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**THE TRAJECTORIES OF PEDESTRIAN DUMMIES STRUCK BY CARS OF
CONVENTIONAL AND MODIFIED FRONTAL DESIGNS**

by

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**Any views expressed in this Report are not necessarily
those of the Department of the Environment**

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THE TRAJECTORIES OF PEDESTRIAN DUMMIES STRUCK BY CARS OF CONVENTIONAL AND MODIFIED FRONTAL DESIGNS

ABSTRACT

Preliminary studies of car impact into pedestrians are reported and these form part of a continuing investigation. The influence of the front-end configuration of cars on the trajectories of dummy pedestrians which they hit has been determined both for the front-ends of conventional cars and for experimental designs.

Tests with conventional cars at nominal impact speeds of 8, 16 and 24 km/h showed that while the adult pedestrian folded over on to the bonnet before falling off, the child was knocked down. Reducing the height of the bonnet sufficiently to pick up the child causes the adult to strike the windscreen.

The simplest method of reducing pedestrian injury is to adopt a front-end which provides optimum trajectories for the adult, and to provide suitable energy absorbing designs for the leading edge of the bonnet and the front face of the bumper.

To pick up both child and adult dummies on the bonnet and retain them requires a sloped front-end and a device which positively lifts the child at low impact speeds. An experimental front-end and catcher has been developed for the purpose which performs satisfactorily at impact speeds up to 16 km/h.

1. INTRODUCTION

On the roads in Great Britain in 1975 the total number of fatalities was 6351. The proportion of this total accounted for by pedestrians was 37 per cent, which is only slightly less than the 38 per cent of fatalities attributed to occupants of private cars and taxis. The total number of pedestrians killed or seriously injured in 1975 was 20795, of which 39 per cent involved children aged 0–14 years.

Currently considerable effort is being directed towards measures which will reduce the severity of injuries to the occupants of cars, such as controlled structural collapse and passive restraint systems. However measures to reduce the almost equally large number of pedestrian fatalities have so far received much less attention, probably because of the inherent incompatibility of vehicles and pedestrians in collisions.

This report describes preliminary studies in which pedestrian dummies were struck by cars in order to determine the influence of the front-end shape on the resulting pedestrian trajectories.

2. PEDESTRIAN DUMMIES

In view of the high proportion of serious injuries sustained by children it was decided to study the trajectories of both child and adult dummies. The dummies were required to be rugged enough to withstand repeated violent impacts and rigid enough to maintain a free standing position up to the moment of impact. After impact however some degree of flexibility was needed to approximate the real life collision. Two sizes of adult and two types of child dummies were used in the course of the investigation.

The adult dummies were basically RAE Type VB corresponding approximately to the 90th percentile and 50th percentile sizes. The hip and knee joints were reworked and fitted with shear pins made of brass wire. Adjustable clamps were also incorporated in the hip and shoulder joints so that the freedom of movement could be controlled. A spigot fitted at the base of the spine engaged an aluminium prop which supported the dummies in a standing position, but which was dislodged at impact.

The child dummies were both nominal 6 year olds to represent small children who might be unaccompanied on the road. One of the dummies was designed and made at the Transport and Road Research Laboratory. Like the Royal Aircraft Establishment type dummies it was robust enough to withstand repeated blows, and it included shear pins in the hip and knee joints together with means for adjusting the friction in the joints. The second child dummy was American in origin and known as Sierra Sammy. Shear pins were not fitted to the American dummy. Both child dummies were supported in the standing position by means of an aluminium prop. Details of the adult and child dummies are given in Table 1. The dummies were clothed in white overalls, and either rubber soles or complete shoes were attached to their feet.

3. TEST PROCEDURE

Each dummy was supported in the standing position to simulate a pedestrian walking across the road in front of a car. The car was manually driven to strike the dummy at predetermined speeds judged from the fitted speedometer. The actual vehicle speed immediately prior to impact was measured by means of two traffic counter tubes connected to a time lapse instrument. The brakes of the car were applied after the dummy was struck. A steel grille fitted to the windscreen surround prevented the dummy from striking the windscreen.

Nominal speeds of 8, 16, 24 and 32 km/h were selected for the initial test runs, each event being recorded on film. Tests at speeds above 24 km/h were soon abandoned however because of the violence of the impacts and the consequent damage sustained by the dummies.

4. DESCRIPTION OF TESTS

4.1 Large, medium and small cars

Initial tests were conducted with the 50th percentile adult dummy and three sizes of car, a Wolseley 6/90 (large), a BLMC 1100 (medium) and a BLMC Mini (small). The front-end dimensions of the cars at the points of initial impact with the dummy are given in Table 2. Comparison with Table 1 shows that for all three cars the height of the leading edge of the bonnet was below that of the centre of gravity of the dummy.

The tests with the large car at impact speeds between 11 and 29 km/h showed that upon impact the torso of the dummy folded over on to the bonnet, and that even at the highest speed the head did not strike

the windscreen grille. For a brief period of time both vehicle and pedestrian travelled with the same forward velocity, but they separated when the vehicle brakes were applied, the pedestrian sliding off the bonnet usually in front, but sometimes to the side of the vehicle.

The tests with the medium-size car at impact speeds between 12 and 19 km/h produced similar trajectories to those observed with the large car, except that at the highest speed the head struck the windscreen grille. The other noticeable difference was that the dummy assumed a more pronounced prone position while travelling on the bonnet of the car.

The tests with the small car at speeds between 10 and 24 km/h showed that the bonnet was too short to allow the dummy to fold over into a prone position. At impact speeds of 14 and 24 km/h the head struck the top of the windscreen grille before the dummy slid off the bonnet either in front of or to one side of the car.

In some of the tests with all three sizes of car violent head impacts occurred with the road surface after the brakes were applied and the dummy slid off the bonnet.

4.2 Bonnet friction and forward bumper extension

In an attempt to retain the 50th percentile adult dummy on the bonnet after impact two heavily pimpled rubber car mats were secured to the surface of the bonnet of the BLMC 1100 car. Three tests at speeds between 13 and 19 km/h showed that the mats did not prevent the pedestrian dummy from sliding off the front of the bonnet when the brakes were applied after impact.

In further tests four rubber mats were used to cover the whole surface of the bonnet and at the same time the front bumper was extended 100 mm in front of its normal position. The effect of extending the bumper forwards was to project the dummy further on to the car and to produce a severe head impact with the windscreen grille at 18 km/h. In one test the dummy remained on the bonnet when the vehicle brakes were gently applied well after the moment of impact. In a test at the same speed when the brakes were applied immediately after impact the dummy slid off the front of the vehicle. Similar results were observed when the bumper extension was reduced to 75 mm in front of its normal position, the dummy remaining on the bonnet in one test at 17 km/h after striking the windscreen grille.

These tests confirmed that introducing friction between the bonnet and the clothing of the dummy decreased the tendency for it to slide off the front of the vehicle but the restraint employed in these tests was insufficient to positively retain the dummy.

The tests also demonstrated a tendency for the dummy to be projected further on to the bonnet with increased forward extension of the car bumper.

4.3 Tapered front-end

The effect on the trajectory of the pedestrian of a pronounced taper in plan view built on to the front-end of the BLMC 1100 was examined. The apex of the taper was 450 mm in front of the normal bumper position, so that in addition to the pointed end the bonnet length was progressively increased from the sides of the car towards its longitudinal centre line. Low density polystyrene blocks 50 mm thick were attached to the bonnet surface to soften the impacts with the vehicle. Both the 50th percentile adult dummy and the TRRL child dummy were used in the tests.

When impacted close to the apex of the pointed front-end, the torso of the adult dummy was flung on to the bonnet in a direction nearly perpendicular to the tapered side. It also moved sideways across the bonnet until eventually it was thrown off to the side of the vehicle. The head of the dummy did not reach the windscreen grille even at a speed of 24 km/h. When impacted close to the side of the car the adult pedestrian was simply flung sideways and struck its head on the road.

The TRRL child dummy was not tall enough to fold over on to the bonnet of the car. It was always pushed to the side of the vehicle and usually the head struck the road. At low impact speeds one leg of the child dummy was sometimes run over.

Thus a tapered front-end is likely to reduce the severity of head impacts of the adult with the windscreen. However for those impacts which occur on the tapered front of the car, adult and child dummies are thrown to the side of the vehicle and this could enhance the risk of runover by an oncoming vehicle.

5. ADULT AND CHILD TRAJECTORIES

Further tests were carried out with the 90th percentile adult dummy and the TRRL child dummy to establish their respective trajectories when struck by conventional modern cars. The front-end details of the four cars used are given in Table 3. For all four cars the slope to the horizontal defined by a plane through the front bumper and the leading edge of the bonnet was greater than 80° , i.e. they all presented a nearly vertical front to the pedestrian.

Tests at nominal speeds of 8, 16 and 24 km/h yielded the following conclusions:—

- 1) For an adult pedestrian the height of the leading edge of the bonnet of current large volume production cars is low enough to allow the torso to fold over on to the bonnet at impact. For a brief period of time vehicle and pedestrian then travel with the same forward velocity.
- 2) At impact speeds of about 24 km/h the head of the adult pedestrian strikes the windscreen of a car with a bonnet length less than about 1 m.
- 3) The child pedestrian is not tall enough for its torso to fold over on to the bonnets of the cars with the result that it is impacted so that it reaches the speed of the car and then is projected on to the road ahead of the car.
- 4) Impact with the car is not the only source of injury to the pedestrian. Having been picked up on the bonnet the adult pedestrian rarely remains there, but falls off to strike the road. The worst situation arises when the vehicle brakes are not applied until after the impact occurs; the pedestrian is then projected forward of the vehicle with the velocity attained whilst lying on the bonnet and may strike the road with considerable force. The child may also strike the road hard after impact with the front of the car.

6. EXPERIMENTAL FRONT-ENDS

Different experimental front-ends were fitted to two cars to study the influence of various configurations on the trajectories of adult and child dummies. Compared with conventional front-ends, bonnet height was

lowered, and the slope of the front-end was reduced by extending the forward projection of the bumper. The two cars were also fitted with individual devices developed with the object of retaining the pedestrian dummies on their bonnets.

6.1 Experimental front-end No. 1 (slope 70°)

An early type Ford Cortina car was extensively modified to reduce the height of the leading edge of the bonnet and to incorporate a front-end rounded in plan view. The front bumper consisted of a steel tube shaped to conform to the rounded front-end, and mounted so that first contact with the legs of the adult dummy was below the knee. The bumper was positioned 100 mm forward of the leading edge of the bonnet, the bumper height being 375 mm and the leading edge height 625 mm. These dimensions produced a front-end slope of 70° to the horizontal.

The pedestrian catcher device consisted of a second steel tube shaped to the periphery of the front and sides of the bonnet, the tube itself forming the leading edge. Sensing was achieved by means of micro-switches at both ends of the tube, a small rearward movement of which triggered the air supply to two pneumatic cylinders which were housed inside the wings of the car. Plates 1 and 2 show the modified front-end and Table 4 contains the important dimensions.

Tests with the 90th percentile adult dummy showed that at nominal impact speeds of 8, 16 and 24 km/h the dummy was picked up on the car, the head always striking the bonnet. At 24 km/h the dummy was laid at an angle across the bonnet due to the rounded front-end. Both the child dummies were flung on to the bonnet at impact speeds of 16 and 24 km/h, but at 8 km/h pick up of the child dummies was unreliable.

At all impact speeds where the adult and child dummies were projected on to the bonnet they were successfully prevented from falling off by the catcher bar. Operation of the catcher imparted an upward thrust to the legs which resulted at 24 km/h in the child almost standing on its head before it fell back on to the car.

At 8 km/h the child dummies were sometimes pushed away from the car by the catcher to strike the road with a corresponding increase in severity of impact.

6.2 Appraisal of experimental front-end No. 1

The complete design of front-end and catcher picked up and retained both the adult and child dummies at impact speeds of 16 and 24 km/h. However at 24 km/h the head of the adult dummy was probably only prevented from striking the windscreen grille by the unusually long bonnet.

The fact that at the low impact speed of 8 km/h the child dummies were sometimes pushed away by the rising catcher bar is a serious disadvantage of the design in that it could increase the severity of child impacts with the road. The low bonnet could also create problems both in housing the engine and in positioning the headlamps high enough to provide an acceptable beam angle.

6.3 Experimental front-end No. 2a (slope 62°)

A BLMC 1100 car was modified by the addition of a bonnet top (made in glass-reinforced plastics) and a section of bumper. The bumper was positioned at a height of 420 mm with a forward projection of

125 mm from the leading edge of the bonnet which was initially set at a height of 650 mm, to produce a front-end slope of 62°.

The catcher device was developed with the intention of positively picking up and retaining the child dummy on the bonnet at low impact speeds. It consisted of a padded steel bar which when actuated moved from its stowed position on top of the bumper first forwards and then upwards. Details of the catcher device are given in Appendix 1. Plates 3 and 4 show the modified front-end and Table 4 contains the important dimensions.

Tests with the 90th percentile adult dummy showed that at an impact speed of 16 km/h the head of the dummy hit the base of the windscreen grille after which the dummy fell off the bonnet. At 24 km/h the head hit the windscreen grille well above its base before the dummy fell over the edge of the bonnet. The catcher device was not operative in these tests.

The child dummies were satisfactorily picked up and retained on the bonnet at impact speeds of 8 and 16 km/h (Plate 5), the catcher-bar providing positive lift to the dummies especially at 8 km/h. However at 24 km/h the vertical rotation imparted to the child dummy by the front-end configuration caused the head to strike the bonnet close to the leading edge with the legs assuming an almost vertical position above the head. Thereafter the dummy collapsed on to the bonnet and catcher bar and then slid off the side of the car. This trajectory was not influenced by the catcher bar which rose to its extended position behind the dummy without ever catching it up.

6.4 Experimental front-end No. 2b (slope 67°)

The height of the leading edge of the bonnet was raised 70 mm to 720 mm, thereby increasing the slope of the front-end to 67°.

At 16 km/h the head of the adult dummy struck the bonnet just short of the windscreen grille (Plate 6). At 24 km/h the head struck the windscreen grille in front of the driver. In both cases the dummy was retained by the catcher.

Tests with the TRRL child dummy showed that it was again picked up and satisfactorily retained on the bonnet and catcher at speeds of 8 and 16 km/h due to the positive lifting action of the catcher. At 24 km/h the rate of vertical rotation of the child dummy was still too high, the dummy virtually standing on its head near the front of the bonnet before collapsing and sliding off to one side of the car.

6.5 Experimental front-end No. 2c (slope 71°)

The height of the leading edge of the bonnet was raised another 70 mm to 790 mm, thereby increasing the slope of the front-end to 71°.

At 16 km/h the head of the adult dummy struck the bonnet 280 mm short of the windscreen grille, an improvement on front-end No. 2b. The TRRL child dummy was not lifted on to the bonnet at any test speed, the almost upright stance of the dummy at impact not providing sufficient purchase for the lifting action of the catcher (Plate 7). At 24 km/h the child dummy rotated to a horizontal position after impact with the front-end, whereupon the catcher bar lifted the legs above the horizontal plane before the dummy fell back to strike the road.

6.6 Experimental front-end No. 2d (slope 81°)

The forward projection of the bumper from the leading edge of the bonnet was reduced from 125 mm to 50 mm by extending the leading edge. In so doing the curvature of the bonnet top was maintained so that the leading edge was reduced in height from 790 to 760 mm, to produce a front-end slope of 81°.

At 16 and 24 km/h the head of the adult dummy struck the bonnet well short of the windscreen grille. In both cases the dummy was retained by the catcher (Plate 8).

The TRRL child dummy was not lifted on to the bonnet at any test speed because of the almost upright stance of the dummy at impact.

6.7 Appraisal of experimental front-ends Nos. 2a, b, c, d

A clear distinction emerges from the tests governed by the conflicting design requirements for the child and adult as exemplified by experimental front-ends Nos. 2a and b on the one hand and experimental front-ends Nos. 2c and d on the other.

6.7.1 Experimental front-ends Nos. 2a and b both picked up and retained the adult and child with acceptable trajectories at impact speeds up to 16 km/h. At 24 km/h the trajectories of both adult and child became too violent to be controlled. Thus to project the child on to the bonnet and retain it from very low impact speeds upwards requires a catcher device which provides positive lift. This in turn requires a front-end slope of 60–70° with a leading edge height of about 720 mm for this layout, a configuration which itself leads to uncontrollable dummy trajectories of adult and child at impact speeds above about 16 km/h.

6.7.2 Experimental front-ends Nos. 2c and d did not pick up the child but the adult trajectories were satisfactory at impact speeds up to 24 km/h, the head of the dummy striking the bonnet well short of the windscreen and the catcher retaining the dummy on the bonnet. Adult trajectories are thus controlled with a front-end slope greater than 70° and a leading edge height of 760–790 mm, a configuration which will not pick up the child.

7. DISCUSSION

Altogether 245 tests were carried out on conventional and modified frontal designs. The work described has established the relationship between the front-end geometry of cars and the trajectories of adult and child pedestrian dummies. It is not known how closely the dummies simulate the trajectories of the human body, but having regard to its greater flexibility it seems unlikely that the trajectory of the human will be more uncontrollable than that of a dummy.

The study shows that the leading edge of the bonnet plays an important part in determining pedestrian trajectories and it is apparent that trajectories would be made less violent if the leading edge was itself an energy absorbing device matched to the tolerance level for the hip and thigh complex of the adult. To reduce injury to the lower leg of the adult the front face of the bumper should also be equipped with an energy absorbing device matched to the tolerance level for the tibia and fibula.

8. CONCLUSIONS

The following conclusions are drawn from the study of trajectories of adult and child dummies. They are early results from a continuing study of how to reduce the severity of impacts between cars and pedestrians.

- 1) The simplest and cheapest modification to existing front-end designs of cars to give improved pedestrian trajectory on to the bonnet is to adopt a configuration which will provide optimum conditions for the adult pedestrian. These are a nearly vertical front-end slope with a low mounted bumper and bonnet leading edge height of 760–790 mm, a configuration which provides controlled adult trajectories up to 24 km/h, but which does not pick up the child, (Fig 1a). The provision of suitable energy absorbing devices to the leading edge of the bonnet and the face of the bumper should provide additional control to all trajectories, and reduce impact severities.
- 2) To pick up and retain child pedestrians on the bonnet as well as adults, from low impact speeds upwards, requires a device which positively lifts the child, together with a front-end slope of 60–70°. With the arrangement tested the appropriate height of the leading edge of the bonnet was 720 mm, but the catcher design was such that it could be suitably stretched to match a higher bonnet. The configuration tested provides controlled child and adult trajectories up to 16 km/h (Fig 1b).

9. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Vehicle Safety Division of the Safety Department of TRRL.

10. APPENDIX I

DETAILS OF CATCHER DEVICE DESIGNED FOR EXPERIMENTAL FRONT-END NO 2a

The mechanism operating the catcher device was built into the engine compartment of a BLMC 1100 car, which was covered with a bonnet top made in glass reinforced plastics.

In its stowed position the catcher bar rested directly on top of the front bumper, but rearward of its front face (Fig 1b). The catcher bar was connected by cranked levers to a shaft mounted under the bonnet top and just behind its leading edge. Strong torsion springs were mounted on the shaft to provide the motive power to actuate the catcher bar. Sensing of the catcher bar was achieved by mounting two microswitches under the bonnet top to respond to a downward thrust at the leading edge. Closure of the microswitches operated a solenoid linked to the mechanical equipment.

Upon impact at the leading edge of the bonnet the catcher bar moved forward horizontally to a position just forward of the front bumper. This movement was rapid and undamped. Thereafter the bar rose vertically, the rate of rise being controlled by adjustable dampers. For the last part of the vertical movement a ratchet mounted on the spring shaft prevented the catcher bar from losing height under the weight of the pedestrian. By adapting the dimensions of the cranked arms the height of the extended catcher bar can be increased proportionally to the bonnet height to maintain the relationship shown in Fig 1b.

It is apparent that the external appearance of the car remains virtually unchanged by the catcher device. For simplicity this version did not include side extensions of the catcher bar.

Further details of the construction of the catcher device are given in TRRL drawing number 1199.04/000.003.

The pedestrian catcher device is the subject of patent application Provisional Specification 10752/75.

TABLE 1
Details of adult and child dummies

Dummy size	Type	Weight (kg)	Overall height (mm)	Height of centre of gravity (mm)
90th percentile adult	RAE type VB	79.15	1867	940
50th percentile adult	RAE type VB	74.61	1714	877
6 yr. old child	TRRL	23.6	1244	686
6 yr. old child	Sierra Sammy	21.8	1168	661

TABLE 2

Front-end dimensions of large, medium and small cars

Car size	Make	Height of leading edge of bonnet (mm)	Length of bonnet mm
Large	Wolseley 6/90	860	1170
Medium	BLMC 1100	750	930
Small	BLMC Mini	720	700

TABLE 3

Front-end details of conventional cars

Car	Height of bumper (mm)	Height of leading edge of bonnet (mm)	Slope defined by bumper and leading edge of bonnet (deg.)	Length of bonnet (mm)
BLMC 1300	380	750	82°	930
Marina	510	790	87°	1180
Mini Clubman	470	740	85°	850
BLMC 1800	450	750	81°	1060

TABLE 4

Details of experimental front-ends

Experimental front-end No.	Height of bumper (mm)	Height of leading edge of bonnet (mm)	Slope defined by bumper and leading edge of bonnet (deg.)	Length of bonnet (mm)
1	375	625	70°	1450
2a	420	650	62°	1130
2b	420	720	67°	1130
2c	420	790	71°	1130
2d	420	760	83°	1180

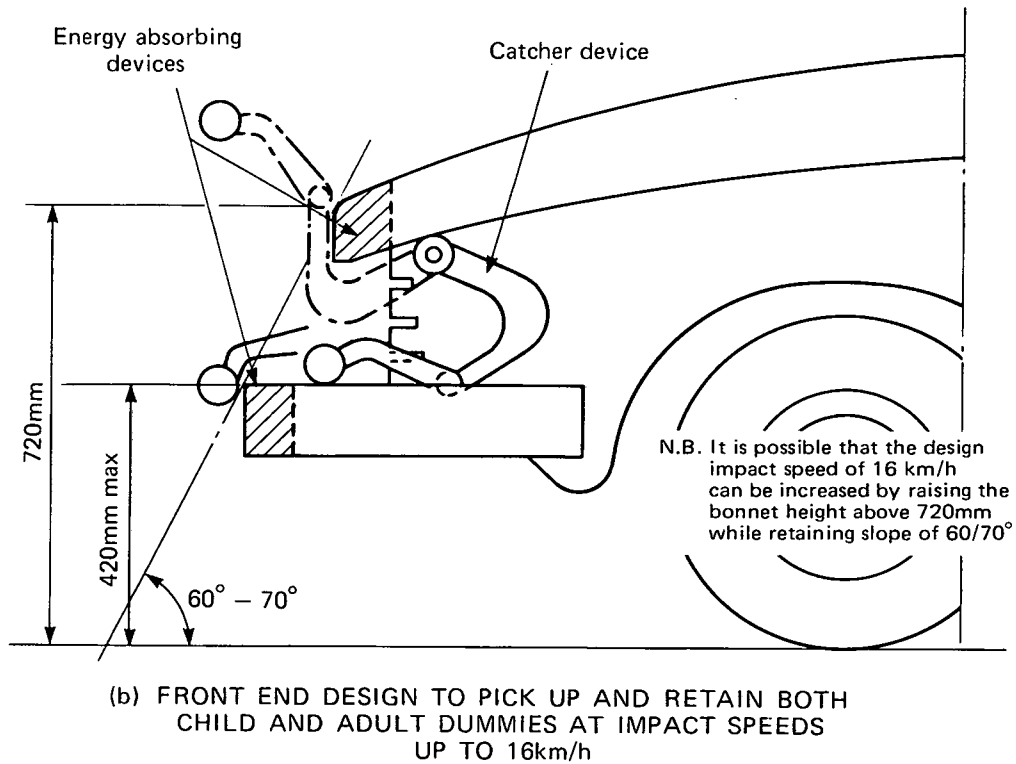
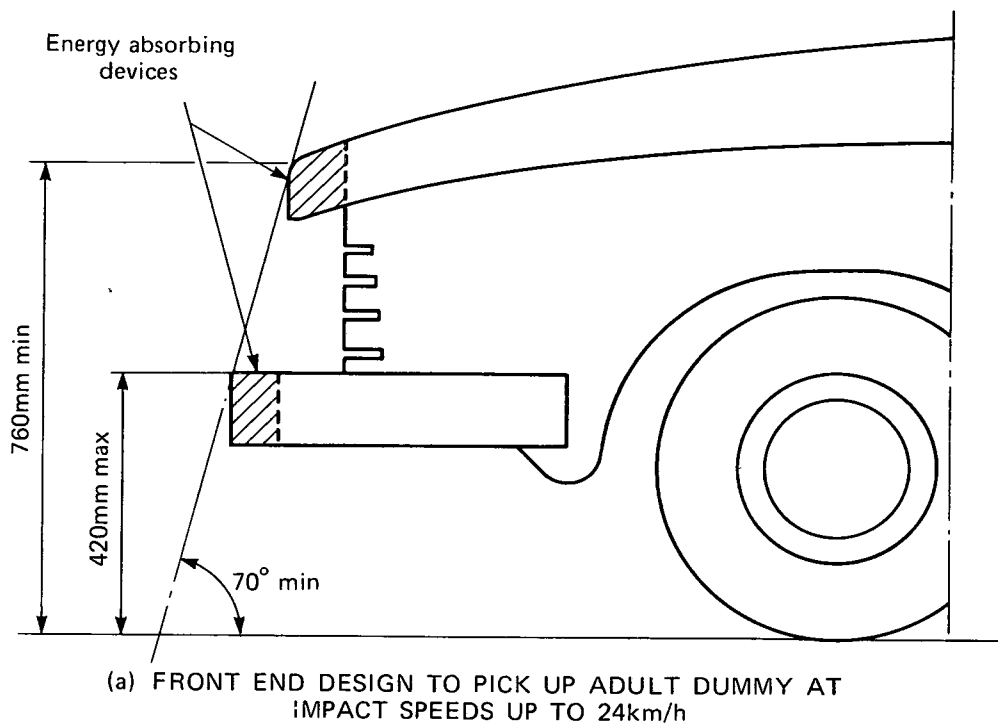


**Fig. 1 FRONT END GEOMETRY TO IMPROVE THE TRAJECTORIES
OF DUMMY PEDESTRIANS STRUCK BY CARS**



Neg no R1492/72/5

PLATE 1. Experimental front-end No. 1



Neg no R1492/72/8

PLATE 2. Experimental front-end No. 1 retaining adult pedestrian



Neg no B1139/74

PLATE 3. Experimental front-end No. 2a with stowed catcher device



Neg no B1141/74

PLATE 4. Experimental front-end No. 2a with raised catcher device



Neg no R1076/74/3

PLATE 5. Experimental front-end No. 2a picking up child at 16 km/h



Neg no R1346/74/5

PLATE 6. Experimental front-end No. 2b
retaining adult on bonnet at 16 km/h

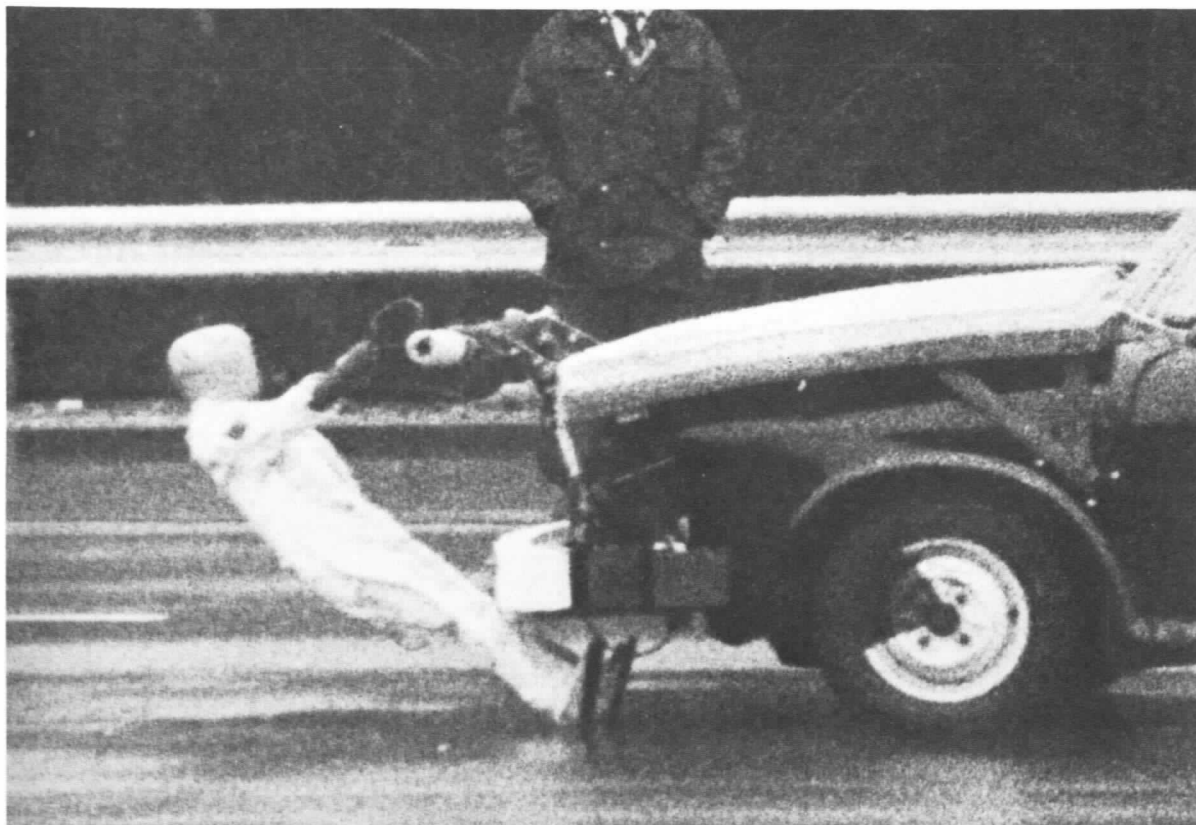


PLATE 7. Experimental front-end No. 2c
knocking down child at 16 km/h

Neg no H 173/75



PLATE 8. Experimental front-end No. 2d
retaining adult on bonnet at 24 km/h

Neg no H 169/75

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Tests with conventional cars at nominal impact speeds of 8, 16 and 24 km/h showed that while the adult pedestrian folded over on to the bonnet before falling off, the child was knocked down. Reducing the height of the bonnet sufficiently to pick up the child causes the adult to strike the windscreen.

The simplest method of reducing pedestrian injury is to adopt a front-end which provides optimum trajectories for the adult, and to provide suitable energy absorbing designs for the leading edge of the bonnet and the front face of the bumper.

To pick up both child and adult dummies on the bonnet and retain them requires a sloped front-end and a device which positively lifts the child at low impact speeds. An experimental front-end and catcher has been developed for the purpose which performs satisfactorily at impact speeds up to 16 km/h.

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The simplest method of reducing pedestrian injury is to adopt a front-end which provides optimum trajectories for the adult, and to provide suitable energy absorbing designs for the leading edge of the bonnet and the front face of the bumper.

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