Status of NHTSA’s Roof Ejection Mitigation Research

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Background

- FMVSS No. 226 Final Rule (Jan 2011) preamble says, “NHTSA is interested in learning more about roof ejections and would like to explore this area further…”
- Annual average 87 fatalities (FARS 2004-2017, coded as roof ejection path, excluding unknown path)
  - “Occupant Injuries Related to Rollover Crashes and Ejections from Recent Crash Data” Jingshu Wu et. al. 26th ESV, 2019
- Tests on production vehicles with laminated sunroof panels at 16, 20 km/h
  - 2009 Ford Flex (fixed); 2014 Ford CMax (fixed); 2013 Subaru Forester (movable)
    - 2016 SAE Government Industry Meeting
    - Paper at 25th Conference on Enhanced Safety of Vehicles (ESV), Detroit, 2017
- Tests on production and countermeasure* sunroof panels at 14, 16, 20 km/h
  - 2016 Ford F-150* (laminated - inner slider); 2010 Toyota Prius (fixed polycarbonate); 2019 Aisin (laminated - outer slider)
    - Paper at 26th Conference on Enhanced Safety of Vehicles (ESV), Eindhoven, Netherlands, 2019
Test Setup

- FMVSS No. 226 Impactor
- Featureless headform (40 lbs. [18kg])
- Displacement, speed from Linear Pot (LVDT)
- Accelerometer on the ram

Impact locations and speeds
- Speeds (14/16/20 km/h)
- Assumes
  - Left-right side are identical
  - Front-back are NOT identical
- Test each panel at
  - Front corner
  - Rear corner
  - Center
  - Mid-point of front transverse edge
  - Mid-point of rear transverse edge
  - At 2/3 of longitudinal edge
Lincoln MKZ

- Large panoramic design
- Outer slider type (opens to outside)
- ProTec 2® (PET) film
- Attached to rails at front and back
- Production and countermeasure panels

PET = polyethylene terephthalate
Lincoln MKZ – Module Description

• Glass panel bonded to ProTec 2® film and glued to steel assembly
  • ProTec 2® film (0.2mm PET film) – bonded to inner side of tempered glass
  • Film does not go all the way to edge of glass just to outside of frit line
• Production film has holes along edges (2) – reinforcement glued to both glass and film
• Countermeasure film does not have holes – reinforcement glued directly to film

Moving Glass Panel Assembly:
1. Moving Glass Panel
2. ProTec2 Film
3. Inner and Outer Glue Beads
4. Steel Reinforcement Assembly

frit = a black enamel band that is baked into the edges of the windshield for better adhesive bond and protect bond from UV
Test Setup

- Custom made frame – module attached to frame using 17 sliding brackets (shown with arrows)

- Glass prebroken on one side (outside)
  - Punched once in corner– glass fractured all the way across

- Brackets with targets for photographic analysis attached at inner glue line (near frit line) – measure edge excursions
Results/Ram Excursion Values

At 14 km/h
At 16 km/h
At 20 km/h

# Plastic film tear

Lincoln MKZ (Webasto) Production ProTec 2®
Plastic Film Tear

Production panel- Front corner – 16 km/h
Lincoln MKZ (Webasto) Countermeasure ProTec 2®

### Results/Ram Excursion Values

- **At 14 km/h**
- **At 16 km/h**
- **At 20 km/h**

- No rips or tears in PET layer
- No gross failures at mounting or attachment brackets
- Some bending of steel reinforcement of glass

<table>
<thead>
<tr>
<th>Side</th>
<th>Front</th>
<th>Passenger Side</th>
<th>Rear</th>
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</thead>
<tbody>
<tr>
<td>Driver</td>
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<tr>
<td></td>
<td></td>
<td>106/102</td>
<td>105/111</td>
</tr>
</tbody>
</table>

Only difference between production and countermeasure panels are holes in PET film
Results – Countermeasure

Some bending of steel frame
  • 4 inch ball did not pass through

Rear edge – mid @ 20 km/h

Bottom edge 2/3 A @ 20km/h

Front edge mid @ 20 km/h
Test Observations – MKZ Countermeasure

• Excursion values below 100 mm at 16 km/h and just slightly above at 20 km/h
• No rips or tears in PET layer
• No gross failures at mounting or attachment brackets
• Bending of steel reinforcement of glass
  • Most severe when impacted at mid points of transverse and 2/3 of lateral edges at 20 km/h
  • 4 inch ball did not pass through
Hyundai-Mobis Roof Air Curtain System
Curtain Air Bag Module

- Headliner (interior) and roof frame (exterior)
- Polycarbonate “glass” → aid in target alignment, zero plane
- Fabricated for testing purposes – not from production or prototype vehicle
- Guide rods and air bag to be installed for each test
Curtain Air Bag Module Assembly

- Guide rods mounted along lateral edges
  - 2 nuts per end
  - Bolt to prevent turning
- Guide rings on both sides hold bag to module along guide rods
Curtain Air Bag Module Assembly

- Air bag mounted on rear of module at six locations, four on interior, two on exterior
- Inflator secured at two locations
Curtain Air Bag Types

• Curtain types
  • One Panel Woven (OPW)
    • 30 bags
  • Seam Sealing (SS)
    • 15 bags
  • Same inflator and chamber layout

• Differences between the two:
  • Material
  • Fabric in OPW sealed by plastic film material, woven together at seam
Test Setup

- Open bag across daylight opening
  - Assumed successful deployment
  - Full automatic deployment found to not be reliable – 2 trials
- 6 Impact Locations
  - Front Corner, Front Edge – Mid, Center, 2/3 Lateral Edge, Rear Edge – Mid, Rear Corner
- 3 speeds
  - 14 km/h, 16 km/h, 20 km/h
- Plexiglass positioning
  - Front panel impacts – front plexiglass down, rear up – “moveable panel”
  - Rear panel impacts – front and rear plexiglass down
  - Plexiglass is zero plane for excursion measurements

Some rear panel targets eliminated per FMVSS No. 226 procedure
Propulsion Methods

- **Method 1**
  - Tested front panel center, front corner, front edge-mid (8 tests)
  - Headform positioned so desired velocity achieved at plexiglass location
  - Zero plane at plexiglass
    - Caused questionable speed readouts

- **Method 2**
  - Re-tested front edge-mid and all remaining impacts (37 tests)
  - Headform positioned so desired velocity achieved just before impact with bag
    - Zero plane at plexiglass

- **6 second delay between inflation and impact**
  - Additional tests done at 1.5, 3 and 8 second delays
# Hyundai-Mobis Curtain - Results

## Results/Excursion Values

<table>
<thead>
<tr>
<th>Speed</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 km/h</td>
<td>120/116</td>
<td>191/192</td>
</tr>
<tr>
<td>16 km/h</td>
<td>144*/138</td>
<td>195/195</td>
</tr>
<tr>
<td>20 km/h</td>
<td>165/171</td>
<td>195/195</td>
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</tbody>
</table>

### Notes:
- * Bag ripped at stitching
- Underline = Method 1
- Seam Sealing Bag
  - Bag more likely to rip or tear when hit at guide ring attachment
  - Excursions less in corners and on lateral edges where more supported by guide rings and rods
  - Excursions less closer to center support area

## Diagram

- **Front:**
  - 120/116
  - 144*/138
  - 165/171
  - 195/195
- **Driver:**
  - 116
  - 142*/120/129
  - 101
  - 124
- **Passenger:**
  - 90
  - 106
  - 176*/215*
  - 107
  - 115
  - 144
  - 161
- **Rear:**
  - 135
  - 145
Failure Modes

- Ripping at stitching of guide ring
  - When headform impacted near stitching
  - Full and partial ripping
  - Headform still contained
Timing Delay Effect on Excursion

**OPW and SS – Front Panel Center 16 km/h**

- $y = 3.9136x + 187.36$
- $R^2 = 0.9478$

**OPW - Rear Panel Center 16 km/h**

- $y = 1.161x + 157.1$
- $R^2 = 0.7735$
Test Observations – Hyundai-Mobis Curtain

- Bag more likely to rip or tear when hit at guide ring attachment
- Excursions less in corners and on lateral edges where more supported by guide rings and rods
- Excursions less closer to center support area
- Delay Timing Effect on Excursion
  - Longer delay = greater excursion
  - Greater effect of delay differences on front panel than rear
  - Greater scatter with OPW than Seam Sealing
Force Comparison

- Front panel – Center – 16 km/h
  - Red – Hyundai Air Curtain
  - Green – Lincoln MKZ
  - Blue – Toyota Prius *
  - Black – Ford F150 *
  - Orange – Aisin *

- Using accelerometer mounted to the ram

* 26th Conference on Enhanced Safety of Vehicles (ESV), Eindhoven, Netherlands, 2019
Overall Observations

• Movable panels with good attachment designs can perform well (excursion <100mm)
  • MKZ had metal rails, pins and cam
• Air curtains feasible for preventing ejection but still in development stages
• Roof air curtain produced similar headform forces and energy as good performing laminate movable sunroofs, higher excursions
  • More testing needed on other air curtain setups
• All components in load path need to be designed for occupant containment
  • Rail, rail inserts, bonding to glass, glass/plastic strength
• Smaller excursions may lead to higher head and neck forces (Prius)
  • Perhaps no worse than metal roof (no testing of metal roof was conducted)
  • May be better than getting ejected!
Data can be found at: Component Test Database (COMDB)
Test Numbers: c01826 through c01888