NHTSA Pedestrian Testing with TRL and Flex-GTR Legforms and the Status of the GTR

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Background – Pedestrian GTR

- **GTR 9 was adopted November 2008**
  - NHTSA has initiated Rulemaking efforts and plans to publish an NPRM by late 2010

- **Amendment 1 to GTR 9**
  - Incorporates the FlexGTR into the GTR
  - NHTSA is participating in evaluation efforts of the pedestrian legform
Background – Previous Tests

Previous VRTC testing of prototype FlexPLI

FlexPLI (Mallory, Stammen and Legault, ESV 2005)
- Durability → Unable to test at GTR speed on US vehicles

FlexGT (Mallory and Stammen, SAE Gov’t Ind 2008)
- Durability improved → Tested 2 US vehicles at GTR speed
- Compared to TRL for same vehicles
  - Injury risk ranked similarly (fracture, knee ligaments bend/shear)
  - FlexGT more likely to exceed injury limits than TRL

Current tests

FlexGTR SN/01
- Prototype provided by Flex Technical Evaluation Group (TEG)

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Objectives

- Test 5 US vehicles using newest Flex (FlexGTR)
- Include vehicles where
  - Previous performance with TRL legform was not overly aggressive
  - A reasonable range of performance was expected
- Compare the FlexGTR injury results with TRL results from the same vehicles
- Evaluate FlexGTR: durability, usability, repeatability

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Vehicles Tested

FlexGTR tests performed on 5 vehicles

– 2006 VW Passat
– 2005 Honda CR-V
– 2002 Mazda Miata
– 2001 Honda Civic
– 2006 Nissan Fuga bumper
  (on 2006 Infiniti M-35)

Compared to TRL tests performed previously

– Passat, CR-V, and Miata
– Civic, Fuga

1 NHTSA, 10th Flex-PLI Technical Evaluation Group (Flex-TEG) Meeting, December 2009.
2 Mallory and Stammen, ESV, June 2009

Relatively good performance with TRL legform
# Instrumentation and Injury Measures

<table>
<thead>
<tr>
<th>Fracture Risk</th>
<th>FlexGTR Onboard DTS Slice</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture Risk</td>
<td>Tibia bending moment</td>
<td>Upper tibia acceleration</td>
</tr>
<tr>
<td>Ligament Injury Risk (Bending)</td>
<td>MCL elongation</td>
<td>Knee bending angle</td>
</tr>
<tr>
<td>Ligament Injury Risk (Shear)</td>
<td>PCL/ACL elongation</td>
<td>Knee shear displacement</td>
</tr>
<tr>
<td>Additional measures</td>
<td>Femur bending moment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tibia acceleration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LCL elongation</td>
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</tbody>
</table>

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Test Setup - Method

- **GTR conditions (40 km/h)**
  - Ground reference level: EEVC/TRL=25 mm, Flex-GTR=75 mm

- **Center impacts**

- **Speed and alignment**
  - Video analysis to monitor alignment during flight
  - Laser speed-traps to measure impact velocity
Results
<table>
<thead>
<tr>
<th>MIATA</th>
<th>FlexGTR</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fracture Risk</strong></td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Ligament Injury Risk (Bending)</strong></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Ligament Injury Risk (Shear)</strong></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>

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Injury Measures: Fracture

CR-V
Fuga
Miata
Passat
Civic

Injury measure as % of limit

TRL - Tibia Acceleration
FLEX - Max Tibia Bend Moment

\( TRL = \frac{\text{Tibia Acceleration}}{170 \text{ g}} \)

\( \text{FlexGTR} = \frac{\text{Tibia Moment}}{340 \text{ Nm}} \)
Injury Measures: Ligament Injury (Bending)

- **TRL - Knee bend angle**
- **FLEX - MCL Elongation**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>TRL BendAngle</th>
<th>FlexGTR MCL Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR-V</td>
<td>19°</td>
<td>22 mm</td>
</tr>
<tr>
<td>Fuga</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passat</td>
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</tr>
</tbody>
</table>

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Injury Measures: Ligament Injury (Shear)

- **CR-V**
  - ACL

- **Fuga**
  - ACL

- **Miata**
  - ACL

- **Passat**
  - ACL

- **Civic**
  - ACL

**Injury measure as % of limit**

**TRL - Knee shear displacement**
- CR-V: 6mm

**FLEX - Max ACL/PCL Elongation**
- CR-V: 13mm

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FlexGTR Durability

Minor or cosmetic damage only

Scuffing (rebound)

Segment face displaced (rebound)
FlexGTR Repeatability

FlexGTR: Good repeatability in paired tests
Example – 2001 Honda Civic
Flex-GTR durability, repeatability, and usability
## Comparison: Ease of Use

<table>
<thead>
<tr>
<th>FlexGTR</th>
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<tbody>
<tr>
<td><strong>Between-test Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>Cable adjustment</td>
<td>Ligament replacement</td>
</tr>
<tr>
<td></td>
<td>Foam replacement, gluing</td>
</tr>
<tr>
<td></td>
<td>Temperature and humidity soaking</td>
</tr>
<tr>
<td><strong>Flight Orientation</strong></td>
<td></td>
</tr>
<tr>
<td>Flat pushing surface</td>
<td>Foam pushing surface</td>
</tr>
<tr>
<td>Onboard acquisition system eliminates cable drag</td>
<td>Possibly complicated by data acquisition cables</td>
</tr>
</tbody>
</table>

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Summary

- FlexGTR tended to measure higher injury risk than TRL relative to proposed injury limits.

- The two legforms ranked these 5 vehicles similarly in terms of fracture risk and knee ligament risk (bending, shear).
  - Corresponded especially well for vehicles that passed GTR in TRL testing.

- FlexGTR tended not to discriminate among more aggressive vehicles (even when TRL indicated there was a performance difference)

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Summary (Cont.)

- Preliminary results show Flex has good repeatability and has several features that make it easier to use than the TRL legform.
  - Certification procedures were not compared.
- The current set of tests did not result in functional damage to either legform.
- The FlexGTR is more robust than the FlexGT. However, thorough evaluation of the durability of the FlexGTR for use with the US fleet would require testing of more aggressive vehicles than those included in this test matrix.
Thank You

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<tr>
<td><strong>Fracture Risk</strong></td>
<td><img src="image" alt="Graph of Tibia Moment vs Time" /></td>
<td><img src="image" alt="Graph of Tibia Acceleration vs Time" /></td>
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<tr>
<td><strong>Ligament Injury Risk (Bending)</strong></td>
<td><img src="image" alt="Graph of MCL Elongation vs Time" /></td>
<td><img src="image" alt="Graph of Bending Angle vs Time" /></td>
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<td><strong>Ligament Injury Risk (Shear)</strong></td>
<td><img src="image" alt="Graph of ACL/PCL Elongation vs Time" /></td>
<td><img src="image" alt="Graph of Shear Displacement vs Time" /></td>
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<td><strong>Fracture Risk</strong></td>
<td><img src="image" alt="Graph showing tibia moment vs. time for Tibia 1, 2, 3, 4 with peaks at 340 Nm" /></td>
<td><img src="image" alt="Graph showing tibia acceleration vs. time with peaks at 250 g and 170 g" /></td>
</tr>
<tr>
<td><strong>Ligament Injury Risk (Bending)</strong></td>
<td><img src="image" alt="Graph showing MCL elongation vs. time with MCL 22mm marker" /></td>
<td><img src="image" alt="Graph showing bending angle vs. time with 19 deg marker" /></td>
</tr>
<tr>
<td><strong>Ligament Injury Risk (Shear)</strong></td>
<td><img src="image" alt="Graph showing ACL/PCL elongation vs. time with 13 mm and 6 mm markers" /></td>
<td><img src="image" alt="Graph showing shear displacement vs. time with 6 mm marker" /></td>
</tr>
</tbody>
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MIATA | FlexGTR | TRL

Fracture Risk

Ligament Injury Risk (Bending)

Ligament Injury Risk (Shear)
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