On the safe side

A US safety standard is said to fail to adequately test vehicles' side-impact protection. Byron Bloch looks at the principles that should be integrated into vehicle design to improve crashworthiness in such impacts

■ If a vehicle is to be deemed reasonably crashworthy, it must sufficiently protect the driver and passengers from severe or fatal injury in collision accidents, including side impacts with other vehicles and roadside objects. And if crash testing is to be valid, it must be relevant to what happens in real-world accidents. Unfortunately, that hasn't been the case with Federal Motor Vehicle Safety Standard 214 (FMVSS 214), as established in the USA, and emulated in other nations. This so-called safety standard has fallen far short of ensuring that complying vehicles offer sufficient or optimal protection in side impacts.

In the USA, the National Traffic and Motor Vehicle Safety Act of 1966 established the Federal Vehicle Safety Agency. Its mandate was to issue safety standards as minimum requirements that vehicles must comply with. The NHTSA was thereby created and empowered to draw up a set of rules – the Federal Motor Vehicle Safety Standards (FMVSS) – which must be fully complied with before an auto maker can sell its vehicles in the USA.

In the USA, compliance to those minimum requirements does not absolve auto makers from any potential legal liability borne out of defective designs that don't offer reasonable protection in actual collision accidents. Therefore, the FMVSSs are not an assurance that a vehicle is appropriately crashworthy, and a vehicle could be judged well below what is available and feasible as an alternative, safer design.

Design improvements for increased passenger protection

Strengthen the rocker sections and the floor pan
High-strength steel, internal baffles, and rigid-foam filling to increase compressive and bending strength by a factor of at least three to five times, so that outboard rocker sections are analogous to a strong full-perimeter frame.

Lateral cross members for floor pan and roof
Tubular closed-section cross-members with internal baffles and/or rigid-foam filling, to help transfer loads from the impacted side to other structural members across the vehicle body.

Strengthened doors with perimeter overlap
Mid-level and high-level beams (to prevent override), integrated fore-and-aft for a continuous 'guardrail' design, with the door overlapping its surrounding perimeter and B-pillar to prevent the door(s) from being pushed inward.

Energy-absorbing foam padding in the interior
Polyurethane or other semi-dense polymeric foam to absorb impact energy and minimize trauma to the occupant's head and chest.

Side-window laminated glazing
Laminated side-window glass, rather than tempered glass, will remain relatively intact and serve as a support for side-curtain airbags and as a 'life-net' to prevent occupant ejection.

Side-torso and side-curtain airbags
Inflatable airbags to cushion and reduce impact trauma to the occupant's head and torso.

Stronger wraparound seats with integral belt restraints
Wraparound contour of the backrest to help stabilize and reduce lateral movement of the occupant in side impacts, with integral seatbelts that tighten with pre-tensioners.

The initial side-impact test requirement in the early 1970s was a 'slow push' laterally by a cylindrical device into the middle of the door, but there was no crash test requirement as such. The previous static test (slow push) was superseded by more stringent loads applied to the doors to measure the initial, intermediate, and peak crush resistance (not less than 3.5 times the vehicle curb weight or 12,000 lb, whichever is less) required to deform the door inwardly over the initial 6in, then 12in, then 18in.

NHTSA upgraded FMVSS 214 in 1990 by adding a new dynamic side-impact test by a moving deformable barrier (MDB) at 33.5mph, but there was no measurement of any impact forces to the test dummy's head. Nor did the moving barrier override the target vehicle's rocker section, as occurs in many real-world accidents. The test focused on thoracic and pelvic injuries in a side-impact crash test by a crabbed (angled) 3,000 lb MDB, simulating a moving vehicle being struck in the side at 90°. The chest-injury criterion was Thoracic Trauma Index (TTI), based on measured acceleration data from the ribs, spine, and pelvis of the test dummy, and the TTI did not exceed 85g for four-door cars, or 90g for two-door models.

In 1995, NHTSA issued a final rule amending FMVSS No. 201 – Occupant

Left: 2004 saw GM conduct its 15,000th crash test at its proving grounds in Michigan, USA, evaluating a Pontiac G6
Above and below: Similar work being carried out in the crash test laboratories of Saab and Volkswagen, respectively

Protection in Interior Impact – to require passenger cars, trucks, buses and multipurpose passenger vehicles with a gross vehicle weight rating of 4,536kg (10,000 lb) or less to provide protection when an occupant's head strikes certain upper interior components.

In 1998, NHTSA published a final rule amending Standard 201 to permit, but not require, the installation of a dynamically deploying upper-interior head-protection system. Manufacturers choosing to install a head-level airbag had to subject their vehicles to a free-motion head-form test at a speed of 12mph, and an 18mph perpendicular vehicle-to-pole test.

Even with Standards 214 and 201 there continue to be a large number of fatalities occurring in side impacts resulting from a variety of crash types and outcomes. Fatalities occur when an occupant strikes a tree or pole; when the striking vehicle has a high front-end, such as a taller pickup, SUV, or heavy truck; when the occupant is ejected out of the side window; and when the crash is of high speed or high severity, even when the striking vehicle is a passenger car.

The death toll in side impacts in the USA is now well over 9,000 per year for passenger vehicles and LTVs (larger, heavier, taller vehicles). The frequency of fatal injuries is three or four times more likely if the striking vehicle is an LTV impacting into the side of a passenger car. This issue, known as a 'mismatch', is not yet considered within the FMVSS testing procedures.

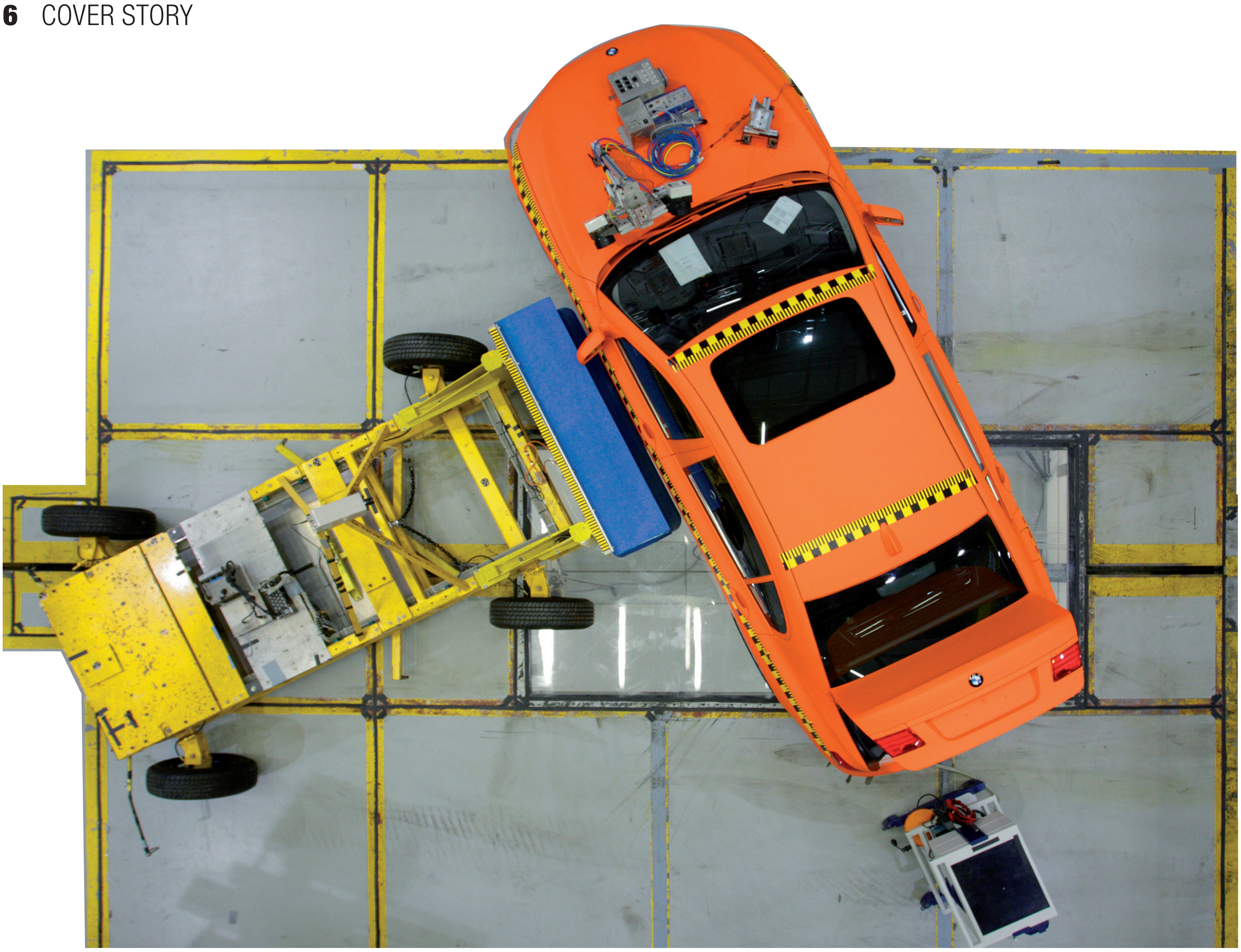
> **"The death toll in side impacts in the USA is now well over 9,000 per year for passenger vehicles and LTVs. The frequency of fatal injuries is three or four times more likely if the striking vehicle is an LTV impacting into the side of a passenger car"**

The latest rule upgrade will modify FMVSS 214 by requiring all passenger vehicles to provide protection in a 20mph, 75°, oblique vehicle-to-pole test by simulating a collision sideways into a narrow fixed object, such as a telephone pole or tree. The pole test will be conducted using a 5th percentile female dummy seated full-forward, or a 50th percentile male dummy seated at the mid-track position of the front outboard driver or passenger seats.

In many side-impact accidents, the impacting vehicle may be larger, taller, heavier, or structurally stiffer than the struck vehicle. For example, a large SUV, pickup or van weighing more than 5,000-6,000 lb may impact into the side of a compact or mid-sized automobile weighing 1,800-3,600 lb. In such a mismatched collision, the larger vehicle will often override the struck car's floor pan and rocker section, loading directly into the mid-body or B-pillar.

Although the mid-body B-pillar may pass the FMVSS 214 compliance test by the 3,000 lb MDB that engages the rocker section and floor pan, the B-pillar may be structurally inadequate and vulnerable to being ripped away at the point where it's attached to the rocker section and/or roof side rail if impacted by a larger vehicle. It is clear that the side-impact crash-test protocol must include more realistic impacts by a larger vehicle, or by a moving barrier that's heavier and taller.

As GM Europe (Opel) stated in its 1993 publication, *Vehicle Safety*, "Because test



standards are often too theoretical, the test program for Opel models focuses on reality – on real accidents on European roads. From analyses of the most frequent types of accidents, Opel has developed test procedures that allow a more reliable simulation of reality… Typical accidents at junctions, such as lateral impacts at an acute angle… with vehicles of various weight classes also belong to the test program."

The text continues, "Side collisions are among the most dangerous car accidents. While in frontal and rear-end collisions the occupants can be well protected by deformation elements placed outside the occupant cell, there is no room for such crush zones in the body's sides."

Opel showed the various side-impact crash tests it conducted, including moving-barrier-into-car at various impact angles, and car-to-car.

In the USA and Europe, the many sizes of vehicles on the roads has prompted greater concern for more stringent crash testing. But in a nation where the populace simply wants affordable basic cars, there may be less demand for more stringent crash testing. International harmonization may be a desirable goal, but not if it settles for the weakest performance requirement.

The Tata Nano, a small car made in India, weighs approximately 600kg (1,320 lb) and costs about US$2,500-3,000. Would the Nano be able to pass a side-impact crash test at 33.5mph by a 3,000 lb moving barrier in order to comply with FMVSS 214? And will side-curtain and side-torso airbags be standard equipment, or available as options, in India and export markets?

Another small car, the Smart, boasts about its crashworthy design, given its weight of about 730kg (1,609 lb), and its cost of about US$12,000-17,000. Crash forces are distributed by a strong Tridion Safety Cell, much of which is high-strength steel, with many interconnected tubular elements, and further reinforced in highly stressed areas. The rigid safety cell is designed to maintain the occupants survival space for protection in all crash situations. The Smart car also includes two full-size frontal airbags, and two side airbags for head and thorax protection.

If crash testing is to have validity, it must include measurements of the forces experienced by the occupants relative to injury causation. Yet a glaring weakness in the FMVSS 214 testing protocol has been the absence of any measurement of forces to the test dummy's head or neck. It is imperative that the measured forces correlate to hyper-flexion and hyper-extension injuries (X-axis), shear injuries (Y-axis), and compressive injuries (Z-axis), respectively.

The range of test dummies should be more expansive, and include the 5th percentile adult female, the 50th percentile adult male, and the 99th percentile adult male, as well as infant and child dummies. It is insufficient to use only 50th percentile adult male test dummies. Consideration should also be given to fragile elderly passengers and larger or obese car occupants, who may require adjustments to the seats and seatbelt restraints beyond their normal design range.

The pending upgrade for FMVSS 214 will be phased in gradually, beginning with at least 20% of each manufacturers' 2010 fleet, expanding to 50% of the 2011 fleet, 75% of the 2012 fleet, and then all vehicles manufactured after 1 September 2012. The new FMVSS 214 upgrade includes new performance requirements and test procedures for head and thorax protection systems in side crashes.

The rule requires a new 20mph, 75°, oblique pole test run in two different configurations, one with a 50th percentile male (ES-2re) dummy, and the other with a 5th percentile female (SID-IIs Build D) dummy. In addition to the oblique pole test, the rule requires the MDB dynamic FMVSS

Left: The latest generation BMW 7 Series captured just a moment before a side impact test
Above: A Mercedes-Benz C-Class at the moment of impact. Note the minimal occupant cell intrusion

214 side-impact test to be carried out with the ES-2re in the front seat and the SID-IIs Build D in the rear seat.

NHTSA states that side airbags for the head and thorax will most likely be used in order to pass the tests, with the addition of door padding, improved armrest designs, and larger side-curtain airbags that come down to the window-sill area, giving better protection to smaller occupants. The estimated costs range from wide, combination head/thorax side airbags with two sensors, at US$126 per vehicle, to separate wide window curtains, and wide thorax side airbags with four sensors, at a cost of US$280 per vehicle.

The ESV (Enhanced Safety of Vehicles) conference showed the feasibility of safer designs. Auto makers were asked to design and test vehicles that could meet a variety of crash-test and crashworthiness requirements, including those for side-impact protection. The tests included a moving-pole side impact at 20mph, and a car-to-car side impact at 32mph. Many vehicles complied with the occupant protection requirements for head, chest, and pelvic injuries, and that was back in the mid-1970s.

At the 1974 ESV Conference, Opel incorporated ESV technology in a modified version of its Kadett sedan. The article noted, "In side impacts – car-to-car, as well as side pole – intrusion characteristics were tailored to the interior survivability space. To control the penetration of the passenger compartment, we filled the door side bars and rocker with polyurethane foam. Bending tests with foam-filled elements showed that the bending load capability for local pole-type loading can be increased drastically."

Side-impact crash tests verified the occupant protection capabilities of the Opel ESV. GM noted that, "The high location of door beams ensured prevention of override for the bullet-car in angular impacts; such a design serves to improve fore-and-aft strength in front and rear impacts."

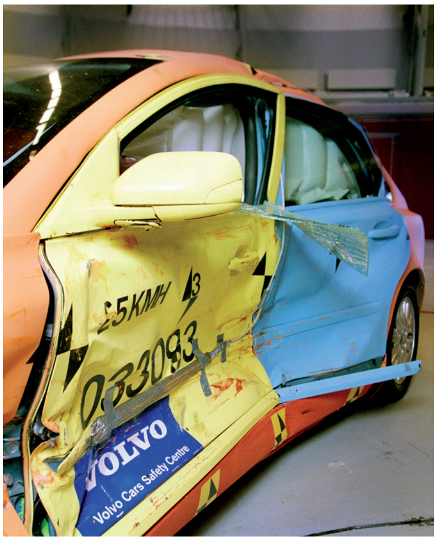
GM showed how rigid foam could dramatically improve vehicle structures. Its engineers demonstrated how the simple and economical use of rigid-foam filling within sheet-metal tubular members could increase their bending and compressive strength.

Rigid-foam strengthening technology was feasible, lightweight, and inexpensive. Many production vehicles have since adopted foam filling to increase the stiffness and strength of various body parts, greatly strengthening the rocker sections, door beams, roof cross-member, and other elements.

Opel also showed how dual door-beams were needed to prevent side-impact intrusion. A safety-cage design is critical, with integration of all the structural elements so as to efficiently distribute forces in a collision, and thereby avoid failures and ruptures at weak links.

Opel's rationale is that crash tests allow a near-authentic simulation of the most common types of accidents. To quote Opel's vehicle safety literature, "Because test standards are often too theoretical, the test program for Opel models focuses on reality… on real accidents on European roads… Typical accidents at junctions, such as lateral impacts at an acute angle…" So despite the promise of safer designs and technology that was demonstrated as feasible in the 1970s and 1980s, NHTSA and other government vehicle safety agencies neglected to advance the safety standards so that they would require more stringent testing and improve side-impact testing.

Some auto makers also relaxed their corporate requirements, deciding to do only the minimum, or just a bit more, than was required by the NHTSA. The US FMVSS 214 standard was finally upgraded to include a 33.5mph crash test by a deformable barrier in the mid-1990s, and now there is a new oblique car-into-pole test at 20mph being phased in for 2009. But these requirements are still far too minimal to ensure optimal safety in side-impact accidents.



Side impact testing at the US81 million Volvo Safety Center in Sweden. The deformation, coupled with the deployed airbags, aids passenger safety

Based on detailed evaluations of what happens in real-world accidents, plus the feasibility of well-tested technologies, an overview of basic side-impact safety features that should be integrated into a vehicle's design can be created, as shown on page 4. The object is to minimize intrusion into the passenger survival space, and to encourage deflection of one vehicle off another.

As more nations expand their vehicle production programs, especially China and India, the depletion of valuable resource materials to manufacture tens of millions of vehicles per year, plus their fuel consumption requirements, suggests it's time for some revolutionary designs. If vehicle weight and cost must be minimized, and fuel efficiency and recyclability must be maximized, what happens to safety and crashworthiness? Will less attention to safety result in more deaths and injuries, and is any nation willing to accept such a trade-off? In other words, what happens to compassion in car design?

When we look at the traffic mix in many nations, there is an extraordinary variety of vehicle sizes, shapes, and weights, so that a mismatch collision might concern a large SUV impacting into a small sedan. Should this mismatch require that vehicle design and side-impact crash testing accommodate such collision accidents of larger, heavier vehicles impacting into the sides of smaller, lighter vehicles? And if so, to what extent?

Governmental safety standards are only a minimum, and should not be relied upon by auto makers or the motoring public as assurances that vehicles are reasonably or optimally safe in actual collision accidents. Performing well in a laboratory test may not predict safe performance in a real-world collision. As has been demonstrated by the ESV conferences since the early 1970s, there are many feasible and economical technologies that can greatly improve crashworthiness.

It is up to the auto makers, the public, and government agencies to encourage safer vehicle design and performance, which will in turn reduce or eliminate the number of deaths and severe injuries in side-impact accidents. If the automobile is to survive as a mode of transportation, it must become more efficient in its use of materials, fuel and its effects on the environment, and much safer in collision accidents and at protecting passengers in those accidents.

Case study

An instructive legal case is Rider versus BMW, which arose out of an accident in which a 1986 BMW 325 two-door sedan impacted its right-front door into a roadside utility pole. The resulting deep intrusion into the BMW's 'survival space' caused fatal head injuries to the driver, who was seated on the left-hand, or far side, of the vehicle. His seatbelt proved ineffective in preventing excessive movement of his upper torso and head toward the right as the pole simultaneously intruded leftward deep into the vehicle's interior.

The vehicle design issues included the short subframe members that were too far inboard to provide perimeter protection, with a structural gap between the front and rear subframe members; the absence of structural cross-members at the floor pan or roof levels; the inner-door beams that were not integrated with continuous strong side structure. In total, there was minimal structural resistance to side impacts.

I testified in the trial as an expert in automobile safety and crashworthiness, and showed both the defective design at-issue and the safer alternatives that were both well-known and feasible, and which would have prevented the fatal head injury.

The jury decided in favor of the plaintiff, and BMW appealed. In 2008, the New Jersey Appellate Court confirmed the verdict. The court stated, "Where the design of a car is at issue, reasonably foreseeable

accidents are a reasonably foreseeable use of the car, and reasonable, foreseeable measures to protect the integrity of the passenger compartment and the passenger in such accidents are part of a safe design."

It is important to note that the defective design analysis for the BMW at-issue would also apply to many other vehicles that have similar deficiencies.

Other vehicles also have short, inboard subframe members as a structural gap in the mid-body area, weak rocker sections without internal baffles, and a lack of structural cross-members at the floor pan and roof levels.

Yet, despite such structural shortcomings, these vehicles would still comply with the minimal requirements of FMVSS 214, underscoring the fact that compliance with an impressive-sounding 'Federal Motor Vehicle Safety Standard' is no assurance that the vehicle is reasonably, let alone optimally, safe.

ABOUT THE AUTHOR

Byron Bloch is a court-qualified auto safety expert in the USA. For 40 years, he has evaluated collision-accident vehicles and exemplar vehicles to assess how and why occupants were severely injured or killed. He has testified at US Congressional Hearings, to NHTSA, and in court cases on vehicle safety topics. His website is: www.autosafetyexpert.com