Background

• Annual average (2002-2012) fatalities (~233) and serious injuries (~200)
• Tests done on production vehicles with laminated sunroof panels
  – 2009 Ford Flex (fixed)
  – 2014 Ford Cmax (fixed)
  – 2013 Subaru Forester (movable)
• Tested at center and corners of daylight openings
• Impactor was contained (no tear-through of plastic layer)
• For fixed panels - ram excursions < 100 mm
• For movable panel ram excursion
  – ~ 100 mm at center and rear corner
  – >> 100 mm at forward corner (rail mount failure)
• Paper at 25th Conference on Enhanced Safety of Vehicles (ESV), Detroit, 2017
• Next step: Evaluate countermeasures
  – F-150 completed December 2017
Why F-150?

- Production panes use laminated glass (glass-PVB-glass 2.1-0.76-2.1 mm)
- Has fixed and movable panels
- Supplier (Webasto) agreed to provide countermeasures
  - Thicker PVB (2.1 - 1.52 - 2.1 mm; annealed glass - PVB - annealed glass)
  - Protec II film (inner surface; 5.0 mm tempered glass)
- The moving panel mount was one of the stronger designs (per Webasto)
- Testing completed December 2017
Front and rear panels attached to sunroof module

Sunroof module attached to vehicle roof from the inside using 22 bolts
Panel attached (6 screws) from the outside to rails that moves in a C channel.
Rail attached to the C channel with metal and plastic inserts.
Rear (fixed) Panel

Panel attached (6 screws) from the outside

Forward edge section height is less than rear edge
Test Setup (Impactor, Instrumentation)

Guided Impactor
- Featureless Headform (176.8 x 226.1 mm)
- 40 lbs. (18 kg)
- Displacement from Linear Pot (LVDT)
- Impact Velocity - 14/16*/20* kph
*Used in FMVSS No. 226

Mounted sideways
Glass pre-broken on both sides (except ProTEC II)
75 mm offset pattern per FMVSS No. 226
Instrumentation

Linear potentiometer measures ram displacement
4 linear potentiometer on the sunroof frame (detect permanent deformation)

Targets at unsupported edges to measure dynamic excursion using photogrammetry (TEMA)
Example of Video and Data

- ProTEC II panel
  - Single tempered glass
  - Plastic layer inside
- Center of panel
- 20 kph
- Ram excursion (LVDT)
  - Used in test procedure
- Edge excursion (TEMA)
  - For research

Note: Edge excursions were higher than ram excursions for ProTEC panels
Initial Assessment Impact locations

- Based on engineering judgment
  - Loading on glass
  - Loading on panel attachment
- Assumes
  - Left-right sides are identical
  - Front-rear are NOT identical
Ram Excursions (Production Glass - Baseline)

At 14 kph
At 16 kph
At 20 kph

* Rail mount failure

Observations: Front movable panel
Center: PVB stretch + transverse frame breaking
Corner: Rail failure => large excursions

Observations: Rear fixed panel
No edge failure
16 kph results "close enough" except:
Forward transverse edge is thinner and weaker
Video of Front Panel Corner

Glazing: Baseline (production)
Location: Front Panel Front Corner
Speed: 20 kph (12.4 mph)
Excursion: 178 mm (at the ram)
Glazing: Baseline (production)
Location: Rear Fixed Panel Center
Speed: 20 kph (12.4 mph)
Excursion: 138 mm (at the ram); 101 mm (at the edge)
Ram Excursions (Double Thickness PVB Panel)

At 14 kph
At 16 kph
At 20 kph
(% change from baseline)

* Rail mount failure

Observations:
- Front Movable Panel
  - Center - Less PVB stretch; more transverse frame bending
  - Corner – catastrophic edge failure

Observations:
- Thicker PVB reduced excursions
  - ~ 10% reduction in excursion (rear)
- Stronger glazing => transfer of loads to edges
At 16 kph
At 20 kph
* Rail mount failure

• Glass punched on the outside (one exception)
• Punching the Protec II layer => no difference
• Protec II film stretches less => transfers more loads to the edges

Observations: Front Movable Panel
Center – much less film stretch; much more transverse frame bending; still less than baseline
Corner – catastrophic edge failure

Observations: Rear Fixed Panel
~ 12% reduction in excursion
Revised Test Procedure

- Based on results and engineering judgement
- Headform rotated
- Additional speed (14/16/20 kph)
- 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
**Observations:**

- **Front movable panel:**
  - Center - PVB stretch + transverse frame bending
  - Corner - Rail failure => large excursions

- **Rear fixed panel:** No edge failure

- Forward transverse edge is thinner and weaker
  - Test showed good repeatability
  - Thicker PVB reduced excursion by ~9 mm

* Rail mount failure

<table>
<thead>
<tr>
<th>Speed (kph)</th>
<th>Thicker PVB</th>
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<tbody>
<tr>
<td>14</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>191*</td>
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<tr>
<td>16</td>
<td>106/97</td>
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<td>108</td>
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<td>109/106/100</td>
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<td></td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>103</td>
</tr>
<tr>
<td>145</td>
<td>93/98/95/94/106/107*</td>
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<tr>
<td>101</td>
<td>92/82/101</td>
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<tr>
<td>124</td>
<td>88</td>
</tr>
<tr>
<td>95</td>
<td>85/95/114</td>
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</tbody>
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**Ram Excursions (Production Glass - Baseline)**
Observations

- Movable panels present more challenges to contain than fixed panels
  - Ford Flex; CMax; Subaru Forester (with movable panel) [2017 ESV]
  - True for F-150 including countermeasures
  - Moving panel - Failure at the inserts (into the rails)
  - Fixed panels can have higher excursions at unsupported transverse edges (F-150 fixed rear panel has front and rear unsupported edges)
- Thicker plastic PVB interlayer (laminated) and PET film (Protec II):
  - Did not tear
  - Reduced stretch (and ram excursions)
  - Transferred more forces to the edges
    - Greater challenge for movable panels
  - Can produce larger opening at an edge (not ram)
- Headform orientation can affect ram excursions
- Results may change for different sunroof designs
Future work

- 2012 Toyota Prius v (trim Five) Technology Package option
  - Polycarbonate sunroof panel - 1 fixed panel with 2 daylight openings
- Additional sunroof designs (opening to the outside; curtains)
# Table of Excursions

<table>
<thead>
<tr>
<th>Excursion Type</th>
<th>Production</th>
<th>Rear Fixed Panel</th>
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<tbody>
<tr>
<td></td>
<td>Center</td>
<td>Forward Edge - Corner</td>
</tr>
<tr>
<td></td>
<td>Ram</td>
<td>Edge</td>
</tr>
<tr>
<td>16 Km/h</td>
<td>115 mm</td>
<td>86 mm</td>
</tr>
<tr>
<td>20 Km/h</td>
<td>154 mm</td>
<td>106 mm</td>
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### Double PVB

<table>
<thead>
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<th>Production</th>
<th>Rear Fixed Panel</th>
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<tbody>
<tr>
<td></td>
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<td>Forward Edge - Corner</td>
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<tr>
<td></td>
<td>Ram</td>
<td>Edge</td>
</tr>
<tr>
<td>14 Km/h</td>
<td>97 mm*</td>
<td>86 mm</td>
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<td>16 Km/h</td>
<td>111 mm (-3.5%)</td>
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<td>140 mm (-9.1%)</td>
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### Protec II

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<tbody>
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<tr>
<td></td>
<td>Ram</td>
<td>Edge</td>
</tr>
<tr>
<td>14 Km/h</td>
<td>95 mm*</td>
<td>93 mm</td>
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<td>16 Km/h</td>
<td>109 mm (-5.2%)</td>
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<tr>
<td>20 Km/h</td>
<td>140 mm (-9.1%)</td>
<td>153 mm</td>
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</table>

- Rail mechanism failure
- Edge excursion greater than ram excursion
- * New Headform Orientation
# Table of Excursions

## Front Movable Panel

<table>
<thead>
<tr>
<th>Speed (Km/h)</th>
<th>Forward Edge - Corner</th>
<th>Forward Edge - Mid</th>
<th>Center</th>
<th>Side Edge - 2/3 A</th>
<th>Rear Edge - Corner</th>
<th>Rear Edge - Mid</th>
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</thead>
<tbody>
<tr>
<td>14</td>
<td>Ram 93/98/95/94/106</td>
<td>Edge ND/120/114/104/127</td>
<td>Ram 111/107</td>
<td>Edge 96/99</td>
<td>106</td>
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<tr>
<td>16</td>
<td>145</td>
<td>194</td>
<td>127</td>
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</tr>
</tbody>
</table>

## Rear Fixed Panel

<table>
<thead>
<tr>
<th>Speed (Km/h)</th>
<th>Forward Edge - Corner</th>
<th>Forward Edge - Mid</th>
<th>Center</th>
<th>Side Edge - 2/3 A</th>
<th>Rear Edge - Corner</th>
<th>Rear Edge - Mid</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Ram 92</td>
<td>Edge 67</td>
<td>Ram 109/106</td>
<td>Edge 87/87</td>
<td>102</td>
<td>69.3</td>
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<tr>
<td>16</td>
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<td>120</td>
<td>119</td>
<td>99</td>
<td>112/113/111/109/110</td>
<td>78/84/84/90/86</td>
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<tr>
<td>20</td>
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</table>

rail mechanism failure

Edge excursion greater than ram excursion
Aloke Prasad (NHTSA)
Steve Duffy (TRC Inc)

www.NHTSA.gov
https://www.nhtsa.gov/research-data/databases-and-software