Vehicle Countermeasures Against Incompatible Crashes

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Safety Improvement

Understand Problem
Field DATA

Design Countermeasure
Engineering
Manufacturing
Repeatability

Way to Evaluate
Injury Criteria
ATD
Test Procedure
Half the vehicles sold in the USA are SUVs, light trucks or vans
Vehicle Incompatibility

Mass, Stiffness, Geometry
Vehicle Incompatibility

Worst Case Scenario
Safety Improvement

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Way to Evaluate
Injury Criteria
ATD
Test Procedure
LTV Front to Car Crashes (NASS 1997-2001)

Frequency

- Front: 22%
- Rear: 29%
- Side: 47%
- Rollover: 2%
LTV Front to Car Crashes
(NASS 1997-2001)
Distribution of Occupants with MAIS>=3

- Rear: 5%
- Rollover: 2%
- Side: 50%
- Front: 43%
LTV Front to Car Crashes (NASS 1997-2001)

Distribution of Occupant Harm

- Front: 33%
- Side: 57%
- Rear: 8%
- Rollover: 2%

Rear: 8%
Rollover: 2%
Front: 33%
Side: 57%
Test Modes/Regulations

- **FMVSS 214 (Dynamic)**
  - Roll-out began in MY 1994, applied to all passenger cars starting in MY 1997

- **LINCAP**

- **ECE R95**

- **FMVSS 201**
  - Upper interior requirements: Roll-out began in MY 1999 (Free Motion Headform)
  - Dynamic Pole test option for vehicles with side curtain airbag systems

- **IIHS LTV Side Impact Test**
ATD’s for Side Impact

Several ATD’s and multiple injury criteria are being used to assess lateral impact injury.

- SID (or US-SID) (FMVSS 214)
- Euro-SID1 (ECER95)
- ES-2
- BioSID
- SID-IIIs (IIHS test ATD)
- US-SID with the Hybrid III head and neck (LINCAP, FMVSS 201)
- World SID

Every ATD style has advantages & disadvantages in testing & bio-fidelity
**FMVSS 214 Load Case**

- **FMVSS 214**
  - Impact Direction: Crab
  - Impact Speed: 33.5 mph
  - Barrier Bumper is 13” (330 mm) above Ground
  - 2 US SIDs
  - Requirement:
    - TTI ≤ 85 G
    - Pelvis Acc. ≤ 130 G
Thoracic Trauma Index

Thoracic Trauma Index (TTI)

\[ TTI = \frac{1}{2} (G_R + G_{LS}) \]

- \( G_R \) - Greater of the peak acceleration of either the upper or lower rib
- \( G_{LS} \) - Peak acceleration of the lower spine

Side Impact Dummy (SID)
LINCAP Load Case

- **LINCAP**
  - Impact Direction: Crab
  - Impact Speed: 38.5 mph
  - Barrier Bumper is 13” (330 mm) above Ground
  - 2 US SIDs
  - Rating: Stars

    5 Star  \( TTI \leq 57 \)
    4 Star  \( 57 < TTI \leq 72 \)
    3 Star  \( 72 < TTI \leq 91 \)
    2 Star  \( 91 < TTI \leq 98 \)
    1 Star  \( TTI > 98 \)

Pelvis G’s noted if exceeding 130g’s
Fatal Injuries: Near-Side Occupants


Occupant Fatality per Million Registered Vehicle Years

Impact by
Car
Less Than
3500 lbs.

Impact by
Car
3500 lbs or
Heavier

Impact by
Light Truck
Less Than
3500 lbs.

Impact by
Light Truck
3500 lbs or
Heavier

Pre-FMVSS214D Cars
Post-FMVSS214D cars
Light Trucks
Fatal/Major Injuries: Near-Side Occupants


[Graph showing the number of occupants with fatal or major injuries per million registered vehicle years for different types of impacts and vehicle models (Pre-FMVSS214D Cars, Post-FMVSS214D Cars, Light Trucks).]
Velocity Time History – FMVSS 214
Side Impact Test (Mid-size Sedan)
Utilize structural load paths to re-direct the energy

Manage the energy

Body Side Structure
Door Structure
Body Side Structure

- A-Pillar
- B-Pillar
- C-Pillar
- Front Body
- Hinge Pillar
- Rocker
- Lock Pillar
Passive Countermeasures (CM)
Safety Improvement

Understand Problem
Field DATA

Design Countermeasure
Engineering
Manufacturing
Repeatability

Way to Evaluate
Injury Criteria
ATD
Test Procedure
The Problem for Interior:

- Occupant is ACCELERATED by application of FORCE
- Contact from Vehicle, Tree, Door or Header
Understanding the Problem - Doors

- Example of low application of force through door.
- Hips are accelerated first followed by the shoulders.
- Application of force to abdomen through armrest is not desired.
Passive side impact
Countermeasures - Door
FMVSS201 Requirements

- Free Motion Headform (FMH)
- 10 lb
- 15 mph
- HIC number calculated from Acceleration.
- Phase-in (MY 1999-2002) will be complete by 2003
Formula from FMVSS201

\[ HIC = \left[ \frac{1}{(t_2-t_1)} \int_{t_1}^{t_2} a_{res} dt \right]^{2.5} \]

- Average Acceleration
- Duration

- Regulation HIC below 1000
- Target HIC below 800
FMH Impact Locations

IMPACT LOCATIONS
AP1-3: A-PILLAR
SR1-2: FRONT SIDE RAIL
SR3: OTHER SIDE RAIL
FH1-2: FRONT HEADER
BP1-4: B-PILLAR
RH: REAR HEADER
RP1-2: REAR MOST PILLAR
UR: UPPER ROOF (NOT SHOWN)
Theoretical Relations

- We analyzed mathematically what drives the HIC number so that we could understand how to lower the number. We also studied the theoretical responses of various acceleration waveforms.
Space is Required

- Ideal Rectangular Wave with No Rebound
- Ideal Rectangular Wave with 1 m/s Rebound
- Average of Actual Vehicle Testing

Deflection (mm)

HIC(d)

Design Zone
Desired Zone
Inefficient Zone
Impossible Zone

System Deflection (32 mm)

FMH CM Steel
Force vs. Deflection Curves

Energy Absorbers
Flat plate, Infinite background @ 13.5 mph

- 12FM20 (793)
- (950) 62FMO
- (940) 63FMO
Pillar Countermeasures
Countermeasure Materials
Case History 1: No Countermeasure

- 1998 Caravan
- Object: 2000 Taurus
- PDOF: 270
- 13 mph delta V
- 68 yo Male
- Restrained
- 172 lb, 5’ 10” (50%)
Case History 1: No Countermeasure
Interior Surfaces
Head & Neck Injuries

• Medical data has been removed to protect patient confidentiality
Case History 2

- 1999 Intrepid
- Object: Tree
- PDOF: 290
- 15 mph delta V
- 36 yo Male
- Restrained
- 165 lb, 6’ 2”
- 26 cm @ sill
- 56 cm @ roof
Damage
Damage
Significant Injuries

• Medical data has been removed to protect patient confidentiality
Head Contact
Side Impact Air Bag Countermeasures

• This section will focus on development of inflatable technology, and addressing what inflatable restraints can do to offer “self-protection” in lateral “incompatible” crashes.
Side Air Bag Evolution

- **MY '95**
  - Thorax System
  - 214/95 Requirements
  - Europe Leading (Volvo, Mercedes)

- **MY '96**
  - Head/Thorax System
  - Due Care (Pole High Hood)

- **MY '97**
  - Curtain / Thorax
  - Low Risk OOP

- **MY '98**
  - Curtain + Pelvic/Thorax
  - Low Risk OOP

- **MY '99-00**
  - Thorax System
  - Tuned Inflator

- **MY '01-02**
  - Head/Thorax System
  - Tuned Inflator

- **MY '03**
  - Head/Thorax System
  - Tuned Inflator

- **MY '04**
  - Thorax/Pelvis Bag

- **Rollover**
  - 5-7 sec hold time

- **Thorax System**
- **U.S. Following**
- **Due Care Considerations**

- **ITS**
- **Europe (BMW)**
Field Data

• To date, relatively little field crash experience is available with inflatable lateral protection devices.
• The data that is available does suggest minimal harm is being induced in field, and there is limited evidence of at least some benefits from lateral inflatables.
What does an airbag do?

Frontal:
The occupant is effectively accelerating towards Steering Wheel / IP as vehicle is decelerating
The frontal airbag:
• Offers increased loading area
• Energy Absorbing (transfers KE into Work through vent holes or fabric) => gradual deceleration
• Prevents hard contacts with wheel, IP, Windshield, Pillars

Lateral:
The vehicle is effectively accelerating towards occupant
The airbag:
• Prevents hard contacts between head & barrier/pole
• Offers stability for Head / Neck / Shoulder complex
• Reduces acceleration for Thorax / Abdomen/ Pelvic complex

Frontal and lateral airbags operate differently in how they mitigate injury.
Additional Considerations for side vs frontal airbags:

- There is little vehicle crush space to accelerate the occupant compartment before occupant loading.

- The occupant is impacted by the striking object with a portion of his vehicle side structure around it.

- The location of a side impact relative to the occupant has a major effect on the severity of the crash as seen by the occupant.

\[ V_{\text{initial}} \]

\[ V_{\text{between occupant and vehicle}} \]

\[ V_{\text{occupant}} \]
Lateral Airbag System
Design Iteration/Balance

Static
Out of
Position

Packaging
Constraints

Establish
Coverage
for
Occupant
Sizes

In-position
Dynamic

AIRBAG
DESIGN
CYCLE
Example of Side Airbag Module

Side Airbag Module:

**Inflator:**
- Hybrid BREED HSI-140

**Cushion:**
- 11 litre single chamber rollfold
- ventholes according to performance
- 700 dtex fabric uncoated with reinforcement and heatshields

**Housing:**
- single injection TPEE (Multiflex)
- colour black

**Cover:**
- single injection TPEE (Multiflex), grained A-surface unpainted
- colours:
  - natural (Lancia 839 invisible)
  - black (Alfa 932 / Fiat 244 visible)
  - grey (ALFA 932 visible)
  - leather covered (blue / red / beige) (Alfa 932 visible)
- opening by tearing 4 pins (ultrasonic welded)
Curtain Airbag Module
Side Airbag Module Curtain Airbag (Product Description)

Module Concept:
- Deployment zone between A and C/D pillar.
- Maximum mass approx. 1600 gr
- Manifold: steel tube
- Filltime max 25ms @ -30°C

Standard Cushion:
- Uncoated 470dtex PA 6.6.
- Volume 30-35 ltr.
- Sewn bag design,

Curtain Airbag Module:

Inflator:
- Inflator Cold gas
- Filling - 100%He
- Pressure - 600bar
- Gas filling weight adjustable

Rollover Cushion:
- Silicone coated, 470dtex, PA 6.6.
- Volume 30-35 ltr.
- Sewn bag design, liquid silicone sealing or OPW coated or STC

Cover:
- Soft pack (pocket)
3 year old HIII Seating Position in Mid-Sized Sedan
6 year old HIII Seating Position in Mid-Sized Sedan
5th%ile (SID-IIs) Seating Position in Mid-Sized Sedan
50th% (EuroSID) Seating Position in Mid-Sized Sedan
Coverage Zone Concept

“A-C” Pillar Protection Coverage

Mid-Seat Euro-SID

“Full ForwardSID-II”s Rear Euro-SID
Static Out of Position

- A Technical Work Group (TWG) - IIHS, Alliance, AIAM, AORC, Transport Canada - has developed voluntary OOP procedures and injury targets for:
  - SID-IIs (5th%ile HIII) w/ instrumented arm
  - Hybrid III, 6 year old sized
  - Hybrid III, 3 year old sized

- Evaluations vary by type of side impact air bag.
  - Door mounted
  - Seat mounted
  - Roof rail mounted curtains and inflatable tubular structures
Out Of Position Test Configurations

7 static positions to assess SAB OOP performance.

3.3.2.1/5 Forward-facing 3Y & 6Y HIII

3.3.2.2 Rearward facing 3Y old HIII

3.3.2.3 Lying on seat, head on armrest 3Y HIII

3.3.2.4 Lying on seat 3Y HIII

3.3.2.6 Inboard facing SIDIIs

3.3.2.7 SIDIIs with instrumented arm
# TWG injury values

<table>
<thead>
<tr>
<th></th>
<th>Hybrid III 3-Yr Old</th>
<th>Hybrid III 6-Yr Old</th>
<th>Hybrid III Sm. Fem.</th>
<th>SID IIIs</th>
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<tbody>
<tr>
<td><strong>HEAD</strong></td>
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<tr>
<td>15ms HIC</td>
<td>570</td>
<td>723</td>
<td>779</td>
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<td><strong>UPPER NECK</strong></td>
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<td>Nij (Ft/Fc/Mf/Me)</td>
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<td>Tension (N)</td>
<td>1130</td>
<td>1490</td>
<td>2070</td>
<td>2070</td>
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<tr>
<td>Comp. (N)</td>
<td>1380</td>
<td>1820</td>
<td>2520</td>
<td>2520</td>
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<tr>
<td><strong>THORAX</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Defl. (mm)</td>
<td>36</td>
<td>40</td>
<td>—</td>
<td>34</td>
</tr>
<tr>
<td>Defl. Rate (m/s)</td>
<td>8.0</td>
<td>8.5</td>
<td>—</td>
<td>8.2</td>
</tr>
</tbody>
</table>

**Reference values**
Side Impact Air Bag Challenges

- **Crash sensing:**
  - Distinguishing the various side impact events (pole, car, truck) in time to fire the lateral airbag, and maintaining immunity from non-severe events (door-slam, ball-hit, bicycle etc.)

  - In general, lateral airbags need to begin deploy about 4 - 8 msec after initial contact. This is about 1/3\textsuperscript{rd} the time: to sense the crash, process the algorithm, and initiate a fire-command, as compared to frontal impact air bags.

  - Thorax cushion requires about ~ 10msec to fill
  - Curtain Airbags require about ~ 25 msec to fill.
Side Impact Air Bag Challenges

- Thorax bags must deploy in gap between seat bolster and door trim, and occupant.
  - Gap is small on small cars
  - Occupant size can affect deployment

- Curtain airbags must deploy over the B-pilar trim, belts, and often over rapidly deforming sheet metal.
  - There is often opportunity for Curtain to interact negatively with structure
Packaging: Decreased packaging volume due to presence of curtain in the roofrail area increases the challenge of meeting FMVSS 201 type head impacts
FMVSS 214 Barrier vs IIHS LTV Barrier Height
IIHS LTV

FMVSS 214

IIHS Test Diagram

Wheelbase (W)
37" 0.5W

Impact Point

Direction of Travel @ 33.5 mph

Vehicle A

Vehicle B

CG

90° 63°

27°

IMPACT REFERENCE DISTANCE (IRD)

50 km/h

WB < 250 cm: IRD = 61 cm
250 cm ≤ WB ≤ 290 cm: IRD = WB/2 - 64 cm
WB > 290 cm: IRD = 81 cm

TEST CONFIGURATION

Figure 3
# Comparison of IIHS High Hood and Regulatory Tests

## Side Impact Crash Test Configurations

<table>
<thead>
<tr>
<th>Description</th>
<th>IIHS High Hood</th>
<th>FMVSS 214</th>
<th>ECE R95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Angle</td>
<td>90 degrees</td>
<td>63 degrees</td>
<td>90 Degrees</td>
</tr>
<tr>
<td>Bullet Weight</td>
<td>1,500 kg</td>
<td>1367 kg</td>
<td>950 kg</td>
</tr>
<tr>
<td>Bullet Speed</td>
<td>50 kph</td>
<td>54 kph in 63 deg. Direction (or 48 kph lat./ 24 kph long.)</td>
<td>50 kph</td>
</tr>
<tr>
<td>Impact Location</td>
<td>300 mm rear of FMVSS 214</td>
<td>Front edge of barrier face @940 mm from half wheelbase plane</td>
<td>Middle plane of barrier face in line with front row SRP</td>
</tr>
<tr>
<td>Barrier Face Size</td>
<td>762 mm H x 1,676 mm W with tapered on both side edges</td>
<td>559 mm H x 1,676 mm W</td>
<td>500 mm H x 1,500 mm W</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>381 mm</td>
<td>279 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>Seating Position</td>
<td>UMTRI position</td>
<td>Designed seatback angle</td>
<td>Designed torso angle (25 if unknown) , mid seat travel, same height as non-adjustable, or mid height.</td>
</tr>
<tr>
<td>Dummy</td>
<td>SIDIIs front and rear</td>
<td>US SID front and rear</td>
<td>EuroSID front only</td>
</tr>
</tbody>
</table>

Because IIHS LTV crash test specifies heavier barrier mass and higher ground clearance than FMVSS 214, the injury values are more severe.
Regulations / Test Modes

From the inflatable restraint viewpoint, the IIHS test protocol is the primary method to assess & improve “self-protection” for “incompatible” lateral crash modes.
The IIHS LTV (incompatibility) test mode has several additional challenges for “Self - Protection” injury mitigation:

- **Likely head-to-barrier contact requires inflatable head protection:**
  - Curtain or Head cushions

- **Higher ATD loads on Thorax / Abdomen / Pelvis (than with LINCAP)**
  - Improved door padding
  - Structural stiffness
  - Increased Airbag pressures and/or hold times in order to offer some protection for thorax / abdomen / pelvis.

- **Sensor Fire time:**
  - Current sensor are either acceleration or pressure based
  - Current sensor are typically located at bottom of B- (and C-) pillar / rocker panel
Comparison of IIHS High Hood vs. US SINCAP Door Motion

An Example of Generic Mid-Sized Sedan IIHS High Hood Full Scale vs. Test Door at Belt Line Velocity Pulse

IIHS High Hood test is much more severe when compared to US SINCAP in the speed of intrusion (thus intrusion amount) and slightly worse in initial intrusion during which side airbag is being fired.
<table>
<thead>
<tr>
<th>MY ‘95</th>
<th>MY ‘96</th>
<th>MY ‘97</th>
<th>MY ‘98</th>
<th>MY ‘99-00</th>
<th>MY ’01-02</th>
<th>MY ’03</th>
<th>MY ’04</th>
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<tr>
<td>Thorax System</td>
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<tr>
<td>214 / 95 Requirements</td>
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<td>Europe Leading (Volvo, Mercedes)</td>
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<td>Head/Thorax System</td>
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<tr>
<td>Due Care (Pole High Hood)</td>
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<tr>
<td>Curtain / Thorax</td>
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<td>Low Risk OOP</td>
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<tr>
<td>Curtain + Pelvic / Thorax</td>
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<td>Low Risk OOP</td>
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<td>Rollover</td>
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<tr>
<td>5-7 sec hold time</td>
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</tbody>
</table>

- Head/Thorax System  
- Tuned Inflator  
- ITS  
- Europe (BMW)  

- Thorax/Pelvis Bag  

Future (MY 06+)  

Designs for IIHS LTV, “new” FMVSS 214
Safety Improvement

Understand Problem
Field DATA

Design Countermeasure
Engineering
Manufacturing
Repeatability

Way to Evaluate
Injury Criteria
ATD
Test Procedure