CONSIDERATION OF THE PECULIAR AND SPECIFIC SAFETY REQUIREMENTS OF THE MOTOR RACING DRIVER

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ABSTRACT

This paper examines the special requirements of racing drivers' helmets and kinematics related to cockpit surrounds including restraint systems as part of the overall crash protection system. Trackside furniture and "ride down" arrester devices currently in use will be discussed and an indication of the direction of future developments proposed. Reference will also be made to accident statistics for the 1976 Grand Prix season.

INTRODUCTION

In certain specific areas, and in particular, with regard to safety helmet design it is now necessary to consider the direction of developments to cater for the unusual requirements of the racing driver, who by definition, operates in a high hazard environment.

Virtually no research has been done collating information which should be readily available from the closely controlled area of motor racing sport. In particular, there has been little analysis of the reasons for, or the cause of, motor racing accidents. This is largely because both drivers and team managers are sometimes reluctant to give accurate information. Structural failure on a racing car, especially if it precipitated an accident, is unlikely to be promulgated. Conversely, driver error is sometimes put down to structural failure.

There is now evidence to suggest that motor racing requires a driver's safety helmet that differs in certain critical areas from the helmet requirements of a motor cyclist's.

Head Protection

One basic rule in preventing head injury is to minimize the amount of energy transmitted.

Deflection - use a hard smooth surface on the helmet to direct the missile and head away from each other and to prevent penetration of sharp points or missiles through the helmet to the head. (1)*

* Numbers in parenthesis indicate references at end of Paper.

It is therefore advisable that there be no unusual changes in the radius of the outer shell that may prevent effective deflection. Failure of the impacting force to be deflected because it strikes a ridge on the helmet can result in violent rotation of the head and lead to a closed head injury (concussion).

At violent impact to the head various mechanical events are produced resulting in brain damage. Such events are: accelerations and deformations of the skull or movements at the cranio-spinal junction with pressure changes and displacement of the intracranial contents.(2)

The helmet shell should therefore be free of protrusions or ridges so that the smoothest circular shape possible consistent with ergonomic requirements is achieved.

Ergonomics

Comfort is best defined as lack of discomfort. Discomforting factors in a protective head piece can be the common stresses e.g. mechanical pressure, pneumatic pressure, temperature extremes, noise, vibration, visual problems (incident and reflected light), and accelerations (linear, angular, and compound). Most of these parameters have been established. The most common sources of discomfort will be contact pressures in excess of 0.3 p.s.i. followed by temperature in excess of 84^{o}F and annoyances such as moisture, noise, etc.

Helmet Sizing

The basic helmet will accommodate 5th through the 99th percentile head size by the use of a maximum of eight different sized units designed to fit in one of two helmet shells of different size.(3)

It is imperative that the helmet fits correctly without extra padding of the low density i.e. soft type of foam. An excees of soft padding can deform quickly and excessively under impact and allow the helmet to come off.

Hardware such as earphone motors and also life support tubing and nozzles should be excluded from inside of the helmet shell to minimize the area of the head which is not in contact with the helmet sizing system and to prevent vibration and the secondary missile effect of inner components. Any protruberence inside the helmet of hard material even when well covered by shock attenuating materials would be likely to cause secondary missile impact injuries.

Kinematics

N.B. When using the medical air life support system it is important that the life support tube from the air bottle to the helmet can be allowed plenty of 'slack'. Safety belt harness is designed to stretch in an accident and a sufficient loop of free play tube should be allowed to cater for this.

The exhaust vents for the medical air system should be as adjacent to the nose and the mouth as possible.

Some consideration should be given to an effective neck protection device to limit the amount of movement within tolerable range of 60° left and right, 60° forwards, 80° rearwards of the head during emergency situations to prevent flailing of the head and distortion of the neck.(4) The neck carries all the vital connections between the head and the body. Any flailing or violent movement of the head can produce sharp bending at the atlanto-occipital joint with possible injury to the spinal cord and brain stem. Compression of the neck can cause circulatory disturbances and stimulation of the cardio-vascular depressor mechanisms as well as cerebrospinal shock. Furthermore, any violent unrestrained movement of the head can cause direct injury to the skull from impact with portions of the cockpit interior. The proximity of the cockpit structure and in particular the roll-over bar and supporting stays should therefore be covered either in a minimum of 25 mm and preferably 30 mm of high density polystyrene of 60 grams per litre or similar shock attenuating material such as polyurathane of similar shock absorbing properties (soft foam is ineffective). N.B. These materials should be covered in fire resisting material because of the danger of toxic gases when exposed to flame. Head rests should be designed so as to progressively collapse under a lineal load of 150 ft. lbs. No protrusions such as bolt heads, tube ends, or brackets should be found on the roll-over bar structure where these could impact the drivers helmeted head in the event of an accident.

HELMET RETENTION

Strap Fixing:

The strap fixing locating hangers (or anchors) in the helmet should be located behind the vertical axies of the head, i.e. as far back as possible without causing discomfort.

The breaking strength of the helmet retention system should be in excess of the current standards requirements. (Snell 300 lbs, BS.2495 300 lbs.). If a frangible system of helmet retention is incorporated this should have a design failure load of not less than 375 lbs. (i.e. in excess of the current standards requirements). A practical level of adequate strength for the chin strap would be 600 pounds. This figure is within the manufacturing capability and there is now evidence to suggest that helmets with a retention fixing of less than 600 lbs. can be torn off early in the accident without causing injury but leaving the head unprotected and vulnerable to injury whilst the accident is still in progress.

Several alternative or supplementary methods of helmet retention have been proposed, e.g. shoulder harness, neck collar or affixing the helmet retention mechanism to the car bodywork. At present none of these have offered any substantial improvement. N.B. In a racing car movement of the head should not be restricted or interfered with since balancing mechanisms (semi-circular canals) must be allowed to operate at the optimum to ensure good balance and control of the vehicle.

<u>Fire-Asphyxiation from Toxic Gas</u>

All helmets currently available use foamed materials. Foam is a three dimensional structure consisting of foam strands and air. Exposed freely to air it will burn rapidly producing thick, dark smoke and it will usually reach its maximum smoke density very quickly. Toxic gases such as Carbon Monoxide, Hydrochloric Acid gas and Hydrogen Cyanide, together with Isocynates, are released, dependent on the type of foam.(5)

Many helmets use P.V.C. which when heated to temperatures between 200°C and 300°C breaks down and in combination with atmospheric moisture produces a white mist of Hydrochloric acid. This can have a corrosive and irritant effect.

In consideration of the above facts it would therefore be advisable that the helmets be flameproofed so as to prevent those materials that are exposed to flame in the event of fire catching fire or smouldering. It should also be noted that certain materials such as rayon - although perhaps meeting the flameproof requirements have very poor scuff resistance with the result that in use this is quickly worn into holes allowing the foam materials in the helmet to become exposed.

Nylon used in nearly all helmets for motorcyclists has the adverse quality of melting at comparatively low temperatures and can cause considerable 'nuisance trauma' which can delay the healing of burns.

The shock absorbing materials in helmets when exposed to flame give off extremely toxic gases. Fire is rarely a hazard in motorcycling and most helmet standards are essentially for motorcyclists. There is no doubt that motor racing is now presenting problems of different nature to hitherto and it may well be that provision will have to be made to cater for fireproofing in racing drivers' safety helmets.

Materials used in the manufacture of both the helmet <u>and the car</u> should therefore be considered carefully before their inclusion. This may cause a conflict of design considerations. For example, certain materials used in the deformable structure of racing cars has excellent shock attenuation properties but gives off highly toxic gases when exposed to flame.

Finally when considering flameproofed materials it should be checked to determine not only the self extinguishing properties but also whether materials continue to carbonise when exposed to continuous flame. Several of the materials used in motor racing safety clothing exhibit this undesirable capacity. (Most fire-proofing tests assume the materials will be quickly moved from the source of flame) i.e. self extinguishing.

Ventilation (Cooling)

Temperature, as well as pressure, is a major factor influencing comfort. To maintain a comfortable temperature with the helmet, some means of thermal control must be provided. In a passive system, ventilation improves as more head surface is exposed to the air. Such a condition directly conflicts with impact protection in which extensive pad systems are required to distribute loads.

Considerable research has been done and systems produced that pass cooled liquid through a series of small plastic tubes which are placed against areas of the body to effect good cooling. However these relatively are difficult to fit easily into a single seater car and also require a power source to be operated.

Dynamic cooling by utilizing the forward motion of the vehicle should therefore be considered.

The environs of a racing car cockpit can reach extremely high temperatures in certain climates with subsequent deterioration in the performance of the driver caused by heat exhaustion (dehydration). Since most helmets are designed for use by motorcyclists where the problem of cooling is not difficult to solve consideration should be given to ventilation of the racing driver's helmet.

Ventilation (Air requirements)

A driver requires a minimum of 60 litres per minute. An average person in a sitting position with low mental and physical activity breathes at the rate of (500 cc) $\frac{1}{2}$ litre/breath at 16 breath/minute. This gives a respiratory rate of 8 litres/minute. However, air requirement is directly related to heart rate. A person operating in a high hazard environment would normally expect an increase in heart rate as a result of sympathetic response of the body (Taggard et.al.). A shortage of oxygen can cause dizzyness and/or nausea and related deterioration in performance. Any air vents to ensure an adequate supply of air to breath must be flameproofed.

Visor misting on Inner Surface

Expelled breath carries a high moisture content heated to body temperature. The moisture will be precipitated and form on the inside of the visor to cause "fogging" or misting with resultant loss of vision. Some method should therefore be provided to ensure good visibility through the visor.

One method is to fit a solid state electrically heated element to the visor and this has proved effective. However a source of electrical power is necessary. The alternative is to coat the visor with a suitable hydroscopic material. However the side effect of this method is to render the visor very brittle with extremely poor impact properties. It should be noted that visors so coated tend to break into long slivers (like glass) which could be most dangerous because of the proximity of the visor to the eyes. Some smears or spray-on coatings are effective for short periods.

A third method is to enable the wearer of the helmet to breathe outside the helmet. This could be achieved by a mask and series of tubes. However enormous ergonomical problems present themselves because of the great variance in chin, mouth and nose sizes. Also it should be remembered when designing such a system that some provision to accommodate the Life Support System must be achieved.

Weight and Centre of Gravity

The mass centre of the helmet should coincide with the lateral C.G. of the head to prevent lopsided sensory motor effects. The centre of gravity of the helmet needs to be low. This is because a motor cyclist when cornering cancels out the centrifugal effect to a large degree by leaning over. In a racing car the driver is more vertical and the roll couple effect of a high centre of gravity above the centre of gravity of the head produces very high loads on the neck. The weight of the helmet is directly related.

The general motion of the head-helmet mass can be represented by a rotation about an instantaneous axis plus a translational velocity. Dynamic considerations (principle of conservation of energy and momentum) point out the need for a minimum helmet mass. In addition, minimization of the resultant moment around the mass centre (pendulum effect) necessitates low centre of gravity for the helmet.(6)

Visual Periphery Considerations

Some consideration should be given to the need for the driver to be able to see fully all instruments and also the seat belt fixing whilst the helmet is being worn.

In the event of fire which requires the activation of controls it is imperative that these are within view of the driver even when the car is inverted. Too small an opening in the helmet may result in difficulty for the driver in locating important life saving switches or inability to unfasten the seat belt.

Visual Considerations

Helmet concepts are based on the principal that all size systems would use the pupils of the eyes as the starting point. Sizing and other helmet design details were oriented to provide at least the minimum field of vision of $+95^{0}$ laterally and 15^{o} above the horizontal.

Visors

The visor should be optically free of distortion and of sufficient thickness to prevent penetration of missiles such as stones/debris which may impact the face shield at high speed. It is recommended therefore that a minimum of 2.5 mm of polycarbonate be the requirements for visors since this thickness not only offers the degree of safety required for missile impact but has also been found to perform better during manufacture in preventing distortion. Also this is the minimum thickness desirable from a fire hazard point of view. Tests have shown that less than this thickness of polycarbonate, unless gold plated (vacuum splutter method) on the inner surface to reflect heat is unable to withstand the heat of petrol fire $800^{o}C$ to $1000^{0}C$ for the 90 seconds of the life support system, in excess of 2.5 mm causes some refraction problems.

TABLE I COMPARISON OF PROPERTIES OF ACRYLIC AND POLYCARBONATE MATERIALS

PROPERTY	ACRYLIC	POLYCARBONATE
TENSILE (PSI)	10,500	9000 to 10,500
ELONGATION (PER CENT)	5	60 to 100
MODULUS OF ELASTICITY (PSI)	450,000	340,000
COMPRESSIVE STRENGTH (PSI)	18,000	12,500
FLEXURAL STRENGTH (PSI)	16,000	13,500
IMPACT STRENGTH		
(IZOD) FT-LB/IN OF NOTCH	0.4	12 to 16
HARNESS (ROCKWELL)	M93	M78
SPECIFIC GRAVITY	1.19	1.20
LIGHT TRANSMISSION	93	65 to 75
REFRACTIVE INDEX	1.49	1.586

Undesirable factors are that polycarbonate has low scratch resistance and great care must be taken to ensure a reasonable life for the visor. "Rip-off" visors are provided with some helmets and where used properly can extend the life of the visor as well as being necessary to ensure good vision during a race. Dark or smoked visors tend to change certain colours and obscure them completely, also oil on the surface of the road can be obscured. It is recommended that dark visors be polarized although it would not be cost effective or practical to attempt to produce 2.5 mm polarized visor. A supplementary visor of polarized material will suffice.

Polycarbonate is attacked by Hydrocarbons which act as a solvent. A dramatic degradation in the impact strength of polycarbonate is caused when allowed contact with Hydrocarbons.

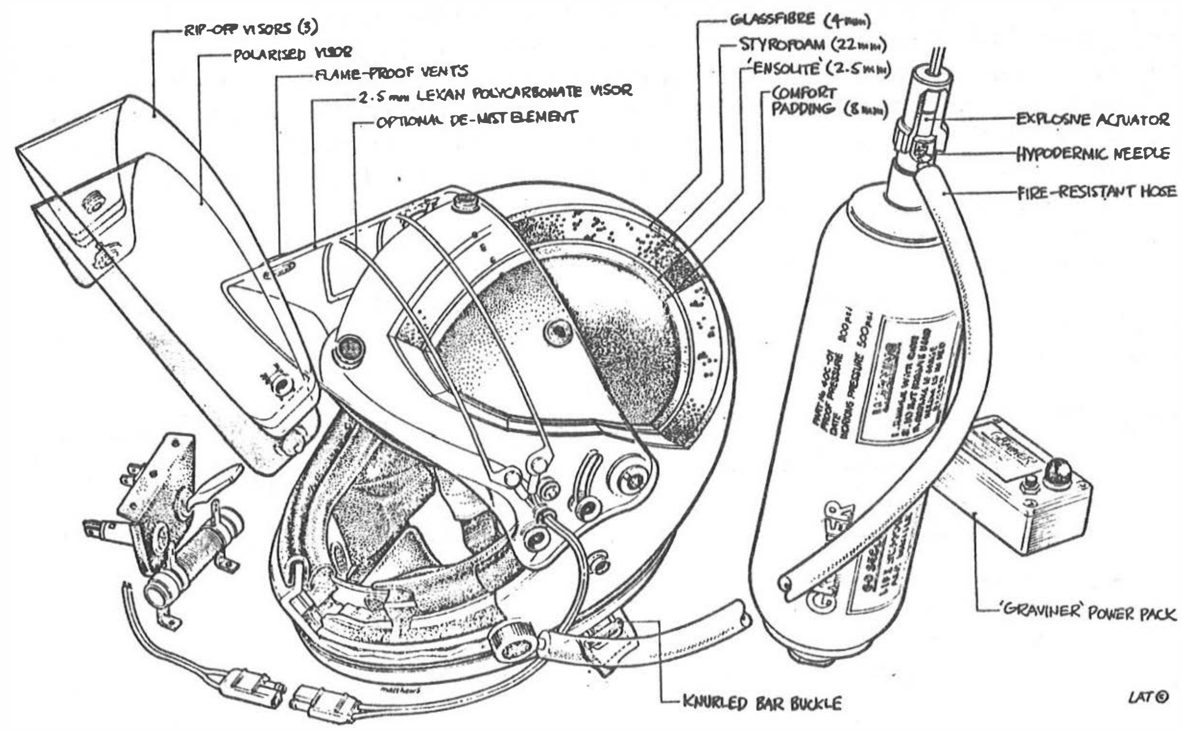

Fig. 1 TYPICAL HELMET USED IN MOTOR RACING

<u>Figure 1</u>

An example of the type of safety helmet now used by racing drivers. Introduced 3 years ago the helmet has proved its efficacy in numerous accidents, however, the emphasis in the design, whilst still meeting the highest mandatory standards, is on primary safety. The pressurized medical air bottle is automatically discharged and air is expelled at a rate of not less than 10.5 litres per minute for a minimum of 60 seconds. The helmet is lined with fireproof material, in the event of fire a unique chin glove ensures flames do not enter the helmet. The 2.5 mm polycarbonate visor is fitted with six fireproof airvents and provision is made for an electrically heated demisting element.

RESTRAINT SYSTEMS

Restraint systems used in motor racing are based on military aircraft six point fixing restraint designs rather than the lap/diagonal systems used in normal road going cars.

The requirement of a good harness system for racing drivers is that it is designed to prevent the wearer moving freely in an accident and coming into contact with the cockpit structure of the car, to reduce the possibility of secondary impact injuries to the driver, and to prevent ejection.

In order to distribute the acceleration load the maximum practical area should be provided by the harness webbing which should distribute the load to the strong parts of the body, i.e. the pelvis and chest, but should not have hardware sited over the bony prominences of the body. Location should ensure retention of the user under violent multi-directional forces acting singly or concurrently. The harness should not fail or the user fail to be retained by the harness up to the level of human tolerance. The seat or its component therefore should not collapse under reversal impacts thereby allowing the harness to become slack.

Aircraft specifications call for a minimal strength requirement of 30 G in the forward and backward and 15 G in the sideways and upwards directions. (7) The harness should provide for energy absorption in the materials of its construction so that the acceleration applied to the user will be minimised. (8) The anchor points must be engineered to ensure effective fixing of the harness under static and crash conditions.

The harness should be easy to fit and release, of simple design with no complex routing and impossible to fit or use incorrectly. The harness should incorporate a pair of over-the-shoulder straps, and lap strap and a negative g strap. The lap straps should be placed so that under impact the straps remain over the anterior superior spines of the pelvis for transmission of acceleration forces. The shoulder straps should be located to prevent an excess of lateral movement. The negative g strap should arise vertically from a point on the centre of the seat so that when fitted for operational use it achieves a snug comfortable fit.

The quick release fitting should be designed so that all restraining straps of the harness can be released from a single fitting. All straps should fall free without need to untangle loops. Road debris (e.g. sand/dust) should not affect the release mechanism, nor should fire.

The position of the harness buckle is low down in the centre of the chassis 'tub' and should be one of the last things to suffer damage in a crash. However, very inflammable steering wheels and seats and restricted cockpit widths create immense problems of rescue in the event of fire.

Seat Belt Harness (Outside Assistance)

Standardisation of release method for seat harness should be considered. Each marshalls' post should be supplied with a large pair of surgical scissors for efficient cutting of the seat belt webbing should this be necessary to free a driver.

Some method of releasing the seat belts by a person other than the driver should be considered. In the event of the structure of the car being deformed or the usual buckle being obstructed a separate method of releasing the driver by a marshall should be achieved. One method would be release pins to the fixed ends of the belt where they locate on the car's structure.

Drivers' Suit Lifting Loops

Driver lifting loops should be completely around the torso of the driver and secure enough to lift the total weight of the heaviest driver.

TRACKSIDE ARRESTER SYSTEMS

The ideal barrier should present a smooth surface to the vehicle to reduce forward deceleration and to prevent the vehicle hooking up, catching or snagging on the barrier. If part of the vehicle gets hooked onto the barrier it may spin round and roll over sideways in the general direction in which it was travelling. The barrier must also be uniformly stiff, i.e. there must be no soft spots into which a vehicle can be driven to form a pocket. When this happens the deceleration of a vehicle can be extremely violent.(9) Continuous concrete walls with a preceding 6 foot wide sand filled bed are now being tested and are showing promise.

Sand Filled Plastic Post: Arrester Forest

Some consideration should be given to the use of serried rows of plastic posts. Use of the standard drain pipe section plastic pipe should be investigated. These could be placed on corners at an acute angle to the direction of a travel of an errant car set in rows with progressive spacing so that a greater density is achieved through the projected linear direction of travel. These posts should be filled with sand. The line immediately in contact with the out of control vehicle would be filled only to a small amount with filling progressively increased through to the greater density of posts the further into the "arrester forest" an errant vehicle might travel.

Fire Retardent Plastic should be used, or an alternative fireproof material considered. Some advantages of the "arrester forest" principle is that it is less susceptible to attack from disadvantageous angles, can be quickly and easily replaced, only the area of forest directly impacted is damaged, materials are readily available, it is durable and easily maintained.

(Also it could prove more effective in preventing injury to motor cycle race riders who, of course, use the same tracks.)

Worn Tyre Carcass Barrier

The principle is being used extensively in North America. The materials are readily available, easily installed and durable. However, the system is aesthetically unpleasing and some consideration should be given to the consequences of fire.

Catch Fencing

In the past there seems to have been little understanding of the mechanics of catch fencing. For posts to have been sawn in half at the base shows a total lack of understanding of the principle. What slows the errant vehicle down is the chopping and destruction of the posts. The wire netting catch fencing is there to effect a greater catchment area. If the posts are removed they must be replaced with something that will require the same amount of energy to destroy. Quite obviously if the posts are cut half-way through they need only be half the diameter.

N.B. The catch fencing should not be nailed or stapled to the post. A method of tying or binding should be used.

Ideally these systems should be utilized on a run-off area that has the same coefficient of friction as the track surface. Wet grass has very low coefficient of friction. The use of very wide tyres with large contact area and high hysteresis qualities ensures that an errant vehicle can slow quickly provided the surface has a good friction coefficient.

Soft Arrester Beds

Some consideration should be given to soft arrester beds (LYTAG). However, it should be noted that the disturbed aggregate (Lytag)(10) will be thrown onto the track surface during an arrester incident and this would constitute a hazard to following vehicles. Such arrester beds should therefore be placed only in areas where other methods of slowing down a car are not viable or at sufficient distance from the track to ensure a hazard to other cars is not caused. Also, a vehicle such as a racing car fitted with wide section tyres and of comparatively low weight may not be slowed as effectively as a normal road vehicle.

Great emphasis is now placed on circuit safety in regard to the racing car driver. It is frequently overlooked that the same tracks are used by motorcycle riders and the two sports are not always compatible in respect of "ride down" systems.

A typical motor racing accident is shown in Figure 2. The hazard to the driver of supporting post in catch fencing is apparent - also the posts have quite frequently been launched into the spectator areas causing injury.

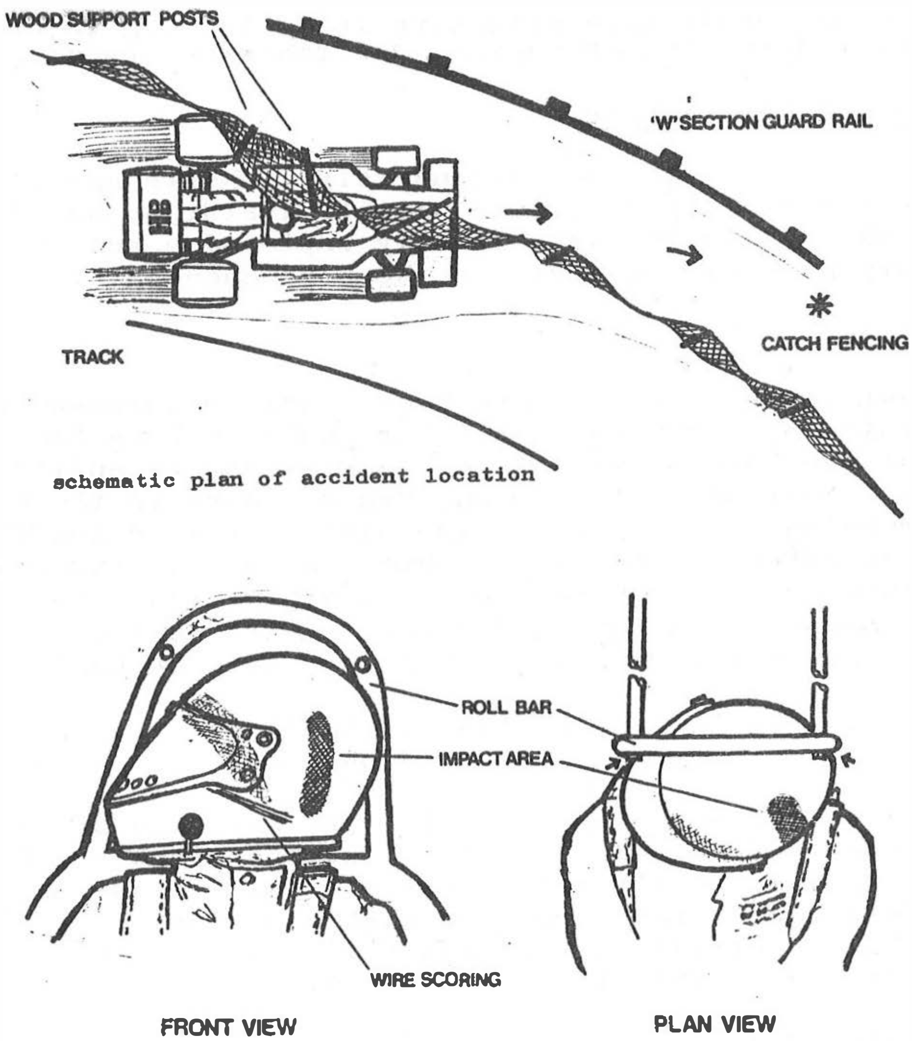

Fig. 2

Roelof Wunderink Accident
Circuit: Zandvoot, Netherlands
Date: 16th May, 1975. PRACTICE - No other vehicle involved
Cause: Probable failure of the left front wheel suspension.
At a speed of about 280 km/hour on a fast curving right hand corner the car went out of control, left the circuit and went into the catch fencing. The catch fencing supported by wooden posts was a single layer fence 2 metres ahead of the 'w' section barrier. Approximately 100 feet of catch fencing was torn up and during the destruction of the fence the driver was impacted several times by the supporting posts. A steel tie wire which was stretched across the post for strengthening also caught on the helmet opening the visor slightly. The driver's head was turned sideways and jammed between the rollbar structure and there is evidence of several massive impacts on the helmet.

The driver survived with a broken cheek bone and was racing 3 weeks later.

ANALYSIS OF ACCIDENTS FOR 1976 GRAND PRIX RACES

NOTE: 89 incidents causing the elimination of at least one car from race, or stopping during practice for repairs. Where the totals do not add up to 89, this is because of accidents which could not be classified from the information available.

1. ACCIDENTS DUE TO DRIVER ERROR (including "oil on track" etc.)

67

2. ACCIDENTS DUE TO CAR

Suspension collapsed	6
Wheel lost	3
Engine seized	2
Brakes failed	2
Tyre punctured	2
Engine cut out	1
Throttle stuck	1
Drive shaft broken	1
Fluid leak onto tyre	1
TOTAL	19

3. HARES AND AIR BOTTLES RUN OVER

1 of each

4. TOTAL OF ACCIDENTS ACCOUNTED FOR

88

5. UNKNOWN CAUSE

1

6. LOCATION OF ACCIDENTS

Corner	67
Straight	4
Start Line	1
Breaking Area	2
TOTAL	74
Not Known	15

7. TYPE OF BARRIER IMPACTED/ EXTENT OF DAMAGE

Catch Fence		
	Heavy	7
	Minor	12
Guard Rail		
	Heavy	12
	Minor	7
Cement wall		
	Heavy	2
	Minor	2
Old Tyres/Kerb		
	Minor	2
	TOTAL	44

CONCLUSION

No helmet standards authority in the world has currently a specification for a motor racing driver's helmet. There is now evidence to suggest the need to provide helmet standards that will cater for the specific requirements of the motor racing driver. In particular, with regard to the question of ventilation and fireproofing. Improved helmet retention, visor protection, aerodynamics and weight distribution would also benefit the motor cyclist to whom the majority of helmets are sold. This latter fact causes problems from a manufacturer's point of view when considering the viability of producing racing drivers' safety helmets.

Currently racing driver seat belts are proprietory units and in the main have proved efficacious. However, retention harness systems should be designed as an integral part of the racing car with more emphasis in future on post accident release of the driver bearing in mind that the car could be inverted, on fire and the driver unconscious.

Regardless of the enormous cost of installation, not enough research or serious consideration has been given in the past to the effectiveness of trackside arrester systems, nor have the side effects been fully explored before installation. The primary consideration must be the protection of spectators and no racing circuit is in itself "unsafe". Provided that the car and its components are properly designed, constructed and maintained to eliminate failure, then the art of the exercise is for the driver to exploit the performance of the car to the limit of his personal driving ability without error. The degree to which he is able to achieve this is the essence of the sport. In other words the circuit becomes as safe or unsafe as the driver wishes to make it. A very considerable responsibility in the area of primary safety rests in the design, manufacture and preparation of the racing car and its proprietory parts.

An enormous benefit would accrue from better reported and investigated accident information which could be quite readily achieved from the closely controlled area of motor sport.

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