PROTOTYPE OF LIGHTWEIGHT HELMET FOR USERS OF LOW-SPEED TWO-WHEELED VEHICLES, COMBINING SATISFACTORY HEAD PROTECTION WITH CHARACTERISTICS OF ACCEPTABLE DESIGN AND WEARER'S COMFORT.

F. Chamouard, G. Walfisch, A. Fayon, C. Tarrière,
Peugeot-Renault Laboratory of Physiology and Biomechanics,
132, rue des Suisses, 92000 Nanterre - France.

Analysis of automobile accident statistics (1)* shows that highway accidents involving cyclists account for a not inconsiderable proportion of the casualties - both injured and killed - among two-wheeled-vehicle users (approximately 4,000 fatal casualties in 1976 in the Common Market Countries), and that their heads are a body sector that is frequently and severely injured, with the ground being the obstacle that is struck with the greatest frequency. In addition, barring exceptions, there is no formal impact attenuating requirement for the protective equipment designed for cyclist head protection.

Moreover, existing cyclist's helmets are often of poor quality with regard to impact attenuation (absence or insufficiency of shock-absorbent material). For these reasons, and on the basis of known data concerning the human head's impact tolerance the Peugeot-Renault Laboratory of Physiology and Biomechanics undertook to design and produce a prototype helmet for cyclists that would be suitably adapted to the head's impact tolerance and that would also embody features of comfort and style. In fact, it is unacceptable for a bicyclist to use a motorcyclist's helmet for reasons having to do both with weight and with problems linked to his considerable amount of sweating.

PROTOTYPE HELMET FOR CYCLISTS.

Our taking into consideration of the two above-mentioned prerequisites combined with the requirements of style, led us to devise the basic solutions adopted for the prototype cyclist helmet shown in Figure 1. This helmet consists basically of an outer shell shaped via the thermoforming of a sheet of thin, lightweight material selected for its shock-absorbent capacity when in its definitive form.

Shock absorption was achieved through the buckling of the vertical panels of the sheet in its final form. Ventilation of the head was achieved by having air circulate through the spaces that divide the various "stud points" in contact with the head.

The small amount of existing accidentological data concerning the forms of the sundry types of obstacles impacted by cyclists' heads (frequently the ground, or the edge of a sidewalk) was also taken into consideration for defining the dimensions of the sections of the prototype helmet in its various planes.

(*) Numbers between parentheses designate references at the end of the paper.

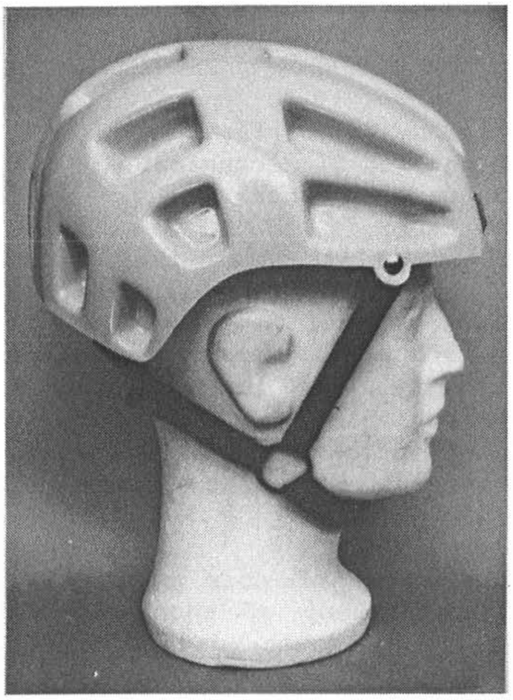
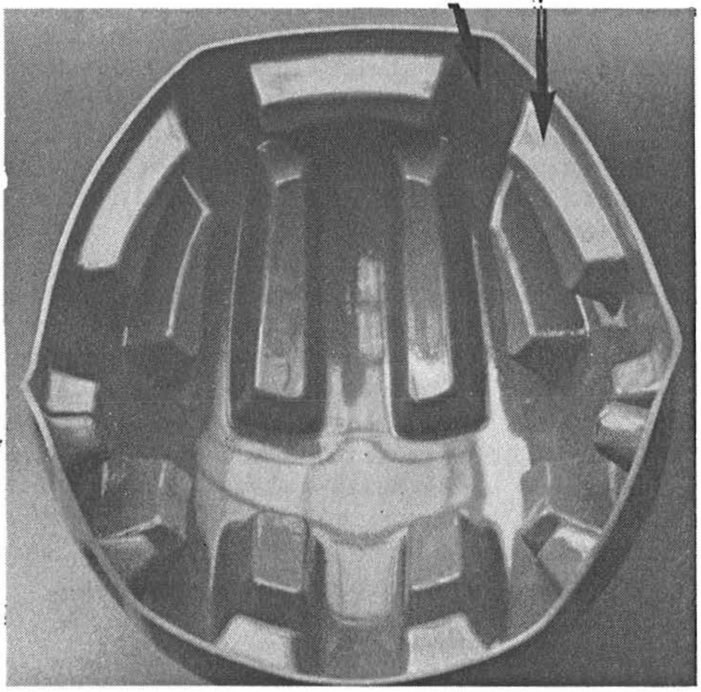
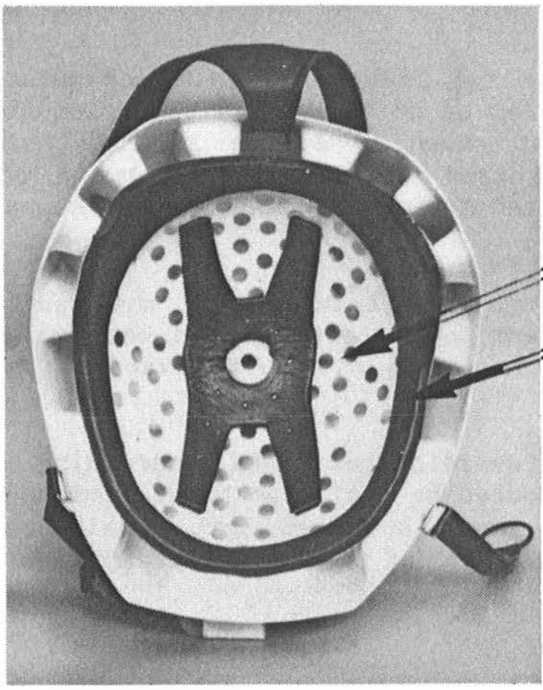


Fig - 1 - A - Side View

Fig - 1 - B - Internal view of the external skull cap

- Shock absorbent block
- Area circulation air





- Internal skull cap
- Confort material

Fig-1 - C - Internal View

FIGURE - 1 - CYCLIST'S PROTOTYPE HELMET

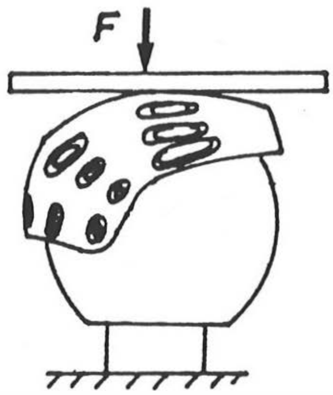
CHOICE OF MATERIALS.

For reasons of cost, the manufacturing process used for producing the helmet during the research and development phase was thermoforming.

The materials selected for crafting the helmet were hence chosen on the basis of their suitability for assuming the desired shape via this manufacturing process. Four materials were ccnsidered, as follows:

- low-density polyethylene,
- polycarbonate,
- ter-ethylex,
- impact A.B.S. (acrylonitrile butadiene styrene).

EVALUATION OF PROTECTION AFFORDED BY PROTOTYPE CYCLIST HELMETS.



For each material selected, we did a preselection of helmets aimed at defining their thickness, by means of static compression tests, as shown in the basic diagram opposite. The thicknesses chosen for each material are shown in Table 1.

DYNAMIC TESTS.

A draft norm issued by the Fédération Française de Cyclisme specifies the principal requirements to be met for protective helmets usable in bicycle racing, as well as the tests designed for checking compliance with these requirements.

With regard to shock absorbency, this draft norm recognizes that a helmet has "sufficient" shock-absorbent effectiveness if the resultant acceleration measured at the center of gravity of a dummy head released in a free fall from a height of 0.9 meter (impact velocity 4.2 m/s) onto a flat, rigid surface does not exceed 150 g during 5 ms cumulated, without ever exceeding 300 g at maximum peak. Without issuing a judgment on the above criteria, we deemed them to be a minimum that should necessarily be complied with.

TEST METHOD.

A 5.6-kilogram head model (size 60) fitted with a prototype helmet was dropped in a free fall onto an anvil. Depending on individual tests the helmet was impacted either on the front part or on the side part, or, again, on the area of occipital protection; impact velocity was 4.5 m/s.

TABLE 1 - RESULTS OF IMPACT TESTS (V = 4.5 m/s)

	CHARACTERISTICS OF THE HELMETS					RESULTS OF MEASUREMENTS	
Test No.	Type of impact	Type of material	Thickness of material (mm)	Inner shell added	Helmet weight (kg)	Maximum resultant acceleration (g)	Maximum force (daN)
1	Side	A.B.S.	3	No	.190	338	1,922
2	Side	A.B.S.	4	No	.250	125	747
3*	Side	ter-ethylex	3	No	.190	495	> 2,000
4	Side	polyethylene	6	No	.310	96	658
5	Side	polystyrene 45 g/l		No	.320	82	503
6*	Side	A.B.S.	3	Yes	.230	81	505
7	Frontal	A.B.S.	3	Yes	.230	76	505
8	Frontal	A.B.S.	3	Yes	.230	103	--
9	Side	A.B.S.	3	Yes	.230	82	--
10	Occipital	A.B.S.	3	Yes	.230	71	--

(*) No acceleration-time curve for these tests

Note: Tests 8, 9 and 10 were performed with the same helmet.

Measurement was taken of the tridirectional accelerations at the center of gravity of the head, and of the forces applied to the anvil. The device used was in conformity with regulation 22.02 governing dummy-head falls.

REMARKS.

In these tests, the helmet deadweight was relatively low, and the forces transmitted to the head could be considered as being closely similar to those measured at the level of the anvil.

We chose to test the helmets against a flat, rigid surface, since this type of obstacle seems to be a good simulation of the ones that are frequently struck by the heads of two-wheeled-vehicle riders in highway accidents, while at the same time simulating a maximum rigidity among the rigidities of the obstacles encountered.

FREE-FALL TEST FINDINGS.

The helmets tested and the test findings are listed in Table 1. Figure 2 gives the curves for resulting acceleration in terms of time, measured at the center of gravity of the head model.

In the absence of references concerning impact attenuation by "satisfactory" cyclist helmets, we compared the results obtained for the various prototype helmets with those obtained for a polystyrene liner taken from a cyclist's helmet and meeting the requirements of E.C.E. regulation 22.02 (test 5, Table 1, figure 2).

Analysis of the findings shows the following:

- the shock-absorbent characteristics of the helmets made of A.B.S. and of 3-mm-thick ter-ethylex (tests 1 and 3) are insufficient.

- However, the prototype helmets made of 4-mm-thick A.B.S. (test 2) and of 6-mm-thick low-density polyethylene (test 4) yielded "satisfactory" results, with maximum acceleration being far below the limits fixed by the draft norm.

In addition, one test (No. 6) was performed with a 3-mm-thick A.B.S. helmet fitted with a bonded inner pierced A.B.S. shell (0.5 mm thickness) (see Figure 3), to enable better distribution of the forces exerted on the head by the contact stud points, on the assumption that the maximum local pressures would prove too great.

COMPLEMENTARY TESTS FOR EVALUATION OF CONTACT PRESSURE.

There was reason to fear that the transmission of forces to the head via relatively small surface-area-contact points would exceed the limits of skull puncture resistance even for low force levels. For estimating the pressures exerted, we obtained an evaluation of the actual surfaces of the contact studs that were in contact with the head, by interposing between a wooden head model and the prototype helmet a sheet of blank paper overlaid with a sheet of carbon paper.

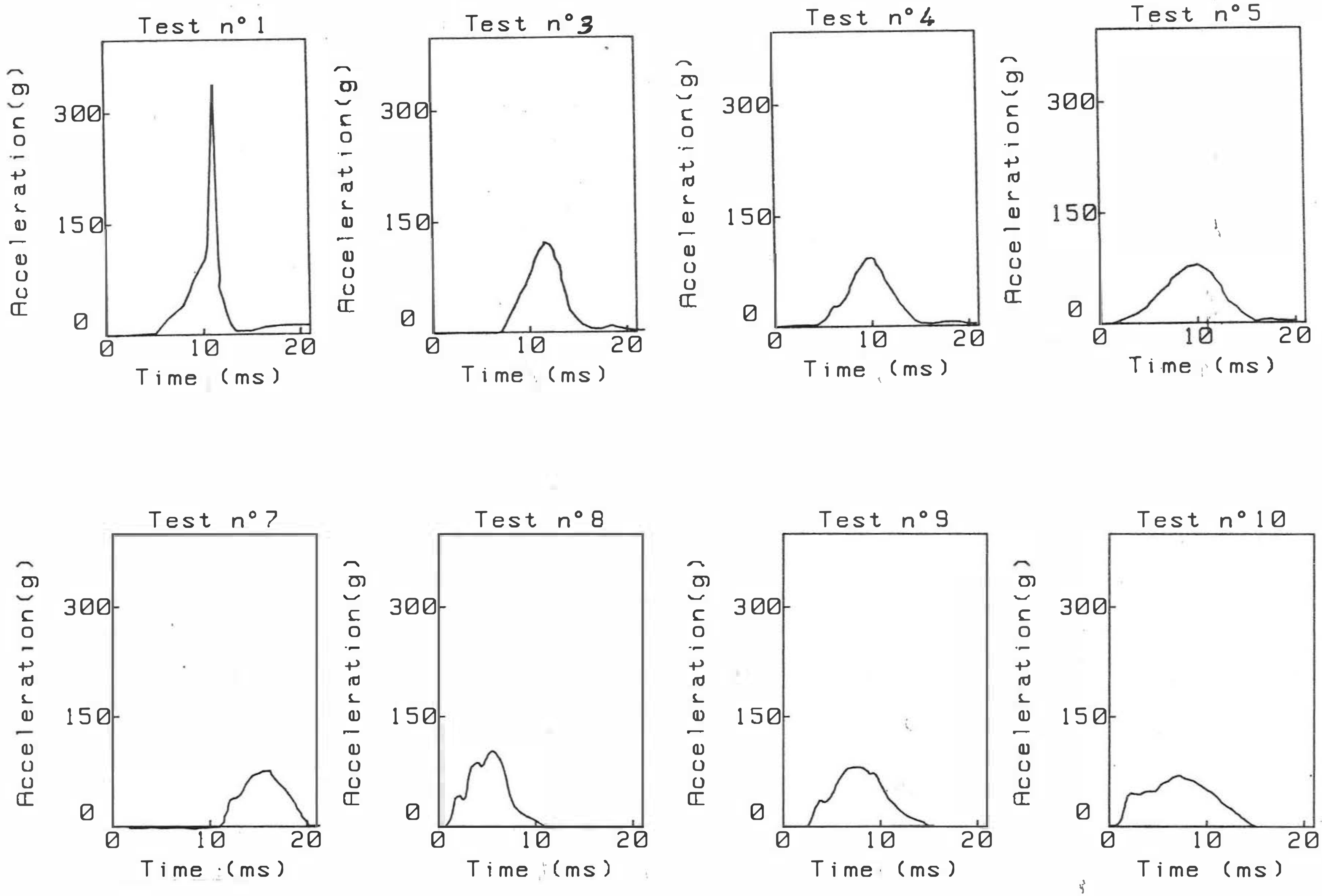


FIG 2 - FINDINGS OF DROP TESTS FROM 1 m HEIGHT - ACCELERATION PULSES (See Table 1).

The ratio $\frac{\text{maximum measured force}}{\text{evaluated surface area}}$ = maximum calculated pressures compared with the existing biomechanical data (6), (7) pertaining to this type of skull loading enabled us to reach a conclusion concerning this point. These data are described below. For dynamically applied loadings, using a 6.45-cm^2 rigid disk, the likelihood of the occurrence of skull fractures is very slight for pressures of around 5.36 N/mm^2 in the event of impacts occurring on the side area, and 10.75 N/mm^2 on the frontal area.

Unfortunately, during the side-impact tests performed here, because of a relative movement of the helmet in relation to the dummy head, due to the latter's rotation subsequent to impact, it was not possible to evaluate the surface area as indicated above.

To remove this difficulty, we performed impacts against the top of the skull, under the conditions described below. For lack of anything better, the pressures that were then calculated were extrapolated for all the areas of the prototype helmet.

These tests were performed with prototype helmets made of 4-mm-thick impact A.B.S. (test 2, Table 1) and of 6-mm-thick low-density polyethylene these being the two types of helmets that yielded the most "effective" results with regard to shock absorption.

The helmet rested on a size 62 wooden dummy head, secured together with a fixed rigid support. Between the helmet and the upper part of the dummy head, we interposed a sheet of carbon paper overlaid on a blank sheet of paper.

A 5-kilogram deadweight (roughly the mass of the head + the neck) was released in a free fall from a height of one meter, and struck the top of the helmet. The impact-induced force was measured.

By measuring the surface of the marks imprinted on the blank paper, we learned the surface area of the head that was subjected to loading during the occurrence of impact.

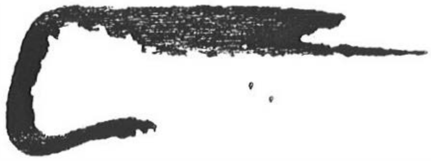
The table below and figures 3 and 4 illustrate the main findings:

Helmet	Thickness (mm)	Maximum force (N)	Surface area parked with imprint (mm^2)	Calculated pressure σ (N/mm^2)
A.B.S.	4 mm	9,670*	1,358	7.1
low density polyethylene	6 mm	5,900	703	8.5

(*) probable skull fracture

It thereupon became evident that the surface areas in contact with the dummy head were too small to provide protection against potential skull punc-

Fig 3 - Material : A.B.S. (thickness : 4 mm)



Occipital area

Frontal area

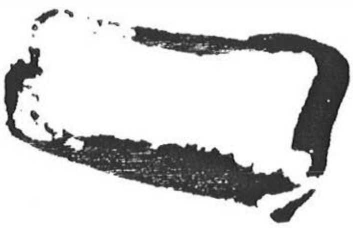


Fig 4 - Material : Polyethylène B.D. (thickness : 6 mm)

Occipital area

Frontal area

EXAMPLE OF THE CONTACT SURFACES ON DUMMY'S HEAD - FIRST PROTOTYPE HELMET WITHOUT REPARTITION SHEET - LOAD DISTRIBUTION FOIL -

turing. In fact, the calculated pressures were greater than those in the data that were considered to be the tolerable limits presented above.

Remarks - The biomechanical data noted previously were obtained with a 6.45 cm^2 impactor; in the absence of other findings, we admitted the values of the pressures induced by these experiments, for the tests performed with the prototype helmet, although the shapes of the marks representing the surface areas in contact with the dummy head are quite different (figures 3 and 4), since the values measured were fairly similar.

The pressures calculated slightly overestimate the puncture risk because of the absence from our tests of a simulation of the human scalp, the effect of which would be to attenuate the maximums of the forces transmitted to the dummy head and to distribute these forces over a greater surface area.

Moreover, the rigidity of the head model eliminates any skull deformability, whence an analogous effect of increased peak force.

Thus, in order to increase the amount of surface area in contact with the dummy head, we added to the inside of the helmet another shell, known as the "inner shell", as shown in figure 1-C. This inner shell was perforated to achieve proper ventilation of the head.

A test performed on a helmet fitted with this inner shell showed a definite increase in the extent of the head's surface area that was subjected to force during the occurrence of impact, an increase sufficient to preclude all risk of puncturing.

We were able to insert these inner shell in the A.B.S. helmets only, because of the impossibility of gluing or bonding it onto the low-density polyethylene.

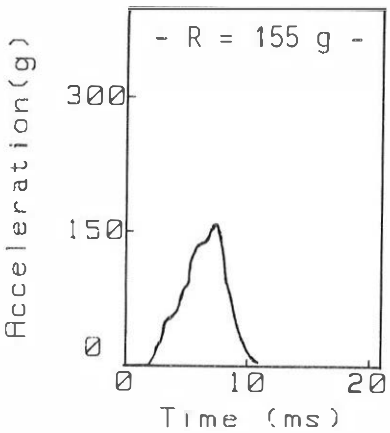
In addition, we found that this inner shell, made of 0.5-mm-thick A.B.S., unduly increased the overall rigidity of the 4-mm-thick kelmet; because of this, we hence installed it inside a 3-mm-thick A.B.S. helmet.

A helmet thus equipped was subjected, under the same conditions as the previous ones, to three successive impacts, as follows:

- a frontal impact,
- a parieto-temporal impact,
- an occipital impact.

The results were highly satisfactory (tests 8, 9 and 10, Table 1, figure 2); they were the best results found for the prototype helmets tested, very similar to those obtained with the polystyrene shell used as a reference test (test 5, Table 1, Figure 2).

Since the post-test helmet deformations were only slight, we increased the severity of an impact localized on the parieto-temporal area by increasing the impact velocity, i.e. V = 5.4 m/s. The results recorded (see hereafter, curve of resultant acceleration as a function of time) make it safe to assume that effective protection of the head can be achieved with this helmet for impact velocities of $\leq$ 5.4 m/s, i.e. 1.5 meters of dropping height instead of 0.90 meter in the above-noted draft norm.



VENTILATION AND AERODYNAMICS OF THE PROTOTYPE HELMET.-

We performed an evaluation of the possibilities for ventilating the head as well as an investigation of the aerodynamic characteristics afforded by the prototype helmet, in a wind tunnel via the method described below.

The head and thorax of a PART 572 dummy (50th percentile, currently used in automobile impact tests) were rigidly secured to a dynamometric platform enabling calculation of the forces that were resistant to penetration into the air.

Two different positions of bust tilt were analyzed.

First case: the dummy's bust was tilted at an angle of 45° with the horizontal: this is the average position of the bust of cyclists in a "cyclotouring" posture. In this configuration, there were two velocities of blown air, corresponding to speeds of 30 to 40 km/hour.

Second case: the dummy's bust was tilted at an angle of 27° with the horizontal; this position is representative of that of a cyclist who is "working up speed". In this case, the blown air corresponded to a speed of 60 km/hour.

FINDINGS FOR THE AERODYNAMICS OF THE LIGHTWEIGHT HELMET.-

The following tests were performed:

- Reference test with dummy bareheaded,
- Test with the dummy's head fitted with a foam-strip helmet (helmet F),
- Test with dummy's head fitted with a helmet consisting of a smooth plastic shell (helmet B).
- Test in which the dummy's head was fitted with the prototype helmet.

Table 2 illustrates the results obtained. The depression located on the front part of the helmet was obstructed to prevent it from producing an "air-trap" effect. It should be noted that whatever the velocity and whatever the bust tilt, the coefficient of air penetration (Cx) of the dummy wearing the prototype helmet was higher than the one obtained with helmet F, and is close to that of helmet B. It can hence be concluded that, contrary to what might have been feared because of the shape of its outer shell, the prototype helmet possesses satisfactory aerodynamic characteristics, which do not increase wind drag any more than do currently

TABLE 2 - RESULTS OF AERODYNAMIC TESTS.

Dummy in "cyclotouring" position ($\alpha = 45°$) V = 30 km/h		Dummy in "cyclotouring" position ($\alpha = 45°$) V = 40 km/h		Dummy in "working up speed" position ($\alpha = 27°$) V = 60 km/h	
Type of helmet	Cx	Type of helmet	Cx	Type of helmet	Cx
Bareheaded dummy	0.605	Bareheaded dummy	0.592	Bareheaded dummy	0.569
Helmet "F" (foam strips)	0.634	Helmet "F" (foam strips)	0.636	Helmet "F" (foam strips)	0.601
Helmet "B" (smooth shell)	0.621	Helmet "B" (smooth shell)	0.617	Helmet "B" (smooth shell)	0.572
Prototype	0.624	Prototype	0.628	Prototype	0.597

existing helmets which have far less absorbency performance.

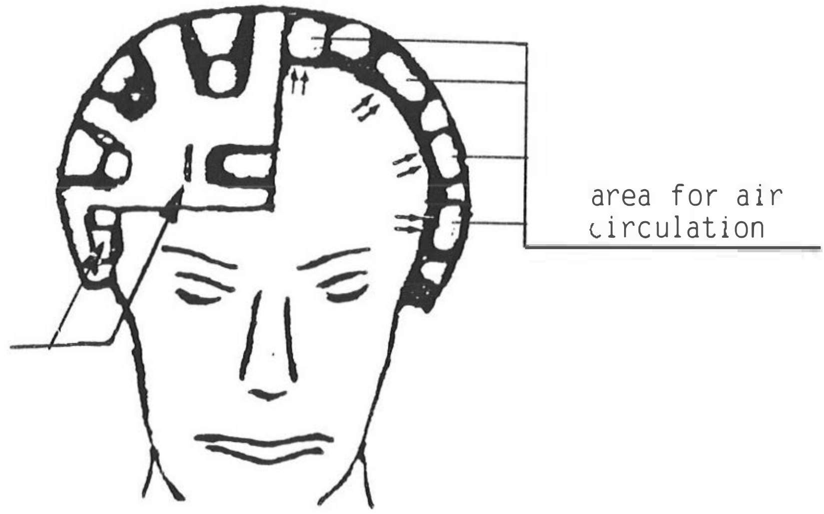
Remark: Evaluation of the aerodynamic qualities of the various types of helmets can be done by comparison with the Cx obtained, the projected areas of the helmeted dummies being closely similar.

VISUALIZATION OF VENTILATION PROVIDED BY THE PROTOTYPE HELMET.-

The depressions constitute energy absorbers, and, among them, they determine the air circulation channels providing constant ventilation of the head.

In order to visualize the air circulation in these spaces (between the prototype helmet and the dummy's head), we used - as we had done in the previous aerodynamic tests - "white smoke" obtained through vaporization of heated white spirit. Figure 5 clearly illustrates the satisfactory air circulation obtained thereby; this is due notably to the installing of two small "lights" located on the front of the helmet (see drawing hereafter).

It was also possible to appreciate the satisfactory ventilation provided by the prototype helmet by noting, after the roughly two-minute-long wind-tunnel tests, the head areas in which there was no longer present any of the dichlorobenzene (saturation-diluted in acetone) that, prior to the test, we had sprayed onto the dummy's head; air friction had caused it to disappear from the well-ventilated areas (see figures 6 and 7).



CONCLUSIONS CONCERNING THE PROTOTYPE LIGHTWEIGHT HELMET.-

A prototype lightweight helmet that is more specifically designed for cyclists and that provides effective head protection for an impact severity of $\leqslant$ 5.4 m/s against a rigid, flat obstacle, has been designed and produced.

The total deadweight of the prototype helmet, made of 3-mm-thick A.B.S., including its inner shell and fitted with its comfort- and head-attachment units, is 400 grams.

Its low cost, its light weight, its "design", its aerodynamics and its satisfactory ventilation are elements of comfort and acceptability that should be appreciated by its potential wearers. It is greatly to be hoped that cyclists will equip themselves with effective protective devices, and a helmet that meets their requirements is an incentive-triggering element.

The data acquired within the scope of this investigation illustrate, on the one hand, the shock-absorbent possibilities of cyclists' helmets and, on the other hand, the requirements with which cyclists could be compelled to comply without being subjected to severe constraint.

ACKNOWLEDGMENTS.-

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Fig - 5 -

Dynamic air circulation in the helmet's prototype.

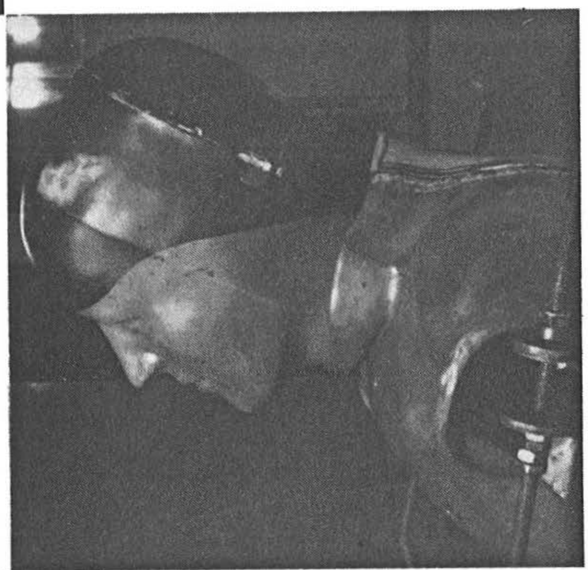

Fig - 6 -

The dummy's head before the test.

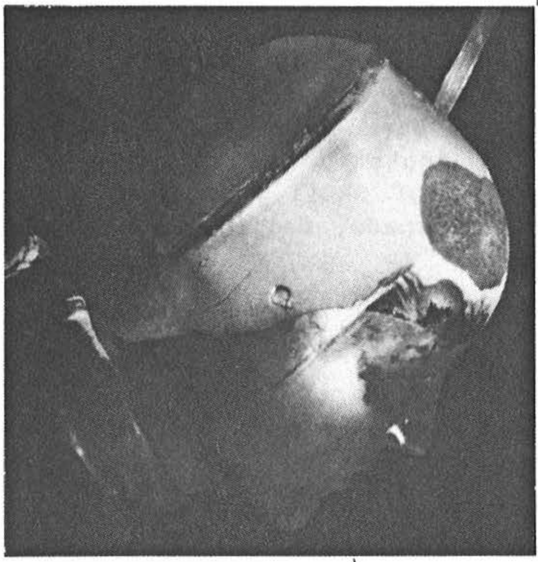

Fig - 7 -

The dummy's head after the test, the areas submitted to air draft have the darker colour.

- WIND-TUNNEL TESTS - V = 40 km/h -

The opinions and conclusions are those of the authors.

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