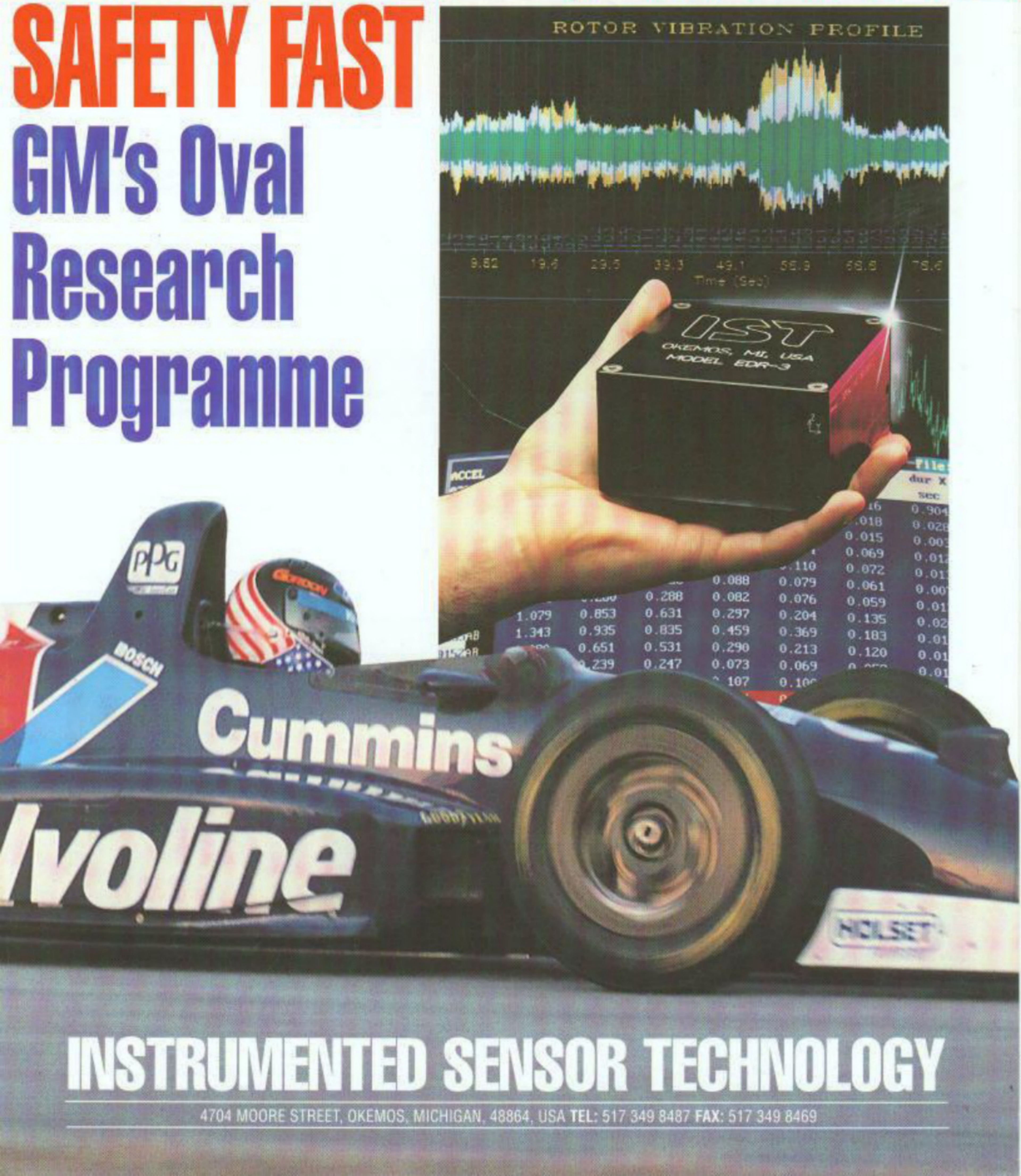
RACECAR ENGINEERING

SPECIAL REPORT

SAFETY FAST

GM's Oval Research Programme



SHORT TAKE

GM MOTORSPORTS SAFETY TECHNOLOGY RESEARCH

Hitting the wall...

All over the world, political walls have been coming down and saving lives — the Berlin wall, Arab-Israeli frontiers, apartheid. If the walls of race tracks came down, on the other hand, the consequences would be dire. However, the walls of secrecy that have tended to surround the accident experiences of motor racing teams have dropped a little, thanks to the formation of GM's Motorsports Safety Technology Research programme which has started its work in IndyCar racing.

By PAUL VAN VALKENBURGH

No motor racing team, nor even motorsports sanctioning body, will ever have the knowledge of impact accidents that has been accumulated by production automobile manufacturers over the past two or three decades. And yet the application of that knowledge to the world of racing can only be fruitless until real, hard data has been obtained from open-wheel or roll-caged vehicles, impacting at multiples of highway speed limits.

Dr Terry Trammell, who has been repairing damaged drivers from IndyCar crashes for the last decade, has accumulated a great deal of anecdotal and human data from these incidents. But it wasn't until GM sponsored the search for an electronic crash recorder that true science entered the picture.

What was needed was a stand-alone device as bulletproof as the familiar aircraft 'black-box' flight recorder, which often documents the final moments of a doomed aircraft. The desired criteria were that the device should be able to measure accelerations up to 200G on three axes, and to digitize the data at 2000 samples per second. It should also have a self-contained battery with a life of a week or more, and it should be essentially invisible to the team and driver.

As it turned out, an off-the-shelf product of a US company, Instrumented Sensor Technology, met these needs. This is a device used to record the abuse that packages get when mailed or shipped. They are not inexpensive instruments, at about $8000 each, but that is probably a lot lower cost than developing something from scratch, and they are indefinitely reusable — allowing for the repairable fatigue damage they get from normal racecar vibrations.

The total event recording time of the IST device is only 1.5sec, beginning at a threshold trigger level of 10G for 5 milliseconds. An IndyCar, say, will often experience 10G vertical impacts when the chassis hits the track over bumps, which gives a false trigger. However, the recording system will

John Pierce's GM Motorsports Technology Group has been analysing racecar accidents with this instrument, the US-made IST model EDR-3 sensor/recorder for shock and vibration. This rugged, battery-powered device, which has a built-in triaxial accelerometer, weighs 1kg (2.2lb) and has been fitted to a number of IndyCars for the purposes of GM's research.

store a maximum of nine events before beginning to overwrite the earliest ones. And the most major event tends to be the last one...

Granted, most teams already have data acquisition systems and accelerometers, but a wall impact would drive their G-force recordings right off the charts, if not destroy them entirely.

Come the month of May, 1993, and the Indianapolis 500 race meeting, a few of the IST units had been installed and, as accidents happened, the data began to flow. The manager of the GM programme, John Pierce has been present at each subsequent IndyCar race to maintain the units, and has immediately downloaded the data to a portable PC after any impact. Ultimately, the data is analysed by John Melvin, Senior Staff Engineer at GM Research in Detroit, who is trying to accumulate a database large enough to indicate what "typical" racecar accident profiles look like.

To avoid embarrassing any team or driver, and also to avoid any legal complications, any release of specific data has to be approved by the sanctioning body. In the interest of speeding up the dissemination of useful engineering information, however, a generic and anonymous "typical" data plot was provided for this article (see panel). It illustrates the impact when a single-seat IndyCar strikes a solid wall of a speedway at high speed.

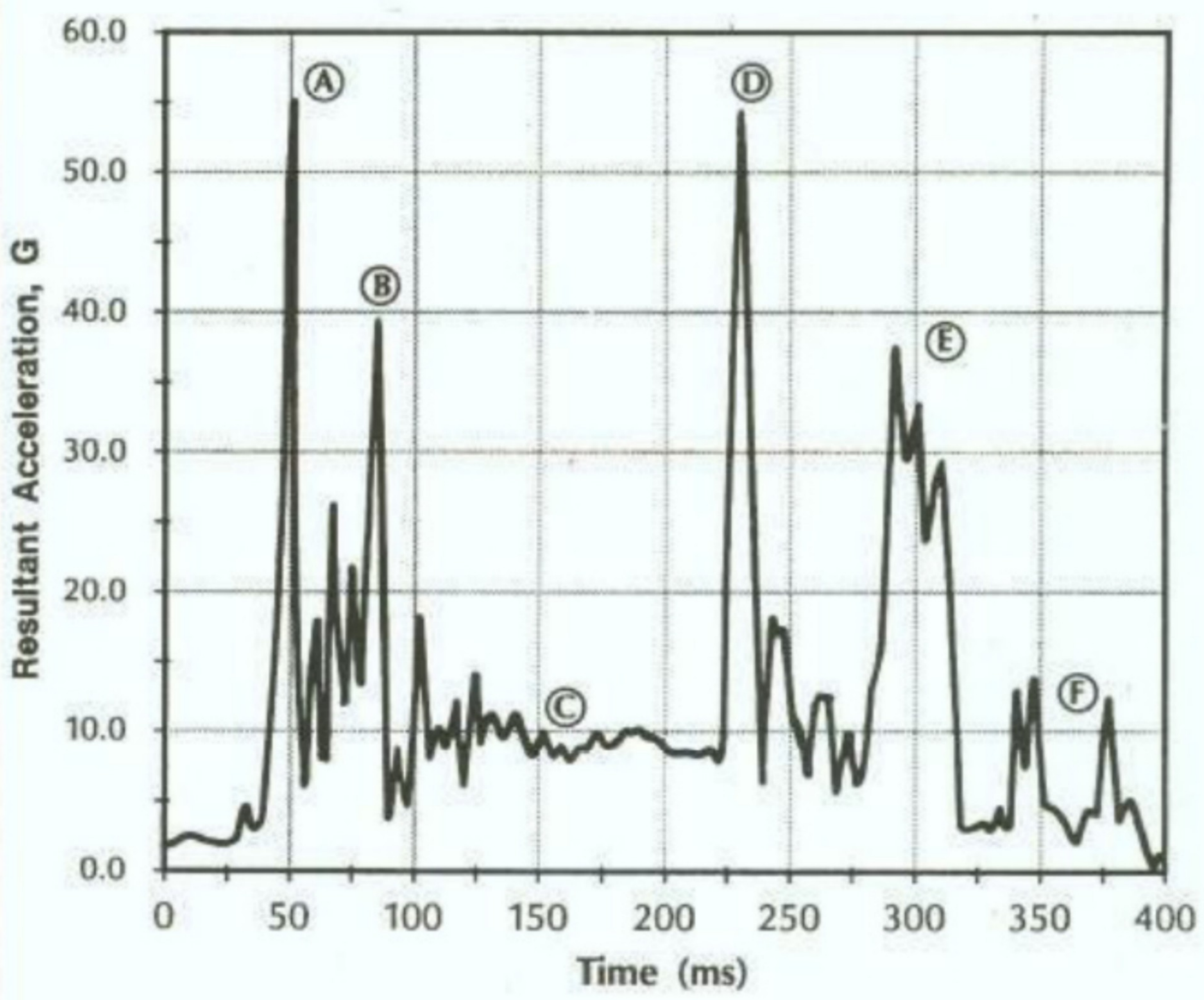
Although three channels of accelerations are taken (fore/aft, lateral, and vertical), for the purpose of looking at the most severe forces, this plot simply shows the resultant maximum vector in any direction. The vertical component is irrelevant as long as the racecar does not overturn, which is apparent in this case from the released illustration of the vehicle dynamics of the impact.

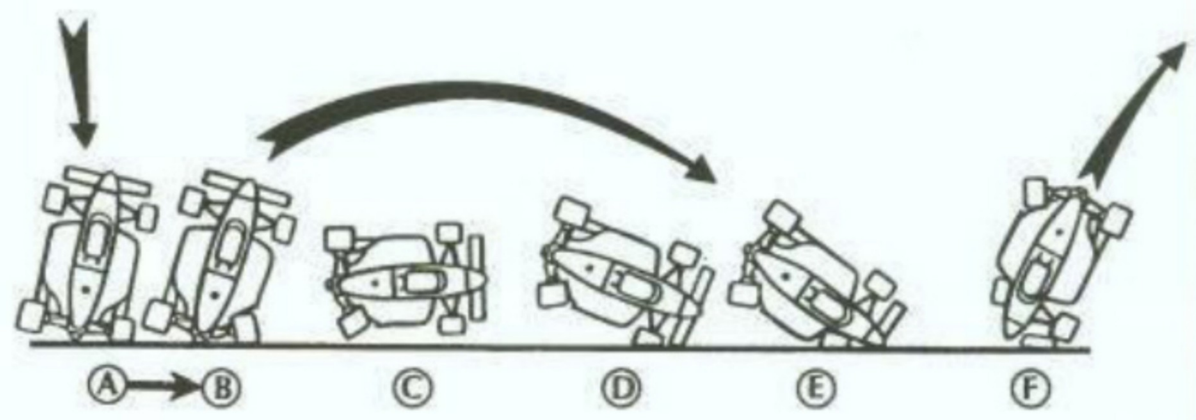
As a verification of the type of data shown in the panel, video coverage is obtained for frame-by-frame timing analysis of speeds and displacements. In this instance, footage that happened to be shot parallel to the wall proved that the actual perpendicular velocity at impact was about 60mph. Also, John Melvin has found that advanced composites racecar chassis leave a good record of total crush distance, as they destruct with little rebound. For example, one nearly perpendicular frontal impact at 60mph collapsed the nose about 42in, proving the value of nosecone impact tests.

So the panel shows the official word — now what does it all mean? What else can we infer?

What GM is going to find most useful is the shape of the impact pulse, for use in their impact sled crash simulator. In one preliminary simulation, a 40G deceleration was applied to a dummy seated and restrained in the typical racecar position, as shown in the photographs (they are badly grained due to the high-speed 16mm film, and shooting reproductions off a pro- ▶

HIGH-SPEED RACECAR COLLISION WITH A SOLID WALL





THE DATA HAS BEEN SLIGHTLY REVISED TO maintain the confidentiality of the driver and team, but the resultant plots are typical of a high-speed IndyCar crash into a solid barrier. The driver sustained no injuries. The analysis is based on a video film of the general vehicle path, and crash dynamics data from the onboard impact recorder.

The data shown is resultant of the combined longitudinal, lateral, and vertical accelerations of the car produced by its interactions with the wall. The acceleration is plotted in G *versus* time in milliseconds. The attitude of the car as it approached the wall was backwards and slightly past perpendicular to the wall, as shown. The sequence of events was as follows:

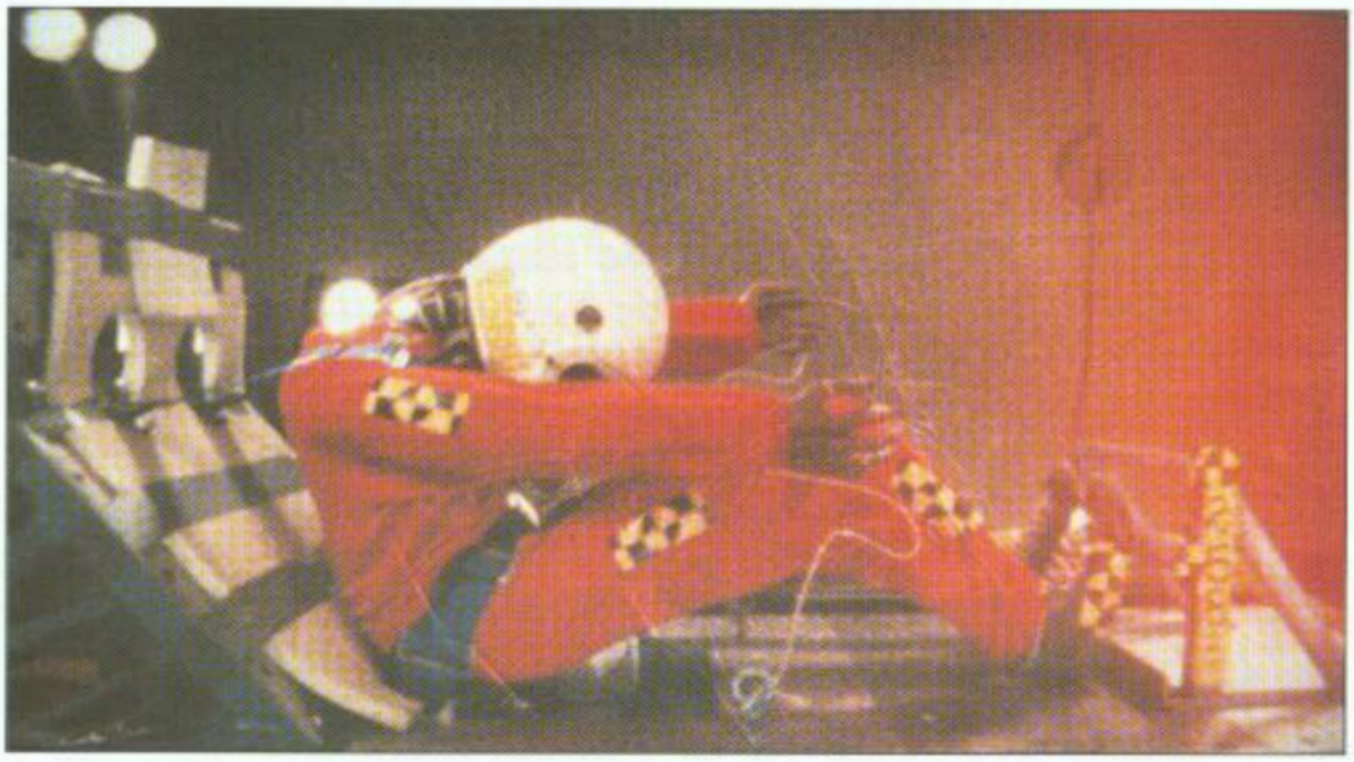
EVENT A The rear of the gearbox strikes the wall, producing a longitudinal acceleration of short duration (10ms) with a 56G peak. The right rear wheel then strikes the wall and the suspension crushes, transmitting the impact into the chassis, and producing the continuing 10-20G acceleration until...

EVENT B The suspension (tyre) bottoms out against the chassis and produces a peak acceleration of 39G, which is followed by rebound of the car from the wall and clockwise rotation of the car. The sequence from A to B takes 0.05sec.

EVENT C While the car rotates, a longitudinal acceleration of about 10G is indicated by the spinning of the car about its centre of mass. This acceleration, which appears as a steady state value for about 0.125sec, is probably not longitudinal, but centrifrugal acceleration due to the location of the transducer not being at the centre of rotation. If we can infer that the car rotated about 90deg in that time, then the angular rate would be 0.5sec per revolution. Using the equation G = 1.22 x radius/time squared, the radius of the rotation would therefore be about 2ft.

EVENT D The car strikes its right front wheel against the wall, resulting in a peak lateral acceleration of 55G and a duration of 0.015sec. The car continues to rotate until...

EVENT E The nose and side structure impact the wall, producing a peak lateral acceleration of 37G with a duration of 0.030sec. The front of the car then rebounds off the wall and continues the spinning motion down the track.



▶ jected image). But now, instead of a steady pulse, the wave form spikes can be included, if the sled can be "souped up" enough to the level of racecar performance. Then, by using the typical anthropomorphic dummy with its dozens of accelerometers, it will be possible to learn what the driver actually experiences.

As it is, the accelerometer package only indicates what G-forces the chassis receives. Due to belt stretch in frontal impacts, and helmet/seat/uniform padding and soft body tissue in other impacts, many of the so-called 'spikes' in the impact pulse are filtered out.

This test is equivalent to the old carnival stunt of a "strong man" lying down with a block of concrete on his chest, which someone breaks with a sledgehammer. The block could receive a 50G impact, but not the man, due to the mass inertia of the block, and the distribution of the force over a large, fleshy area.

On the other hand, things can get worse. As instrumented dummies show, and indicated by the sled photos, whip of the head and neck can amplify head impact forces to over 100G. It's not a simple problem.

So, even though there are high-G spikes in the data plot shown in the panel, it probably works out to a fairly tolerable pulse to the driver, after all. It might be nice to have a smooth, steady deceleration at a constant 20G, but the space and engineering challenges make it almost unattainable, anyhow. Decades of experience, intuition and luck have produced what appears to be a relatively safe package.

In this crash, for example, after the first violent impact of the transmission case, there appears to be a series of three smaller peaks, probably caused by the collapse of different suspension links, before the tyre hits the tub. Also, the glancing blow, and subsequent rotation of the chassis, allows crush distance to be spread out instead of being concentrated at one point. Granted, this seems to have been a fairly benign crash (except to the driver and car owner) in that it was not fatal. Unfortunately, perhaps the most valuable information would come from an impact in which the driver is not so lucky, so as to bracket what the human limits of tolerance are.

This is pretty exciting stuff. Not since the widespread adoption of fuel cells has there been such a potentially valuable technical contribution to racecar safety. It should lead to new recommendations for component locations and strengths, especially in the collapse mode. It could also lead to changes in barrier design, or better driver restraints.

The automobile industry may even benefit from racecar accidents, as this system can provide real-world (if not perhaps truly representative) data that could not be obtained without instrumenting random passenger cars in everyday use. ■

GM's research has included subjecting a dummy, wearing a racecar harness and a typical race helmet, to a deceleration of 40G on an impact sled test rig. The whiplash effect can amplify head impact forces to as much as 100G.

SUMMARY OF THE DYNAMICS OF A CRASH

ALL TOO OFTEN, WE HEAR EXAGGERated estimates of the speed at impact after racecar accidents — as in, "He was doing 200 at Indy when he went straight into the wall!"

Trust me on this — if any racecar hit a concrete barrier head-on at 200mph, after the mushroom cloud subsided, the total unrecognizable mass would probably be about two feet thick.

But if you have enough data, the true impact dynamics can be easily estimated, and fairly closely. All it really requires is one irrefutable law of physics: $V^2 \times .033 = G \times d$, which shows that the change in speed squared, multiplied by .033, equals the G multiplied by the stopping distance in feet. It also requires one very crude rule of thumb: the maximum impact a human being can survive without serious injury is about 50G.

The survivability criteria present a very complex physiological problem that has been under serious research for over three decades. It depends on the direction of impact, the duration of the G-forces, the distribution of the G-forces, the health of the victim, and so on. Lower G-forces spread over a longer period is always better, but it's a tradeoff in the equation against stopping distance available: halving the G-forces requires twice the distance.

The real secret to survival at barrier tracks is the pre-impact skid and the glancing blow.

First the skid. When a car breaks loose and goes sideways in a turn, it's just like jamming on the brakes. At speed in an IndyCar, the deceleration due to skidding tyres and aerodynamic drag (especially sideways) will be over 2G.

Looking at typical skid marks on the Indianapolis Motor Speedway, the distance from the apex breakaway point to the wall somewhere down the track could be about 200ft. Going back to the equation, that calculates to a deceleration of about 110mph. So the car is only going about 90mph at impact — which still isn't something to look forward to...

Since the car is travelling diagonally across the track, it will never hit directly, but at some glancing blow, with speed vectors perpendicular to and parallel with the wall.

If the angle happens to be 45deg, say, then each of the two speed vectors will be about 70% of the total, or in this case about 65mph directly perpendicular to the wall. Still no fun...

Using the equation a different way, to stay below the nominal 50G limit would require almost 3ft of crushable space — an expensive commodity in an open-wheel racecar.