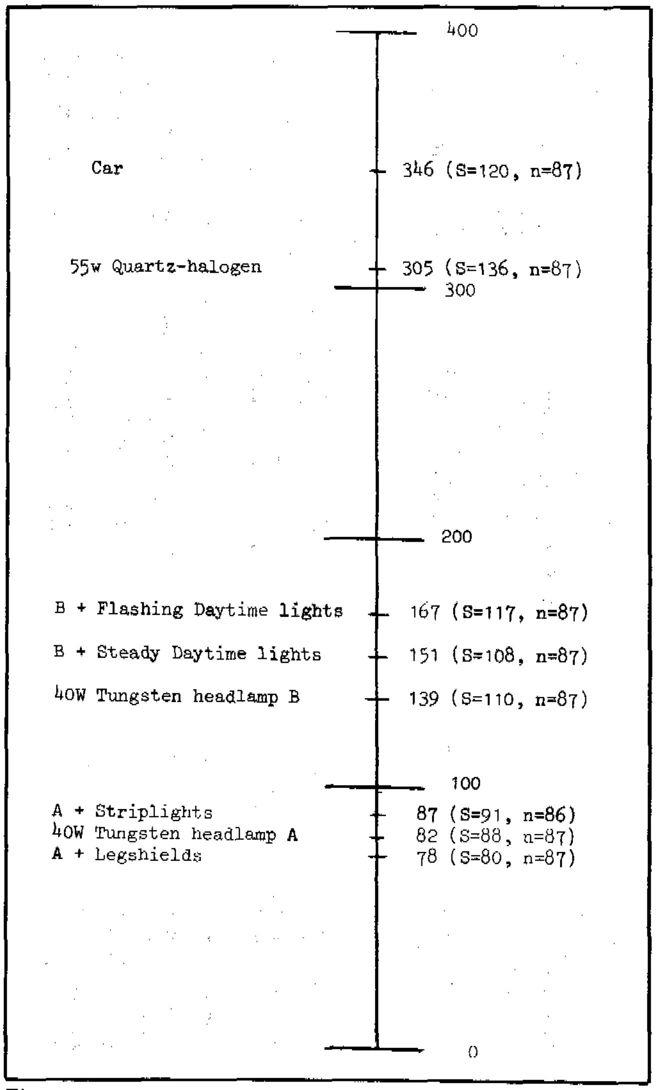


Figure 2. Results of peripheral-detection experiment Mean detection distances (m) from subjects' position (2 Motorcycles, A and B, were used with nominally-similar 40 watt headlamps). (S is standard deviation, n is number of observations)

might be modified, or supplemented, to make it more effective in meeting these requirements.

Experimental studies in lit streets at night

Various lighting arrangements were selected and tested to examine the ways in which they might contribute to the ease and accuracy with which observers perceived motorcycles.

Single headlamps of various powers (up to 55W quartz-halogen) and size (up to 180mm in diameter) were tested, both in steady-state and modulated form (at 3-4 Hz). These were also tested coloured by a yellow filter intended as a means of providing a unique signal to indicate a motorcycle. Various lamps were used in conjunction with the single headlamp in order to provide both additional illumination and a pattern of lights peculiar to motorcycles (Figure 1). These included the existing amber front direction-indicator lamps, wired so that both were permanently illuminated; pairs of handlebar-mounted daytime running lamps, both white and with yellow filters, steady-state and flashing; a pair of 300mm long strip-lights mounted vertically, one alongside each fork leg. The final arrangement used with the existing headlamp was a pair of white legshields, illuminated by a pair of running lamps. This and the strip-light arrangement were selected because they were believed to convey information about the form of the motorcycle to assist identification as well as providing additional light.

These lighting arrangements were tested in a series of experiments, each concerned with one aspect of the visual problem.

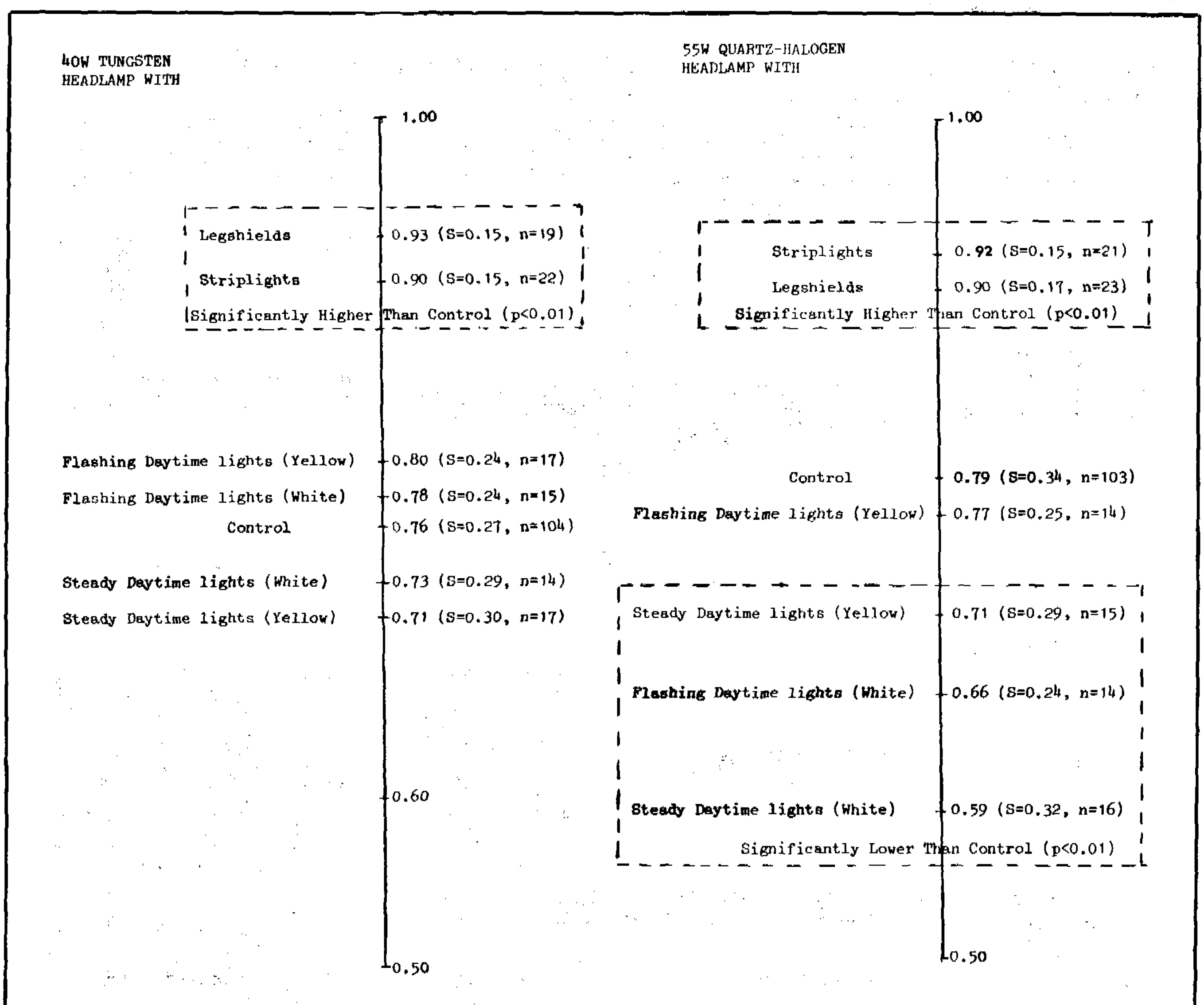


Figure 3. Results of identification experiment Mean proportion of correct identification of motorcycle. (S is standard deviation, n is number of observations)

The first was a peripheral-detection test. Observers were given a task to occupy their central visual-field and asked to indicate when they were aware of a vehicle which approached at an angle of 60° to their line-of-sight. The distances at which the motorcycle was detected were used as the measure of the detectability of the lighting-arrangements. A car was used to provide a control condition.

The second experiment was concerned with vehicle identification. Observers were given brief glimpses of groups of approaching traffic constituted in different ways, sometimes including the test motorcycle as the leading vehicle. They were asked to identify the leading vehicle. The test measure was the proportion of correct responses.

The third series of trials examined judgment of speed and location in two experiments. In both, the test motorcycle travelled towards observers at a range of predetermined speeds between 25 and 60 mile/h. In one experiment the motorcycle was obscured from the observers' view at a distance of 50m, and they were asked to judge the time for the motorcycle to reach them, without the aid of any further information, either visual or audible. In the second experiment, observers were asked to estimate approach-speeds.

Results from all these trials may be summarized, as follows:

i) Peripheral detection. (Figure 2). Most of the experimental arrangements were not as detectable as the car (control condition). It was evident that to improve the detectability of motorcycles it is necessary to increase the amount of light reaching other drivers' eyes. To achieve this the most simple and effective way is probably to increase the intensity of the motorcycle's headlamp rather than apply additional lighting. However, it is not as simple as just increasing the power output. The lamp's beam pattern is as important in determining the amount of light which reaches an observer's eye. For instance, it has been shown that a relatively low-powered lamp with an ill-defined beam-pattern can produce more light at an observer's eye than a 55 watt quartz-halogen lamp with a well-controlled beam. Stroud et al(1986). An ill-defined beam-pattern has serious disadvantages in respect of illuminating the road ahead for the rider. More light at an observer's eye should be achieved by using a high-intensity lamp with a well-defined beam.

ii) Identification of motorcycles in traffic (Figure 3). Motorcycles with illuminated legshields or striplights in addition to a headlamp were identified correctly in approaching traffic significantly more often than motorcycles using a headlamp only. Running lamps of both colours (white and yellow) and flashing white lights, each of which, in conjunction with the 55 watt quartz-halogen headlamp, performed significantly worse than the headlamp alone.

The effect of the illuminated legshields and the striplights was beneficial with either a standard 40w headlamp or a 55w quartz-halogen headlamp. Either arrangement used in combination with the latter headlamp would have the additional benefit of enchancing an observer's peripheral-detection performance.

The illuminated legshields and striplights performed equally well. From a practical viewpoint the legshields and the lamps used to illuminate them have the advantage that they are standard motorcycle accessories.

iii) Speed judgement (Figure 4). Experiments on speed judgement confirmed the findings of other research about peoples' tendency to underestimate high speeds. This was independent of vehicle type and lighting. The speed of the control motorcycle was underestimated to the greatest extent but this was generally not statistically-significant. In some circumstances, motorcycles using daytime running lamps (white or yellow, steady or flashing) had their speed estimated more accurately than those with only the control condition. However, this was not consistently the case.

On the whole, the results of these trials suggest that there would be advantages to be gained by increasing the light-output from motorcycle headlamps and from illuminating the form of the motorcycle. In the trials, the latter was achieved by illuminating legshields or by providing additional lamps which described the motorcycles' shape. These measures appear to offer improvements in both the detectability and the identification of motorcycles.

Introduction of dim/dip lighting

There is an interesting post-script to the work described above which could affect the needs of motorcycle lighting at night. A change was made to the U.K. lighting regulations which required vehicles sold after October 1986 to be fitted with the means to dim the dipped-beam of their headlamps to an intensity of approximately 10 percent of normal. This is combined with changes in vehicle-wiring which make it impossible to drive with only parking lights in use and drivers are encouraged to use the dimmed beams in well-lit areas at night. The purpose of the change in regulations is two-fold. First, it prevents vehicles being driven with only parking lights in use. Second, there should be a reduction in the problems which are presumed to arise as a result of glare produced by normal dipped headlamps when they are used in well-lit streets. Motorcycles are not included in the new regulation. TRRL with ICE has investigated the implications of allowing motorcycles to continue to be ridden at night, using a normal dipped-beam. (7). The experimental findings suggest that motorcycles should gain an advantage over other vehicles in terms of detection and judgement of their speed. This is because motorcycles will retain the intensity of their normal dipped beams in conditions in which other vehicles may use dimmed dip, i.e., in lit built-up areas. It is in these that the majority of multi-vehicle collisions occur. Detection of the motorcycle is essential before any other judgement can be made.

Conclusions

From the foregoing consideration of motorcycle lighting in well-lit conditions at night, the following conclusion can be drawn:

There appear to be benefits to be gained from motorcycles using a large and powerful headlamp at night. With currently-available designs of headlamp this means a lamp of at least 180mm in diameter and of 40w power, with a well-defined beam-pattern. The use of a headlamp of at least these dimensions has been shown to have advantages in daylight also.

The use of some types of accessory lamps has been found to have advantages. Unfortunately, those which are recommended for use in daylight—i.e., front directed daytime running lamps—are not beneficial at night. In fact, they have been shown to have a detrimental effect on correct identification of motorcycles in traffic. This conflict should not, however, be regarded as indicating that lighting-systems for day and night use are inherently incompatible. Those forms of additional lighting which were found to be advantageous at night (those which provided information about the shape of the motorcycle) have not been assessed in daylight. Moreover, one of these, the illuminated fairing, used a pair of running lights although in a different orientation from their daytime use. These findings should be regarded as a stimulus to the design of forms of lighting which can meet the night time requirements of motorcycles and be compatible with the needs of daytime conspicuity.

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