BA Falcon Intelligent Safety Systems - A Systems Engineering Approach

Bruce Priddle[1] (Presenter); Ian Singleton[1]; Ming Loo[1]; Mark Fountain[1]
[1]Ford Motor Company of Australia Ltd.

Biography

Bruce Priddle is the Manager of Environmental and Safety Engineering for Ford Motor Company of Australia Limited.

In this position, Mr. Priddle is responsible for assuring regulatory compliance of all vehicles sold in Australia and for liaison with government regulatory agencies and other organisations on product safety and environmental matters.

After graduating from Deakin University with honours in Electrical Engineering, Mr. Priddle joined Ford Motor Company in 1980 on the Graduate (Management Trainee) Program. Since then he has held a number of Product Development positions involved with designing, testing and developing a variety of vehicle systems, the last 15 years being in management roles.

In his current role, Mr. Priddle acted as the BA Falcon Safety Attribute Leader, responsible for leading a multi-disciplined engineering team to deliver specific product safety objectives and was closely involved with the launch of the BA Falcon.

Mr. Priddle lives in Geelong, Victoria, with his wife and two sons.

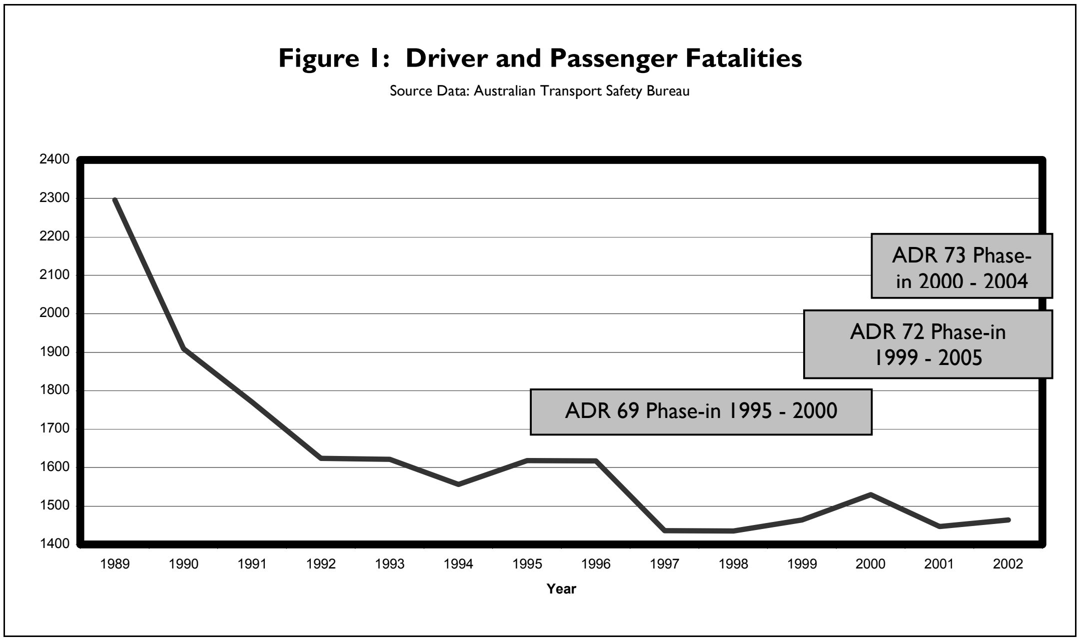
Abstract

Road safety is a classic systems engineering problem. It involves three main systems; the road environment, the vehicle and the driver. While each system can contribute individually to improving safety, the reliability of the road system depends heavily on the interactions between these three systems with road trauma invariably the consequence of a system interaction failure. In advancing in the direction of a "Vision Zero" each system must be designed with the other in mind so that the interfaces can be managed optimally. This was the philosophy applied to the BA Falcon Intelligent Safety Systems. This paper describes the BA Falcon safety features, designed to manage the interfaces between the vehicle occupants and the road environment, which deliver significant advances in vehicle safety. The paper also describes how systems engineering was employed to cascade high-level vehicle design targets down to system, sub-system and ultimately component level so that the role in delivering the high-level safety objectives is understood for each part of the vehicle system.

1. INTRODUCTION

Historically, the pursuit of ever-increasing vehicle crash safety has been the domain of body structure and restraint engineers. More recently developments in computer aided engineering and predictive finite element models have allowed these two disciplines to collaborate to take a total-vehicle perspective in improving occupant protection in the early phases of vehicle design. This was the beginning of a total-vehicle system approach where the importance of understanding vehicle system interactions became critical.

To date this approach has contributed substantially to the reduction of Australian road trauma. However, if fatalities are assumed to reflect the general trends in road trauma, figure one suggests that progress has slowed as significant gains in occupant protection become more and more difficult to realise.



As major occupant protection regulations are phased in from 1995, and these penetrate the vehicle fleet with an average age of 10.5 years, we expect to see further gains but these may not be sufficient to achieve the 2010 National Road Safety Strategy fatality targets of 5.6 per 100,000 people. In any case, the only acceptable number is zero.

We need to do more and one of the greatest opportunities for further advances exist in applying Systems Engineering to manage the interfaces between the vehicle occupants and the road system. Access to sophisticated occupant protection technologies and advanced computer aided engineering tools have enabled Ford to adopt such an approach to the design of BA Falcon Intelligent Safety Systems.

Before describing the BA Falcon Intelligent Safety features and their benefits in detail, it is useful to briefly explain how systems engineering principles were applied to the BA Falcon.

2. THE VALUE OF SYSTEMS ENGINEERING

Road safety is a classic systems engineering problem. It involves three main systems; the road environment, the vehicle and the driver. While each system can contribute individually to improving safety, ultimately the safety of the road system depends heavily on the interactions between these three systems with road trauma invariably the consequence of a system interaction failure. In advancing in the direction of a "Vision Zero"[1] each system must be designed and validated with the other in mind so that the interfaces can be managed optimally. This was the philosophy applied to the BA Falcon Intelligent Safety Systems.

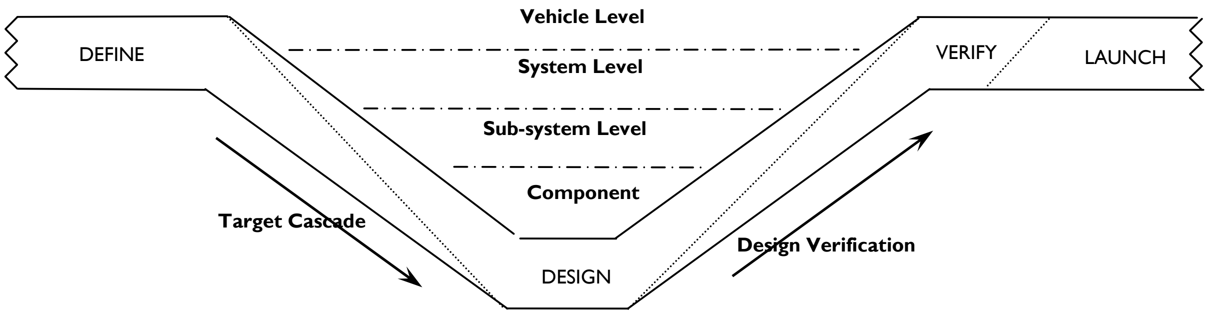
Fundamentally, Systems Engineering recognizes that the performance of a system is greater than the sum of its parts. Conversely, this also means that if there is a failure within any one of the system components or their connections, the whole system fails. Therefore, not only must the components of a system function independently they must also interrelate well with each other. Understanding these interfaces is the key to the Systems Engineering. The inputs and outputs of each part of the system and sub-system must be understood along with how each output is affected by down-stream components or sub-systems. Only by

[1] Tingvall, C & Haworth, N. (1999) Vision Zero – An Ethical Approach to Safety and Mobility. 6th ITE International Conference, September 2000, Melbourne

understanding these relationships can high-level objectives be cascaded down to sub-systems and components. The primary objective is to link every performance outcome, right down to component level and directly back to a customer performance requirement. (see V-Diagram in figure 2)

This requires that the high-level system attribute; in this case, Road Safety, be "partitioned"

Figure 2: Systems Engineering V-Diagram



into sub-systems for the purpose of target setting and outcome validation. The way a system is partitioned is as important to success as the targets themselves. Since road trauma reduction is of primary interest, Ford engineers chose to partition road safety into sub-attributes relating to various crash modes. This contrasts with the traditional approach of partitioning according to vehicle system which invariably ignores the influence of important real-world system interfaces and ultimately results in road safety being tackled separately as either a road environment, vehicle performance or driver behaviour issue.

3. TARGET CASCADE USING ATTRIBUTE AND SYSTEM TEAMS

To drive Systems Engineering in Ford, "Attribute Leaders" are assigned for key customer requirements. Attribute Leaders then form cross-functional program teams to manage the delivery of customer, legal and corporate requirements. Accordingly, the Safety Attribute Leader develops a Vehicle Design Specification (VDS) which prescribes the vehicle-level safety objectives. In line with the above decision to partition the Safety attribute according to crash mode, sub-attribute leaders were assigned to manage the delivery of safety targets for each of the key crash events. These sub-attribute leaders were responsible for developing and cascading their respective sub-system targets to vehicle System Teams and ultimately Component Engineers so that component and system designs progressed with these in mind. During the design validation phase, targets are verified at component, sub-system and ultimately back up to vehicle level per the V-diagram above.

Suppliers are key members of system and component teams and some of these are resident at Ford for the duration of the program. Consequently, it is critical that suppliers are nominated for key commodities early in the program so that they develop ownership of targets and understand their importance. Restraint systems are a good example in this respect where Autoliv worked closely with Ford to meet seat belt and airbag system requirements from the outset. Statements of Work are used to define supplier and Ford individual and joint responsibilities.

4. TARGET VERIFICATION (DVP&R)

The Design Verification Plan and Result (DVP&R) is a vital tool in mapping out the necessary activities, such as tests, computer simulations or design checks, required to confirm components and systems meet targets. Each activity is timed and tracked versus required program milestones using a central database. Most activities will be repeated at several stages of a vehicle program depending on prototype level. As designs mature, each iteration moves from target feasibility, through design verification, to product validation of fully off-tool parts and finally, verification of production representative systems and components.

Progress versus targets is tracked with status reported at regular vehicle program gateway reviews. For the vehicle program to proceed through the gateway, targets must be on track or have recovery plans in place.

In the case of the Safety Attribute, performance was monitored by tracking detailed injury and structural targets for each sub-attribute crash mode.

5. POWERFUL COMPUTER TOOLS

Ford Australia is fortunate to have access to the enormous computing capability of the 25 supercomputers at the Ford US, Numerically Intensive Computing (NIC) Center, with dedicated access to one NIC. Leading-edge analytical software was also at the BA Falcon's disposal to enable highly sophisticated and detailed full-vehicle crash simulations to be run in every crash mode.

These models typically consist of approximately 500,000 elements as they include many major vehicle components. Depending on the crash mode, finer elements are generated in the area of impact so that the area undergoing the greatest deformation is most precise. This requires enormous amounts of computing power because the calculations to predict how each element behaves need to keep being recalculated based on the result of a calculation moments earlier.

Ford obtains the result, overnight, in around 14 hours using a supercomputer capable of 157 GigaFLOPS (Floating Point Operations) per second or a 157 thousand million calculations per second. As a result the BA Falcon safety systems benefited from over 1750 crash simulations, which is one every day for the last four years, on average.

The skill of developing these models is highly specialised and requires an ability to relate virtual crash events to physical crash events so that models can be properly correlated. There is also a real talent in developing a model that runs efficiently without over-using costly supercomputer time and yet is a reliable predictive tool and design guide. Fortunately, the BA Falcon had some of the best analysts in the industry working passionately to achieve road safety objectives.

Computer Aided Engineering (CAE) played a crucial role in the setting, cascading and validation of BA Falcon systems engineering targets. Predicted crash test results of mature FE models were generally within five percent of actual for body structure. This meant that the first physical prototypes were used primarily for fine tuning, without the need for major tooling changes.

Notwithstanding the reliability of computer modelling, the BA Falcon safety systems design was backed up by over 80 actual crash tests.

6. BENEFITS TO THE COMMUNITY

Ford was keen to ensure that the BA Falcon delivered new levels of occupant crash protection to its customers and it sought to do this through the use of Systems Engineering and Intelligent Safety technologies. These were used to provide enhanced protection in a variety of crash events. It is therefore appropriate that the benefits of the BA Falcon Safety features be discussed in terms of their contribution to road trauma reduction in each crash situation. However, first it is important to explain how the BA Falcon's intelligent safety technologies are used to manage interfaces between the road environment and the driver, in support of Systems Engineering philosophies.

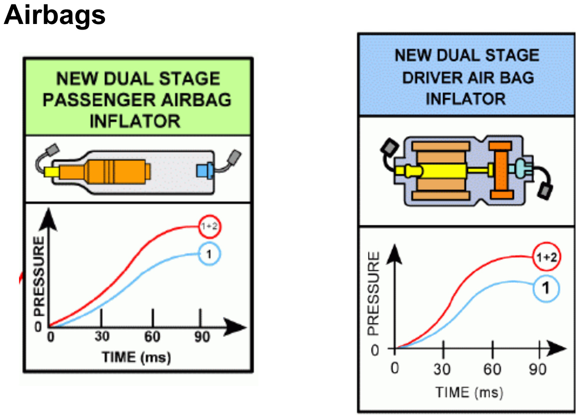
6.1 Intelligent Safety System (ISS)

Sophisticated airbag technology of this nature is expected to be required in the United States from 2006 when the new version of frontal crash regulation FMVSS 208, known as the Advanced Airbag Rule is progressively phased in. Canada will adopt a similar regulation from 2007. Australian BA Falcon customers are benefiting from ISS being standard equipment since October 2002.

6.2 Dual-Stage Front Airbags (see figure 3)

At the heart of ISS is the Autoliv dual-stage driver and passenger front airbags. These contain two separately detonated inflators which enable the inflation pressure of the airbags to be tailored to the circumstances of the accident. Why is this beneficial? Research of real-world crashes found that drivers of airbag equipped vehicles suffered fewer head injuries (5% c.f. 10% for non-airbag vehicles) and fewer neck injuries (19% c.f. 31% for non airbag vehicles). However, drivers of airbag equipped vehicles sustained more injuries to upper extremities (48% c.f. 31%)[2]. Airbags can also cause minor bruising. Consequently, by controlling airbag inflation, the key benefits of airbags in reducing major trauma can be delivered while minimising the risks of minor injuries.

Figure 3: Dual Stage Airbags



Due to Australia's relatively high seat belt wearing rates, most crashes will only require the first stage to be inflated. Even if both stages are needed e.g. in the case of an unbelted driver, the 15ms staggered inflation of the second stage ensures that the pressure rise rate is gentler, even though the peak pressure is similar to that of a traditional single stage inflator. Furthermore, extensive "Out-of-Position" tests are conducted by Ford to ensure that the airbag meets corporate injury targets in circumstances where the occupant is in too close to the airbag prior to inflation e.g. if the driver falls asleep and slumps over the steering wheel prior to impact.

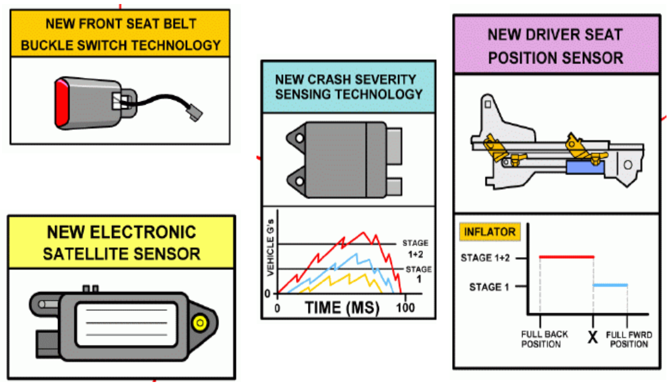
6.3 System Monitoring (see figure 4)

The brain of ISS is the **Advanced Restraints Module (ARM)**. This is a small but powerful computer mounted on the transmission tunnel inside the cabin which makes vital decisions about the level of occupant protection required in just a few milliseconds. It has its own built-in accelerometer to continuously monitor the forces to which the occupants are subjected but

[2] Morris, Fildes, Seyer, et.al. Effectiveness of ADR 69: A Case-Controlled Study of Crashed Vehicles Equipped with Airbags, Monash University Accident Research Centre for Dept. of Transport and Regional Services, CR 199, May 2001.

in order to make complex decisions considering the driver situation and severity of a crash it needs the help of additional sensing technology.

Figure 4: System Monitoring



- **CRASH SEVERITY SENSOR**
  An additional satellite sensor is mounted in the best position to quickly detect a crash event; at the very front of the car. The ARM constantly compares the deceleration measured at the front of the car with that which itself and the occupants are experiencing in the cabin, thereby enabling it to rapidly detect a wide variety of crash events. ISS has been demonstrated to reduce airbag trigger times by as much as 40% and thereby dramatically enhance occupant protection. The use of the two sensors also allows an improved prediction of crash severity, thereby allowing the ARM to determine if, zero, one or two inflator stages are appropriate.

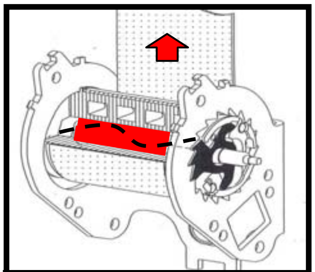
- **SEAT TRACK POSITION SENSOR**
  The driver's seat incorporates a sensor which detects whether the seat is forward or rear of mid position. If the driver is positioned close to the steering wheel, it is most likely that only the first stage airbag inflator is required as the drivers head velocity prior to contact is likely to be lower. It is also likely that the driver is smaller in stature. Conversely, if the seat is adjusted rear of centre, the driver's head velocity is likely to be higher with both airbag stages being more likely to be required. This means that the driver is free to adjust their seat for optimum comfort and vehicle control. A benefit further complemented by a fully adjustable steering column and the electrically adjustable pedal option.

- **SEAT BELT BUCKLE SWITCH**
  Switch contacts are fitted to the driver and front seat passenger seat belt buckles to determine if the seat belt is being worn. If the seat belt is not worn, it is most likely that both stages of inflation will be required because the occupants will need maximum protection.

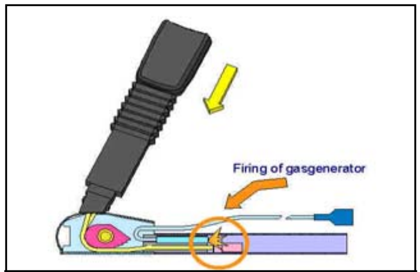
6.4 Advanced Restraints Features (see figure 5)

The ISS airbags have been tuned to work in concert with a state-of-the-art seat belt system which incorporates **Energy Management Retractors** (EMRs) and **Pyrotechnic Buckle Pre-Tensioners** attached to the front bucket seats. Consistent with Ford's philosophy of Systems Engineering, these augment ISS by helping to manage the interface between the occupant and the seat belt systems.

Figure 5: Advanced Restraints



Energy Management Retractor



Pyrotechnic Buckle Pretensioner

BELTMINDER™

The benefits of seat belts have long been understood by road users and research shows that unrestrained occupants are three times more likely to be hospitalised in a frontal crash[3]. Fortunately, Australia is credited with having one of the highest seat belt wearing rates in the world with approximately 95% seat belt usage. However, fatality statistics confirm that some people are still not wearing their seat belts with 20% of fatally injured car occupants being unrestrained[4].

The innovative Beltminder™ system again uses systems engineering principles to influence driver behaviour so that the interaction between the restraint system of the car and the driver is conducive to maximum occupant protection – put simply; to make the driver wear the seat belt. The effectiveness of this was proven in a US study[5] where an Oklahoma population, with traditional seat belt wearing rates as low as 68%, was exposed to the Beltminder™ feature. The study found that seat belt wearing rates increased from 71% to 76%. In a culture with such a high proportion of hard core seat belt non-users this is a very significant result.

A Swedish study[6] clearly demonstrated the opportunities afforded by a seat belt reminder system. It found that only 7.6% of the study group were "dedicated non-users" and therefore the balance of the population would respond well to an "effective" reminder. (see figure 6)

Figure 6: Swedish Survey Results
"Why didn't you wear your seatbelt on this occasion?"

Only a short trip	34.5%
Carelessness	32.9%
Forgetfulness	23.0%
Stressed, in a hurry	10.6%
Professional driving, job	10.6%
Had no time to put it on yet	4.5%
Habit, "bad habit"	4.5%
Uncomfortable to wear	3.4%
→ Do not use as a matter of principle	3.4%
→ Feel locked in	2.8%
Only urban trip	2.3%

Frequent stops	1.8%
Cumbersome to put on	1.6%
→ Belt is / can be dangerous	1.4%
Belt is not necessary	0.9%
Restricts reach	0.9%
Don't know, no answer	0.9%
Drives (drove) slowly	0.7%
Avoids accidents	0.7%
Interference with clothes	0.7%
Tired	0.7%
Usually "always" wears belt	0.7%

→ Conclusion: "Dedicated" non users (ie firm resistance group) are a very small proportion of total non belt users.

From P Larsson, SNRA

3 Monash University Accident Research Centre, 1991
4 1997 Fatality Statistics, VicRoads, 1998
5 Insurance Institute of Highway Safety, Oklahoma, 2001
6 P. Larson, SNRA

Ford corporately conducted extensive research to develop a system that would provide an "effective" reminder. The challenge was to devise a warning strategy which was not so gentle as to be ignored or too intrusive and result in disconnection, perhaps in an unsophisticated manner which might interfere with the operation of ISS, e.g. buckle switch tampering. The result was an ingenious speed-dependent system with a combination of periodic, visual and clearly audible warnings. A key feature being the selection of an audible tone and volume which could be heard above the car sound system and climate control fan at moderate vehicle speeds.

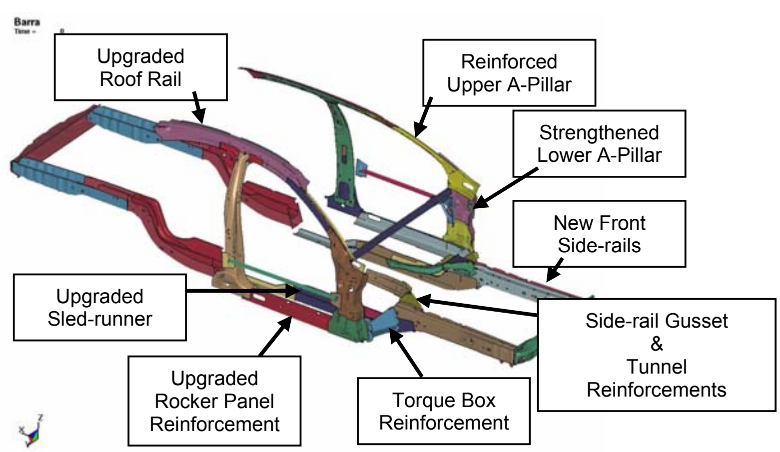
6.5 Frontal Crash Upgrades

Frontal crashes represent around 60% of Australian crashes, of these about a third are full-frontal, a third offset and a third oblique offset crashes[7].

Full frontal crashes can result in severe and sometimes fatal injuries because of the high decelerations involved. Offset crashes, where only part of the front of the car collides with another car or object (e.g. in a partially overlapping head-on collision, usually on the driver's side) can be among the most debilitating types of crash due to the risk of severe lower leg injury. Around 20% of lower leg crash injuries are estimated to be in this category[8].

The substantial investment in the BA Falcon program paved the way for extensive body structure upgrades which further refine crash energy management and substantially reinforced the passenger safety cell. (see figure 7) Using systems engineering, structural component targets were cascaded from higher level crash targets using computer modelling so that body engineers knew exactly what their objectives were e.g. for stiffness and torsional rigidity.

Figure 7: Body Structure Upgrades



Comprehensive structural upgrades were introduced in almost every aspect of the vehicle body including;

- Upgraded roof rail
- Reinforced upper A-Pillar
- Strengthened lower A-Pillar
- Upgraded rocker panel reinforcement
- Redesigned and upgraded front siderails with enhanced energy management

---

[7] Passenger Cars and Occupant Injury – Fildes et al , MUARC
Federal Office of Road Safety CR 95, March 1991.
[8] Development of an Australian Design Rule for Offset Frontal Crash Protection – Seyer, Terrell
Federal Office of Road Safety OR 21, 1998.

- Upgraded rocker panel reinforcement
- Upgraded sled runner beneath the front occupants
- Reinforcing gussets added between the siderail and transmission tunnel
- Additional transmission tunnel reinforcement
- Strengthened torque box between rocker and siderail

A key enabler for more efficient energy management was the achievement of **straight front siderails**. These allowed crash forces to be transmitted through the body structure in a controlled manner without promoting buckling.

These upgrades translated to the following occupant protection gains in an offset crash versus the prior model AU2 Falcon;

- Footwell intrusion reduced 45%
- A-Pillar movement reduced 40%
- Instrument panel displacement reduced 30%
- Steering column intrusion reduced 53%
- Brake pedal intrusion reduced 55%

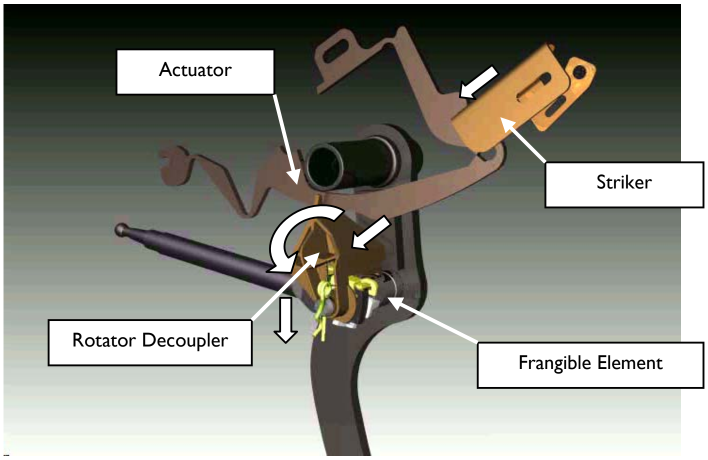
In addition to this the BA Falcon continues to incorporate a **Laminated Impact Protection Panel (LIPP)** in the drivers footwell, under the carpet. The LIPP is almost 30mm thick and consists of a layer of steel covered with energy-absorbing foam.

In a severe crash, the LIPP carries the driver's heels rearward with any intruding floor panels and as a result, helps to avoid over-rotation of the ankle joints and entrapment of the feet. In addition, the steel acts like armour and the foam reduces heel shock. Crash tests indicate that it reduces the lower leg injury measure called "tibia index" by an average of more than 60%. The end result is better lower leg protection for Falcon drivers.

Despite the significant gains in structural integrity achieved during laboratory crash tests, as listed above, Ford was aware from the field data that in more severe real-world events, brake pedal intrusion could be much greater and was therefore a potential source of lower leg injury. Consequently, an **Anti-Intrusion Brake Pedal** was developed in conjunction with Ford's suppliers; Air International (Pedal Box Assembly) and PBR (Brake Booster).

In crash events which result in high levels of intrusion e.g. an offset frontal pole impact, the brake booster can be driven rearward with the dash panel. This in turn, causes the booster push-rod to drive the brake pedal rearward potentially causing a lower leg hazard. The BA Falcon Anti-Intrusion pedal design prevents this by using the relative movement between the dash panel and the instrument panel cross-car beam (mounted between the A-pillars) to activate a cleverly designed mechanism. The intrusion causes a four-bar link actuator to operate a rotator to place a downward force on the brake booster push-rod which pops out an intricate frangible element. Hence the vehicle deformation decouples the brake pedal from the brake booster push rod and the brake pedal is allowed to swing freely without loading the lower legs. (see figure 8)

Figure 8: Anti- Intrusion Brake Pedal



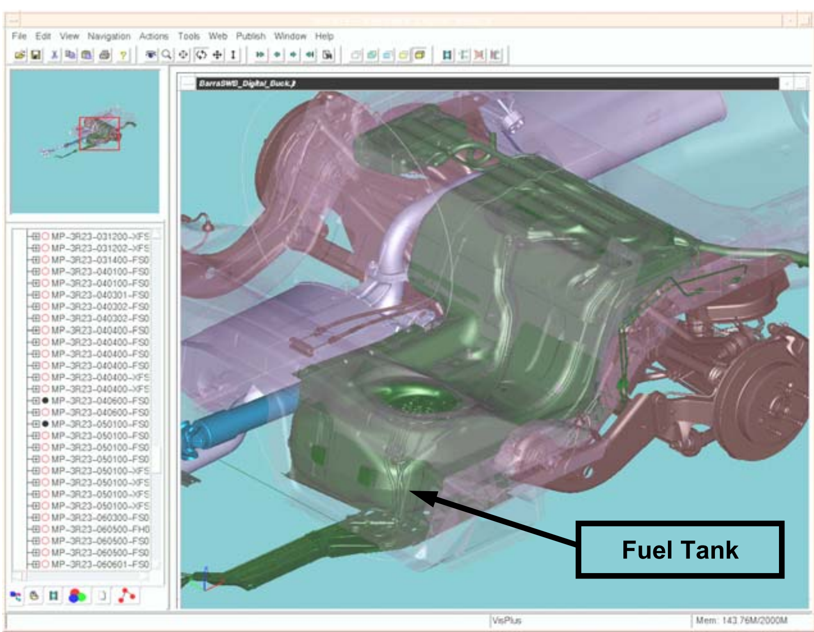
Mindful also of the real-world risk of knee injury in a frontal crash, the BA Falcon steering column shroud is equipped with a **high density EVA foam** to cushion the driver's knees from contact with the steering column structure. This foam is similar to that used in sports footwear.

6.6 Rear Impact Enhancements

As with the front of the BA Falcon, a key strategy was to straighten the rear siderails for optimum energy management in a rear impact. This ensures that the passenger compartment integrity is preserved and rear door openability targets are achieved. The BA Falcon rear rails also feature two-stage crumple zones, similar to those used in a frontal crash to allow progressive energy dissipation in a rear impact.

The BA Falcon sedan rear end is completely new as a result of the "Control Blade" independent rear suspension. (see figure 9) This enabled the sedan fuel tank to be positioned forward of the rear axle away from the crush zone.

Figure 9: Rear End Architecture



The BA Falcon is also fitted with a fuel shut-off inertia switch which cuts off power to the fuel pump in the event of an impact. This switch works in all impact directions.

6.7 Side Impact Upgrades

Side impacts account for about 35% of all crashes[9]. Although these are less frequent than front impacts, they can result in severe injury because there is little space between the occupant and the impacting vehicle in which to manage the crash energy. BA Falcon offers improved protection in these crashes by providing some cleverly engineered design features.

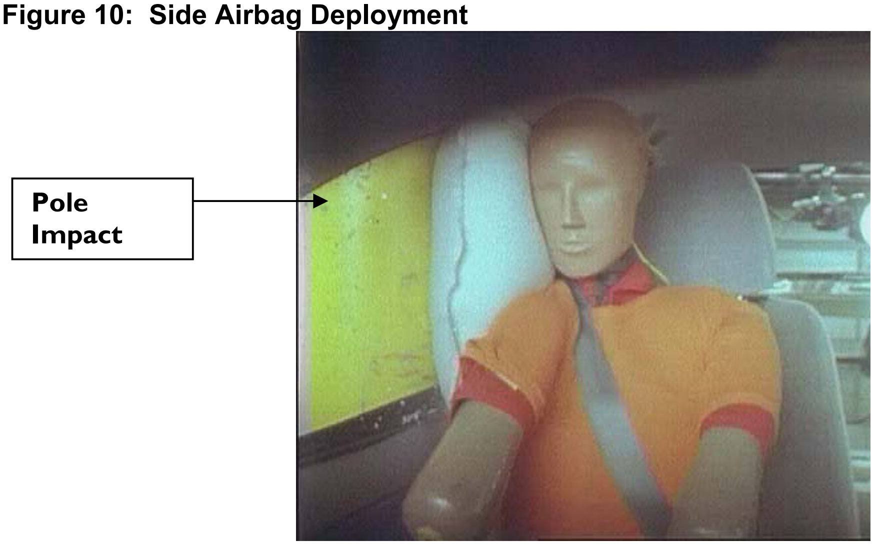
The BA Falcon body boasts further upgrades to the side structure, some of which are also effective in frontal impacts.

Ford engineers determined that B-pillar intrusion velocity was a key measure of injury reduction and used this throughout the computer aided engineering design phase. This was the logical target to cascade to side structure and trim components which resulted in some subtle but significant design developments.

The bulk of the door trim is constructed of a crushable Loprefin material and, particularly in the area of the arm rest, this substantially reduces the forces applied to the pelvis in a side impact. The arm rest rear attachment boss was designed in such a way as to crush under load and the map pocket incorporated a chamfered trailing edge with a moulded-in failure seam. To complement this, energy absorbing foam is packaged inside the front door to spread the load and minimise the impact to the occupant. These systems were all extensively validated against their respective targets through purpose-built rig tests so that the achievement of higher level injury targets was assured.

Of course, in the real world there are some side impact events where the structure and trim material can offer little protection. A classic example is a pole impact. The BA Falcon introduces a **Side Airbag** option (standard on Fairmont up to LTD and optional on the rest of the passenger car range) which inflates to protect the torso and head. The airbag is mounted in the front passenger seat side-bolster and bursts through the trim seams on deployment. (see fig. 10)

Figure 10: Side Airbag Deployment



[9] Passenger Cars and Occupant Injury – Fildes et al , MUARC
Federal Office of Road Safety CR 95, March 1991.

Since the airbag is deploying very close to the occupant, it is critical that it inflates in the correct manner and direction. The Deployment Chute (another bag that contains the side airbag) plays a key role in this. However, bearing in mind that we are dealing with people who may not be positioned in ideal locations like crash dummies, Ford conducts a comprehensive range of Out-of-Position airbag tests to confirm that corporate injury targets are met. These tests are conducted with a dummy positioned in the path of the deploying airbag to assess the risk of injury. Ford's tests and acceptance criteria are based on US voluntary industry Out-of-Position requirements published by the Insurance Institute for Highway Safety on August 8, 2000.

In a pole-type impact where there is often nothing between the occupant and the intruding object, a side airbag can provide a vital form of protection. Research shows that 48% of the harm caused by side impacts results from head, face and neck injuries[10] so the added protection of a side airbag is a very worthwhile investment.

7. SUMMARY

In designing safer cars it is important to be aware that we are dealing with people not crash dummies and real-world road environments not test laboratories. A Systems Engineering approach helps engineers to remember this and continue to strive for a better understanding of the interactions between the vehicle, the road system and the occupants. In-depth real-world safety research, such as the Australian National In-Depth Crash Study (ANCIS) led by Monash University Accident Research Centre, will be of increasing value in this respect.

The BA Falcon Intelligent Safety Systems project was a massive undertaking in terms of feature content, the extent of change and level of sophistication. It was made possible by having a close-knit team of engineers, CAE analysts and managers who are passionate about safety and had the access to and support from Ford senior management. This was augmented by the tremendous power of computer aided design and engineering tools which enabled rapid turnarounds on complex engineering analyses.

Consequently, the BA Falcon has made another significant contribution in the battle to reduce road trauma with its Intelligent Safety Systems and Systems Engineering philosophy.

Acknowledgements
Ford would like to acknowledge the efforts of its many suppliers, particularly Autoliv (restraint systems) and Air International (seats and anti-intrusion brake pedal). This project relied heavily on their expertise in delivering targets and understanding interfaces with other vehicle systems.

Keywords
Vehicle Safety, Crash, Systems Engineering, Airbags, Computer Aided Engineering

[10] Benefits of a Hybrid Side Impact Regulation - Fildes, Seyer, et.al. , MUARC
Federal Office of Road Safety, CR 175, 1998