# Bumper Test Area – Legform Tests – Results from Round 2, Flex-PLI

Prepared by Brian Hardy & Jolyon Carroll

30 January 2014

# Legform tests

## Objectives

**1**

- Assess pedestrian protection levels across vehicle front
  - Could support justification for need to change bumper corner definition
  - Provide supporting information for the benefit estimate (i.e. predicted risk of injury around bumper corners)

**2**

- Determine practicality of extending bumper test area
  - Does impactor slide off vehicle giving very low values?
  - Does impactor rotate so as to invalidate measurements?

# Legform tests

## Simple summary from EEVC legform tests

### Injurious?

- Hard points identified through test results
- Could be more injurious than centre of bumper
- Reason for extending test area
  - Not sure if that is feasible, etc.

### Rotation

- Legform rotates substantially in oblique impacts
- Didn't see vast differences in injury metric results
  - Not obviously over-reading
  - Not obviously under-reading

### Practicality

- Tried rotating vehicle
- Reduced test speed to match 'normal' velocity
- Seemed to produce sensible peak values without large rotation
- Don't know whether vehicle rotation is a viable solution for Test Services

# Legform tests – Round 2

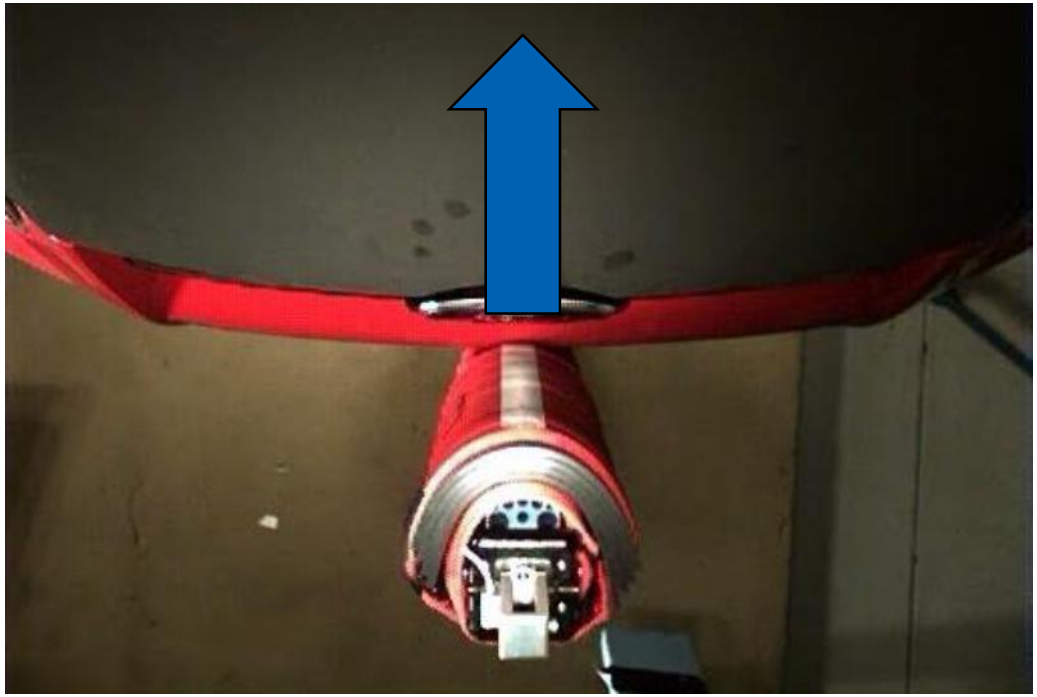
Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

| | |
|---|---|
| 1 | Centre of bumper, no vehicle rotation |
| 2 | End of bumper beam, no vehicle rotation |
| 3 | End of bumper beam, vehicle rotated to remove oblique component |
| 4 | 45 degree position with car rotated 15 degrees |
| 5 | Centre of bumper, vehicle rotated 30 degrees |

# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

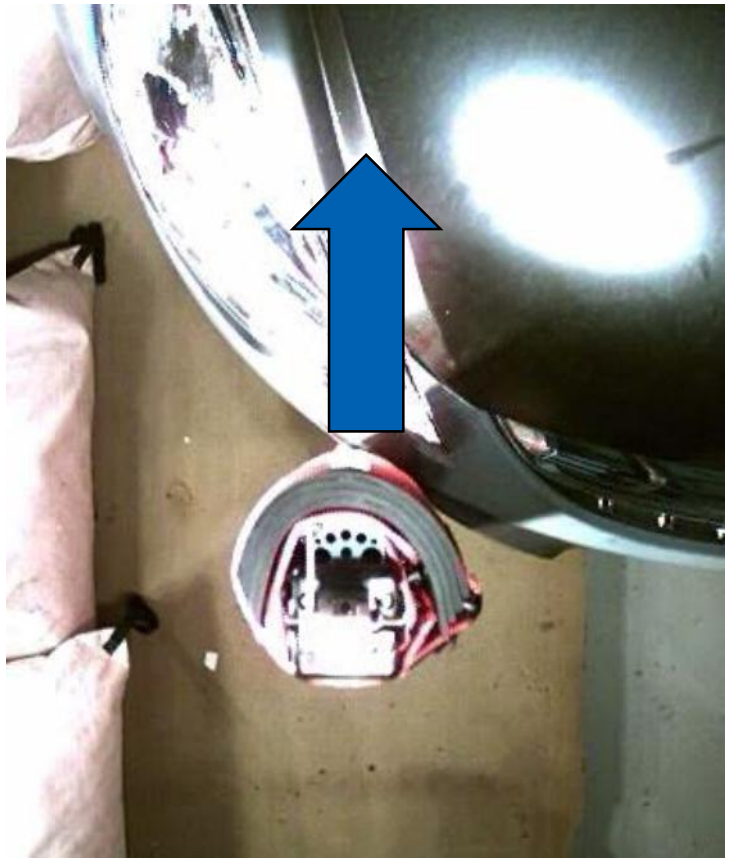
| | |
|---|---|
| 1 | Centre of bumper, no vehicle rotation |



# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

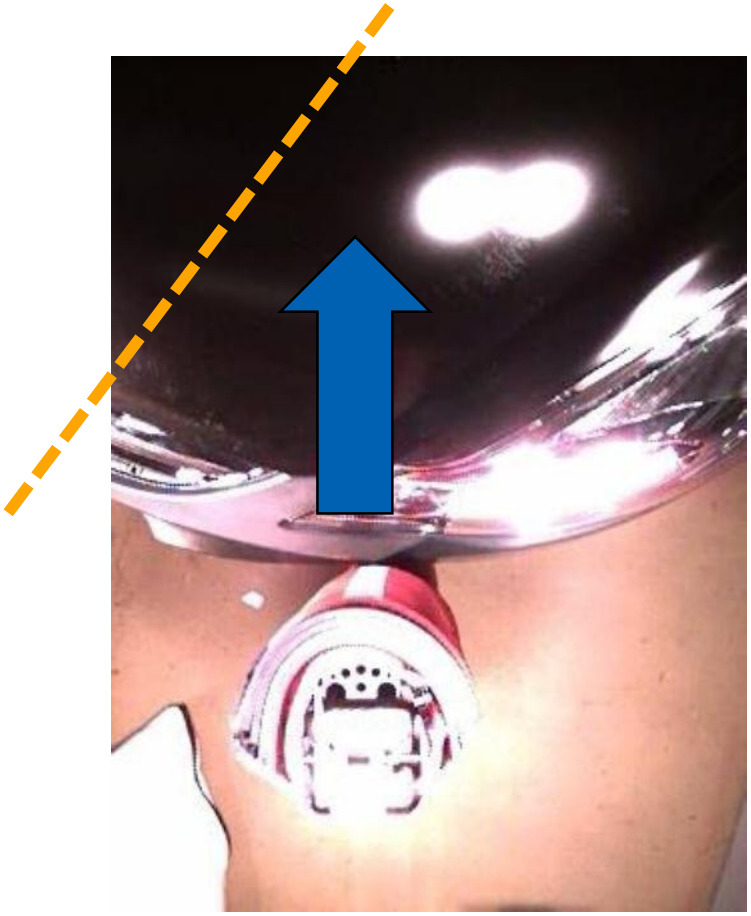
| | |
|---|---|
| 2 | End of bumper beam, no vehicle rotation |



# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

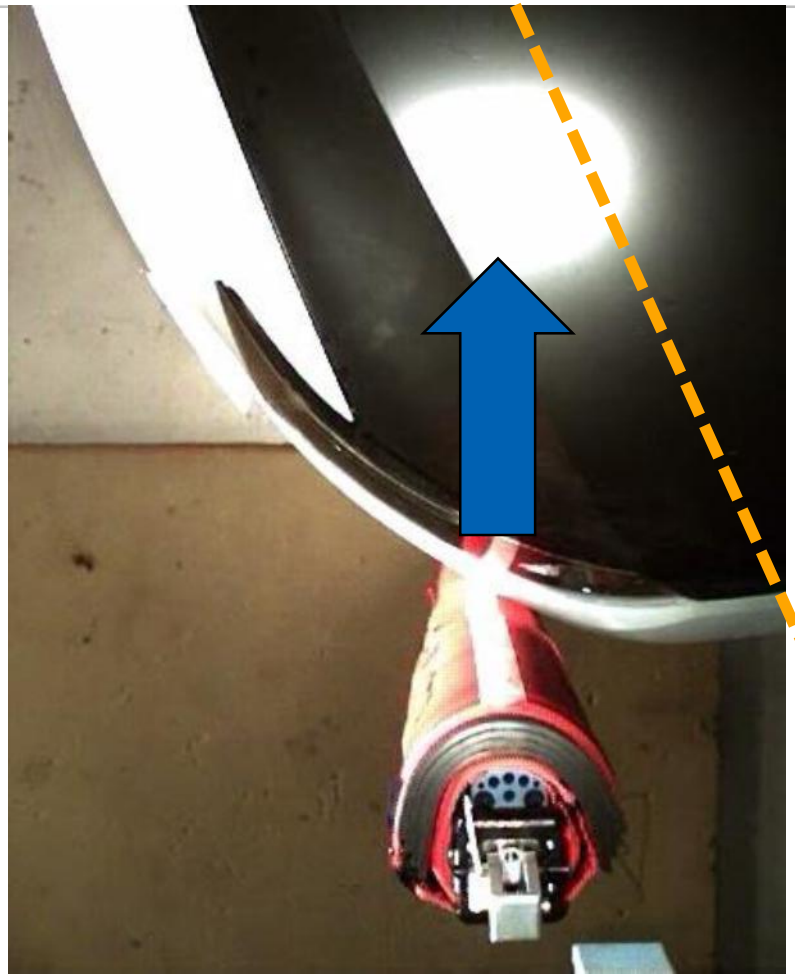
| | |
|---|---|
| 3 | End of bumper beam, vehicle rotated to remove oblique component |



# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

| | |
|---|---|
| 4 | 45 degree position with car rotated 15 degrees |



# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

| | |
|---|---|
| 5 | Centre of bumper, vehicle rotated 30 degrees |

# Legform tests – Round 2

Scheme for tests with Flex-PLI – updated at 4th TF-BTA meeting

| Test number | Position on bumper | Vehicle rotation | Impact speed (m/s) # |
|---|---|---|---|
| 1 | Centre | None | Usual (11.1 m/s) |
| 2 | End of bumper beam | None | Usual (11.1 m/s) |
| 3 | End of bumper beam | Sufficient for normal impact | Calculated based on vehicle rotation |
| 4 | 45 degree plane | 15 degrees | 9.1 m/s |
| 5 | Centre | 30 degrees | 9.1 m/s |

# See next slide

# Explanation of test velocities 1

- Tests 1 & 2: standard longitudinal tests at standard 11.1 m/s
- Test 3: Car rotated to test normal to vehicle front at that point
  - Test at velocity = normal velocity of the longitudinal test (Test 2)
  - Test velocity = 11.1 * cos (rotation angle) m/s
  - Vehicle 1: 35° rotation angle gives 9.09 m/s test velocity
  - Vehicle 2: 36° rotation angle gives 8.98 m/s test velocity
  - Vehicle 3: 45° rotation angle gives 7.85 m/s test velocity

# Explanation of test velocities 2

- Test 4: At point where 45° plane contacts
  - Normal to vehicle front is 45° to longitudinal direction, so normal velocity in standard longitudinal test would be:

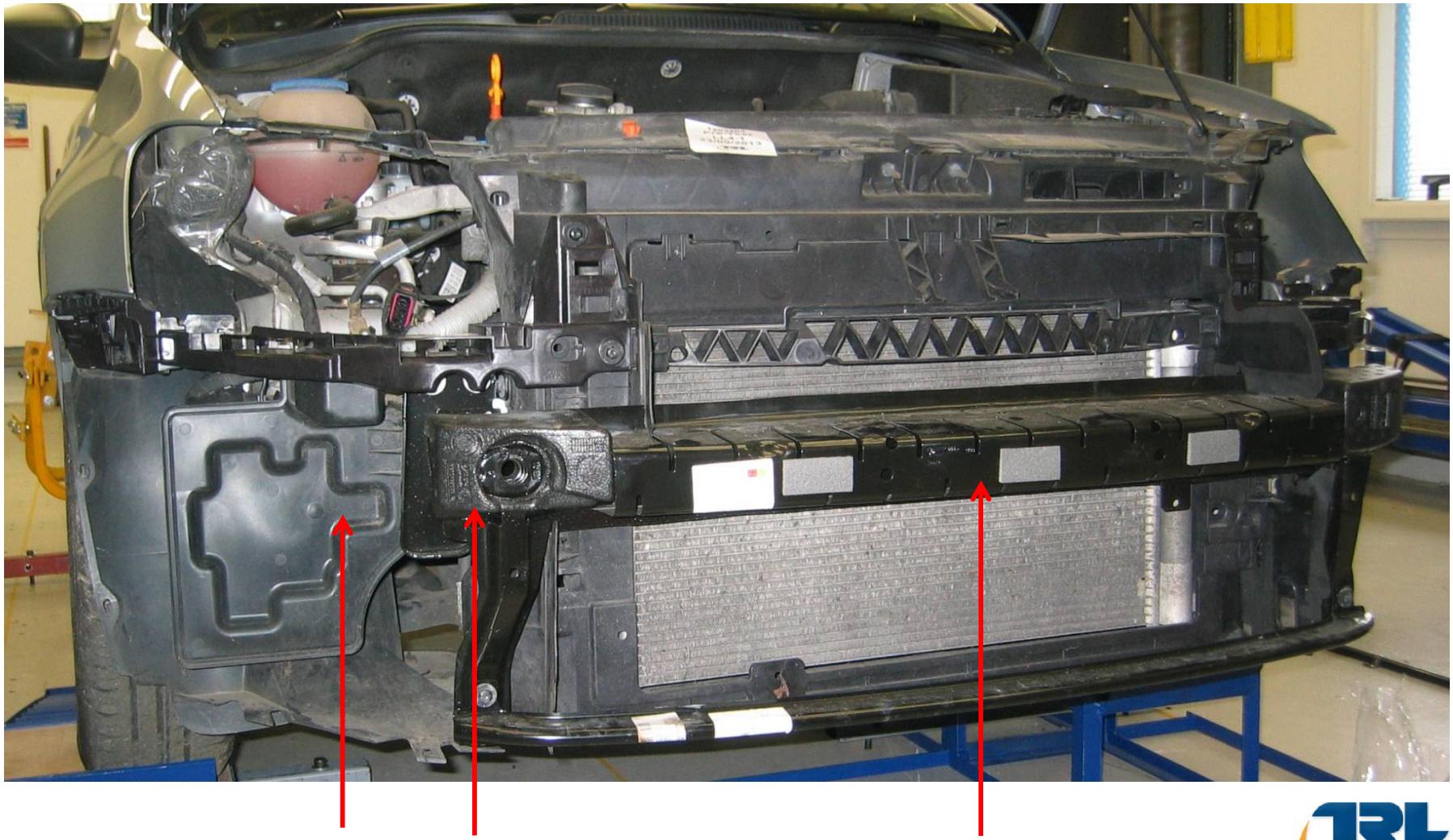
    11.1 * cos (45°) m/s = 7.85 m/s
  - Vehicle rotated 15° for Test 5, so impact is at 30° to normal
  - Standard test velocity would give a normal velocity of:

    11.1 * cos (30°) m/s = 9.61 m/s
  - Pro rata, required impact velocity for a normal velocity of 7.85 m/s:

    11.1 * 7.85 / 9.61 m/s = **9.06 m/s**
    - To confirm this, 9.06 * cos (30°) m/s = 7.85 m/s
- Test 5: This test is intended for comparison with Test 4, with both impacting at 30° to the normal, so the same test velocity (9.06 m/s) is used

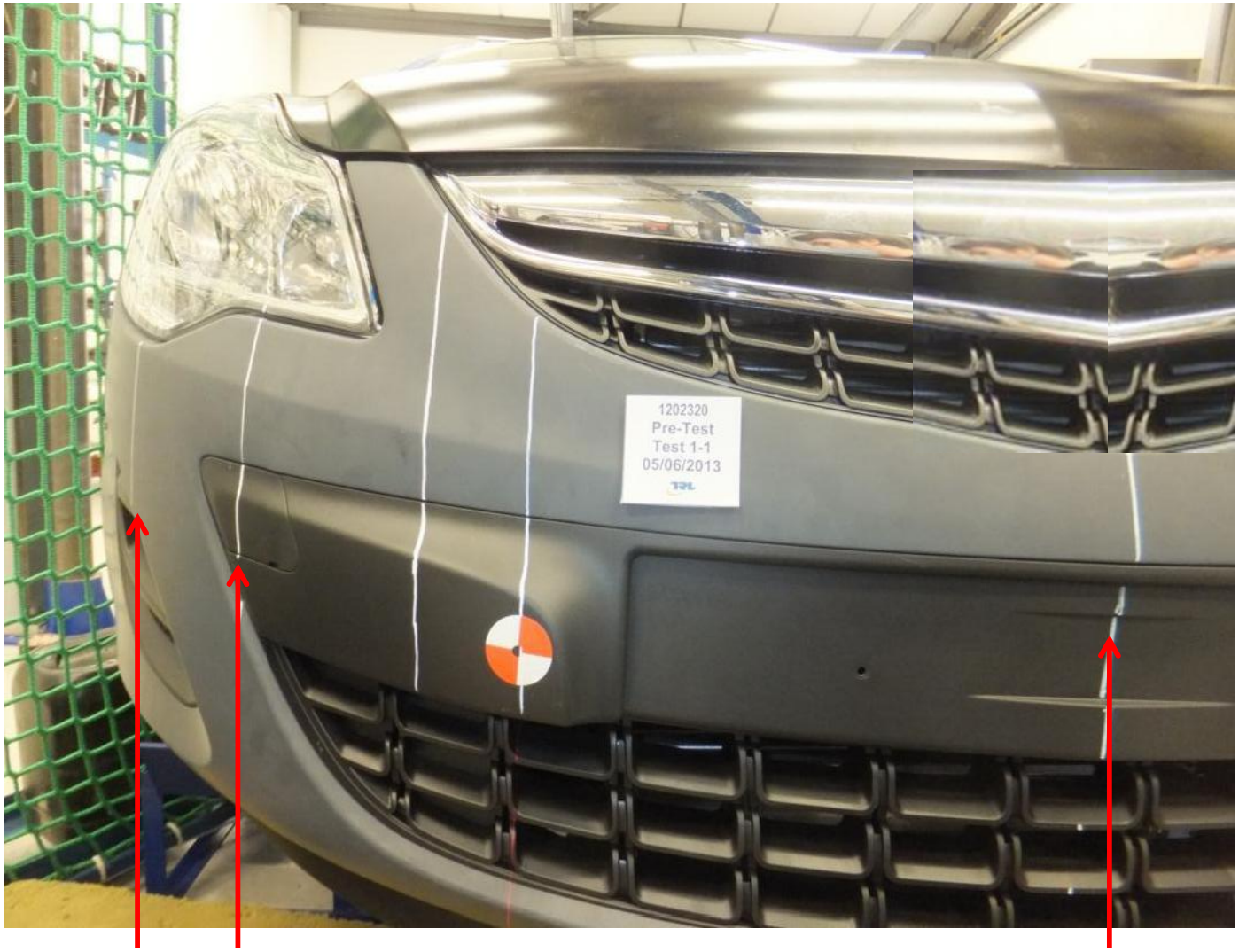
# Legform tests – Round 2

## Alignment on Vehicle 1



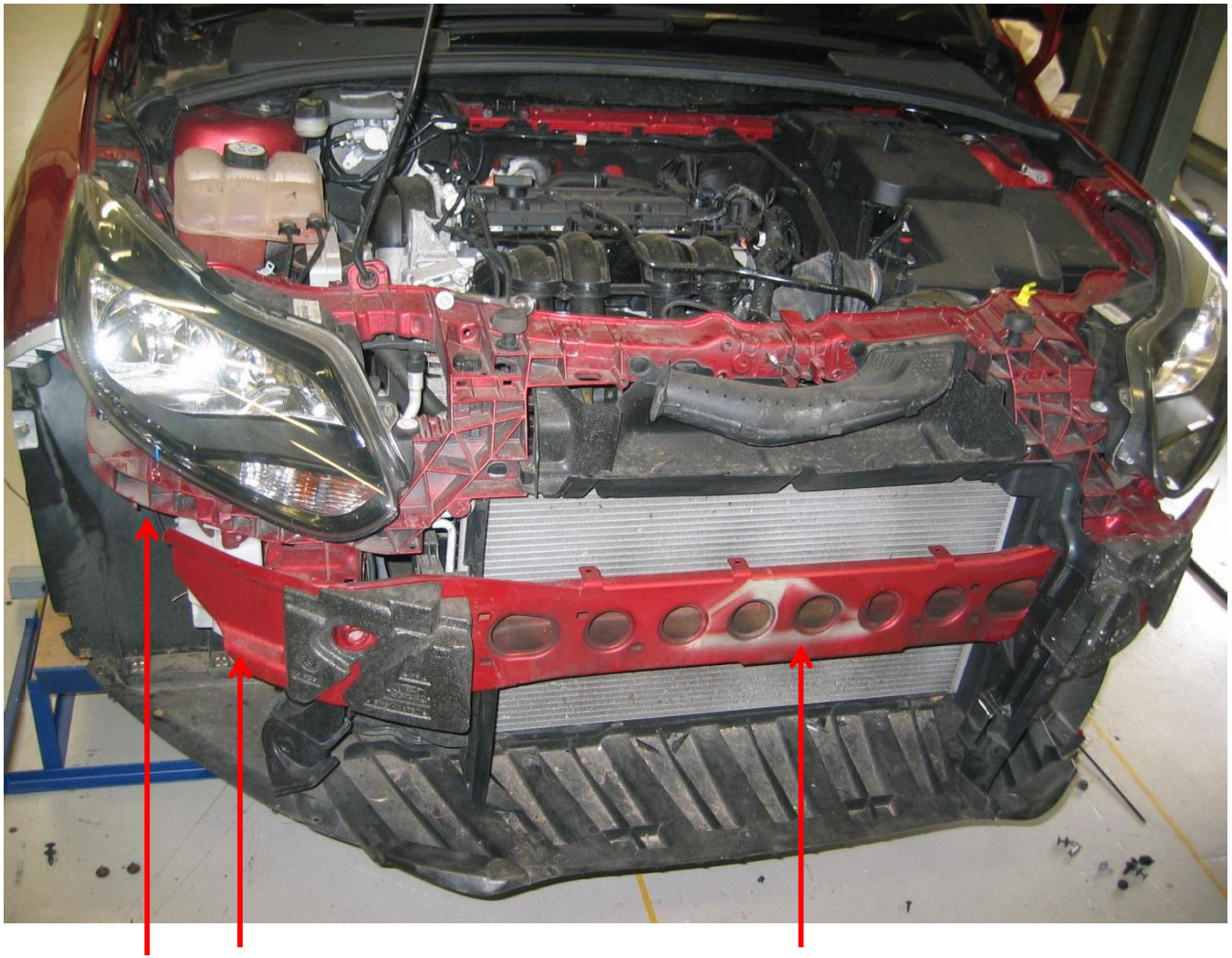
# Legform tests – Round 2

## Alignment on Vehicle 2



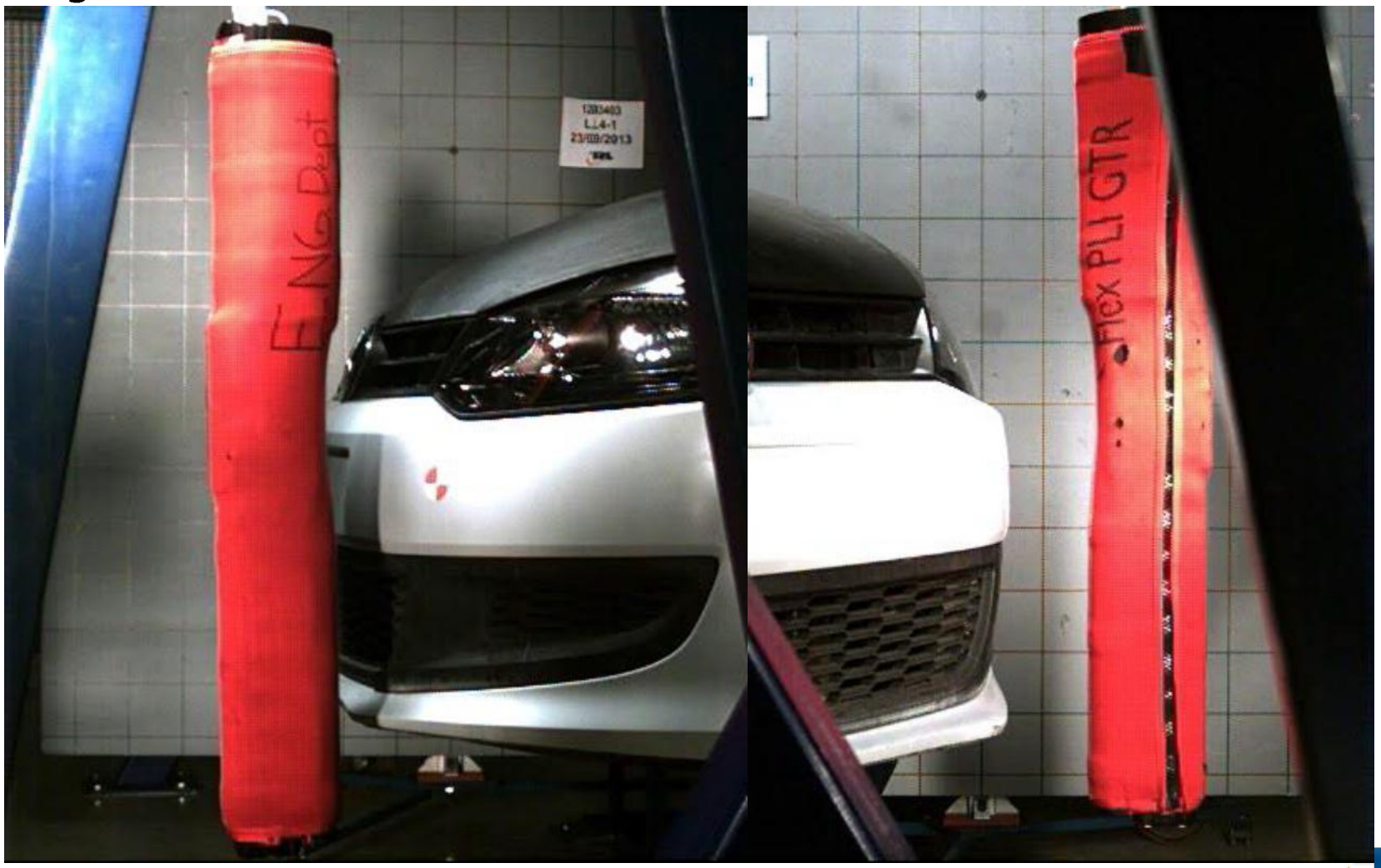
# Legform tests – Round 2

## Alignment on Vehicle 3



# Vehicle 1

Angle of rotation – visual




End of bumper beam tests:

Left = straight, Right = vehicle rotated to give tangential impact

# Vehicle 2

Angle of rotation – visual

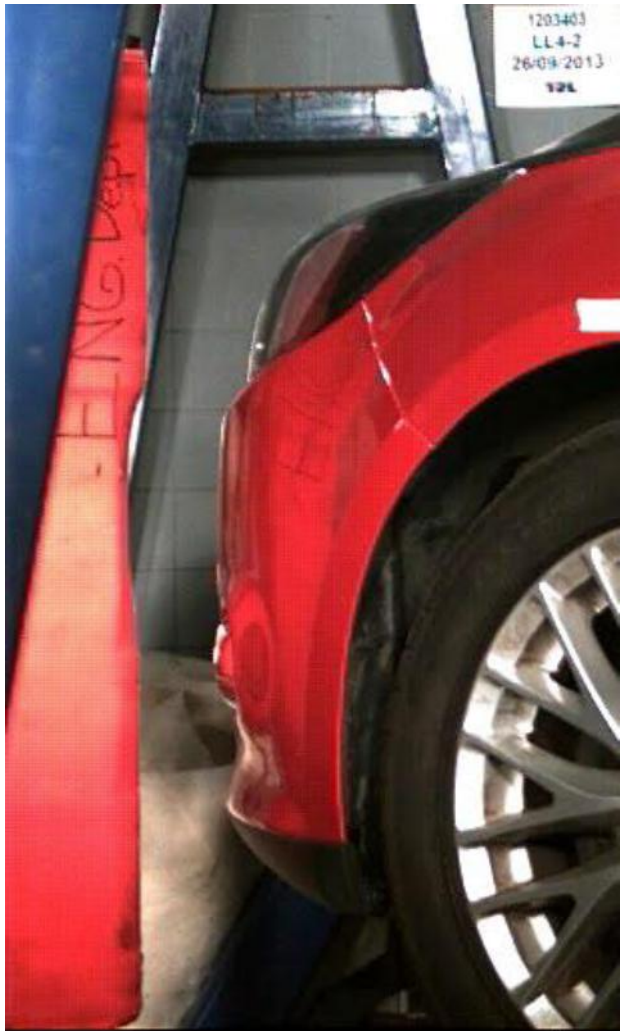


End of bumper beam tests:

Left = straight, Right = vehicle rotated to give tangential impact

# Vehicle 3

Angle of rotation – visual




End of bumper beam tests:

Left = straight, Right = vehicle rotated to give tangential impact

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 5.6 | 5.6 | 18.2 | 225 |
| End of bumper beam | 10.0 | 6.3 | 18.8 | 314 |
| End of bumper beam – normal impact (car rotated 35 degrees) | 9.5 | 5.2 | 15.8 | 286 |
| 45 degrees – 15 degree rotation of car | 5.4 | 4.9 | 14.7 | 151 |
| Centre – 30 degree rotation of car | 4.3 | 5.4 | 12.1 | 175 |
| **Limits** | **13** | **13** | **22** | **340/380** |

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 5.6 | 5.6 | 18.2 | 225 |
| End of bump | | | | 314 |
| End of bump (car rotated | | | | 286 |
| 45 degrees – 15 degree rotation of car | 5.4 | 4.9 | 14.7 | 151 |
| Centre – 30 degree rotation of car | 4.3 | 5.4 | 12.1 | 175 |
| **Limits** | **13** | **13** | **22** | **340/380** |

All peak values within proposed acceptance criteria

# Vehicle 2

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 1.8 | 2.3 | 6.8 | 191 |
| End of bumper beam | 12.9 | 7.4 | 23.7 | 395 |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 | 6.0 | 20.3 | 332 |
| 45 degrees – 15 degree rotation of car | 7.1 | 7.1 | 18.9 | 166 |
| Centre – 30 degree rotation of car | 3.0 | 5.9 | 10.2 | 140 |
| **Limits** | **13** | **13** | **22** | **340/380** |

# Vehicle 2

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 1.8 | 2.3 | 6.8 | 191 |
| End of bumper beam | 12.9 | 7.4 | 23.7 | 395 |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 | 6.0 | 20.3 | 332 |
| 45 degrees – 15 degree rotation of car | 7.1 | 7.1 | 18.9 | 166 |
| Centre – 30 degree rotation of car | 3.0 | 5.9 | 10.2 | 140 |
| **Limits** | **13** | **13** | **22** | **340/380** |

Exceeding thresholds

# Vehicle 3

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 3.7 | 3.7 | 12.1 | 230 |
| End of bumper beam | 9.4 | 8.6 | 24.8 | 265 |
| End of bumper beam – normal impact (car rotated 45 degrees) | 7.7 | 8.6 | 23.1 | 271 |
| 45 degrees – 15 degree rotation of car | 4.5 | 5.9 | 14.6 | 195 |
| Centre – 30 degree rotation of car | 2.3 | 3.2 | 9.0 | 144 |
| **Limits** | **13** | **13** | **22** | **340/380** |

# Vehicle 3

## Peak values

| Description of test location and rotation | ACL (mm) | PCL (mm) | MCL (mm) | Peak tibia bending moment (Nm) |
|---|---|---|---|---|
| Centre | 3.7 | 3.7 | 12.1 | 230 |
| End of bumper beam | 9.4 | 8.6 | 24.8 | 265 |
| End of bumper beam – normal impact (car rotated 45 degrees) | 7.7 | 8.6 | 23.1 | 271 |
| 45 degrees – 15 degree rotation of car | [illegible] | [illegible] | [illegible] | 195 |
| Centre – 30 degree rotation of car | 2.3 | 3.2 | 9.0 | 144 |
| **Limits** | **13** | **13** | **22** | **340/380** |

Exceeding thresholds

# Legform rotation

Tables to follow
Rotation angles from video analysis

- Normally using overhead camera view of hip end of Flex-PLI
  - No correction made for viewing angle effects

| Test location | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| | **Peak value** | | | |
| | **Rotation at peak** | | | |
| | | | | |
| | | | | |
| | | | | |

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 5.6 mm | 5.6 mm | 18.2 mm | 225 Nm |
| | 0º | 1º | 1º | 1º |
| End of bumper beam | 10.0 mm | 6.3 mm | 18.8 mm | 314 Nm |
| | -1º | -20º | -20º | -3º |
| End of bumper beam – normal impact (car rotated 35 degrees) | 9.5 mm | 5.2 mm | 15.8 mm | 286 Nm |
| | -1º | -3º | -4º | -2º |
| 45 degrees – 15 degree rotation of car | 5.4 mm | 4.9 mm | 14.7 mm | 151 Nm |
| | 6º | 36º | 38º | 48º |
| Centre – 30 degree rotation of car | 4.3 mm | 5.4 mm | 12.1 mm | 175 Nm |
| | 18º | 33º | 35º | 2º |

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 5.6 mm | 5.6 mm | 18.2 mm | 225 Nm |
| | 0º | 1º | 1º | 1º |
| End of bumper beam | 10.0 mm | 6.3 mm | 18.8 mm | 314 Nm |
| | -1º | -20º | -20º | -3º |
| End of bumper beam – normal impact (car rotated 35 degrees) | 9.5 mm | 5.2 mm | 15.8 mm | 286 Nm |
| | -1º | -3º | -4º | -2º |
| 45 degrees – 15 degree rotation of car | 5.4 mm | 4.9 mm | 14.7 mm | 151 Nm |
| | 6º | 36º | 38º | 48º |
| Centre – 30 degree rotation of car | 4.3 mm | 5.4 mm | 12.1 mm | 175 Nm |
| | 18º | 33º | 35º | 2º |

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 5.6 mm | 5.6 mm | 18.2 mm | 225 Nm |
| | 0º | 1º | 1º | 1º |
| End of bumper beam | 10.0 mm | 6.3 mm | 18.8 mm | 314 Nm |
| | -1º | -20º | -20º | -3º |
| End of bumper beam – normal impact (car rotated 35 degrees) | 9.5 mm | 5.2 mm | 15.8 mm | 286 Nm |
| | -1º | -3º | -4º | -2º |
| 45 degrees – 15 degree rotation of car | 5.4 mm | 4.9 mm | 14.7 mm | 151 Nm |
| | 6º | 36º | 38º | 48º |
| Centre – 30 degree rotation of car | 4.3 mm | 5.4 mm | 12.1 mm | 175 Nm |
| | 18º | 33º | 35º | 2º |

# Vehicle 1

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 5.6 mm | 5.6 mm | 18.2 mm | 225 Nm |
| | 0º | 1º | 1º | 1º |
| End of bumper beam | 10.0 mm | 6.3 mm | 18.8 mm | 314 Nm |
| | -1º | -20º | -20º | -3º |
| End of bumper beam – normal impact (car rotated 35 degrees) | 9.5 mm | 5.2 mm | 15.8 mm | 286 Nm |
| | -1º | -3º | -4º | -2º |
| 45 degrees – 15 degree rotation of car | 5.4 mm | 4.9 mm | 14.7 mm | 151 Nm |
| | 6º | 36º | 38º | 48º |
| Centre – 30 degree rotation of car | 4.3 mm | 5.4 mm | 12.1 mm | 175 Nm |
| | 18º | 33º | 35º | 2º |

# Vehicle 2

Note – values in parentheses estimated from side view

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 1.8 mm | 2.3 mm | 6.8 mm | 191 Nm |
| | (0°) | (0°) | (0°) | (0°) |
| End of bumper beam | 12.9 mm | 7.4 mm | 23.7 mm | 395 Nm |
| | 2° | 26° | 27° | 15° |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 mm | 6.0 mm | 20.3 mm | 332 Nm |
| | -1° | -10° | -11° | -5° |
| 45 degrees – 15 degree rotation of car | 7.1 mm | 7.1 mm | 18.9 mm | 166 Nm |
| | 24° | 38° | 39° | 44° |
| Centre – 30 degree rotation of car | 3.0 mm | 5.9 mm | 10.2 mm | 140 Nm |
| | (75°) | (60°) | (75°) | (75°) |

# Vehicle 2

Note – values in parentheses estimated from side view

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 1.8 mm | 2.3 mm | 6.8 mm | 191 Nm |
| | (0°) | (0°) | (0°) | (0°) |
| End of bumper beam | 12.9 mm | 7.4 mm | 23.7 mm | 395 Nm |
| | 2° | 26° | 27° | 15° |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 mm | 6.0 mm | 20.3 mm | 332 Nm |
| | -1° | -10° | -11° | -5° |
| 45 degrees – 15 degree rotation of car | 7.1 mm | 7.1 mm | 18.9 mm | 166 Nm |
| | 24° | 38° | 39° | 44° |
| Centre – 30 degree rotation of car | 3.0 mm | 5.9 mm | 10.2 mm | 140 Nm |
| | (75°) | (60°) | (75°) | (75°) |

# Vehicle 2

Note – values in parentheses estimated from side view

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 1.8 mm | 2.3 mm | 6.8 mm | 191 Nm |
| | (0°) | (0°) | (0°) | (0°) |
| End of bumper beam | 12.9 mm | 7.4 mm | 23.7 mm | 395 Nm |
| | 2° | 26° | 27° | 15° |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 mm | 6.0 mm | 20.3 mm | 332 Nm |
| | -1° | -10° | -11° | -5° |
| 45 degrees – 15 degree rotation of car | 7.1 mm | 7.1 mm | 18.9 mm | 166 Nm |
| | 24° | 38° | 39° | 44° |
| Centre – 30 degree rotation of car | 3.0 mm | 5.9 mm | 10.2 mm | 140 Nm |
| | (75°) | (60°) | (75°) | (75°) |

# Vehicle 2

Note – values in parentheses estimated from side view

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 1.8 mm | 2.3 mm | 6.8 mm | 191 Nm |
| | (0°) | (0°) | (0°) | (0°) |
| End of bumper beam | 12.9 mm | 7.4 mm | 23.7 mm | 395 Nm |
| | 2° | 26° | 27° | 15° |
| End of bumper beam – normal impact (car rotated 36 degrees) | 9.3 mm | 6.0 mm | 20.3 mm | 332 Nm |
| | -1° | -10° | -11° | -5° |
| 45 degrees – 15 degree rotation of car | 7.1 mm | 7.1 mm | 18.9 mm | 166 Nm |
| | 24° | 38° | 39° | 44° |
| Centre – 30 degree rotation of car | 3.0 mm | 5.9 mm | 10.2 mm | 140 Nm |
| | (75°) | (60°) | (75°) | (75°) |

# Vehicle 3

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 3.7 mm | 3.7 mm | 12.1 mm | 230 Nm |
| | -4° | -1° | -4° | -1° |
| End of bumper beam | 9.4 mm | 8.6 mm | 24.8 mm | 265 Nm |
| | 42° | 5° | 43° | 38° |
| End of bumper beam – normal impact (car rotated 45 degrees) | 7.7 mm | 8.6 mm | 23.1 mm | 271 Nm |
| | -3° | -1° | -3° | -2° |
| 45 degrees – 15 degree rotation of car | 4.5 mm | 5.9 mm | 14.6 mm | 195 Nm |
| | -46° | -36° | -46° | -46° |
| Centre – 30 degree rotation of car | 2.3 mm | 3.2 mm | 9.0 mm | 144 Nm |
| | -52° | -40° | -52° | -4° |

# Vehicle 3

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 3.7 mm | 3.7 mm | 12.1 mm | 230 Nm |
| | -4° | -1° | -4° | -1° |
| End of bumper beam | 9.4 mm | 8.6 mm | 24.8 mm | 265 Nm |
| | 42° | 5° | 43° | 38° |
| End of bumper beam – normal impact (car rotated 45 degrees) | 7.7 mm | 8.6 mm | 23.1 mm | 271 Nm |
| | -3° | -1° | -3° | -2° |
| 45 degrees – 15 degree rotation of car | 4.5 mm | 5.9 mm | 14.6 mm | 195 Nm |
| | -46° | -36° | -46° | -46° |
| Centre – 30 degree rotation of car | 2.3 mm | 3.2 mm | 9.0 mm | 144 Nm |
| | -52° | -40° | -52° | -4° |

# Vehicle 3

## Peak values

| Description of test location and rotation | ACL | PCL | MCL | Peak tibia bending moment |
|---|---|---|---|---|
| Centre | 3.7 mm | 3.7 mm | 12.1 mm | 230 Nm |
| | -4° | -1° | -4° | -1° |
| End of bumper beam | 9.4 mm | 8.6 mm | 24.8 mm | 265 Nm |
| | 42° | 5° | 43° | 38° |
| End of bumper beam – normal impact (car rotated 45 degrees) | 7.7 mm | 8.6 mm | 23.1 mm | 271 Nm |
| | -3° | -1° | -3° | -2° |
| 45 degrees – 15 degree rotation of car | 4.5 mm | 5.9 mm | 14.6 mm | 195 Nm |
| | -46° | -36° | -46° | -46° |
| Centre – 30 degree rotation of car | 2.3 mm | 3.2 mm | 9.0 mm | 144 Nm |
| | -52° | -40° | -52° | -4° |

# Legform tests – Round 2

## Comparison with EEVC results

### Injurious points

- Hard points identified through test results – end of bumper beam
- Could be more injurious than centre of bumper
- Reason for extending test area
- Not sure if that is feasible, etc.

### End of bumper beam

- Vehicles 2 and 3 failed to meet injury criteria thresholds (MCL and tibia bending) at the end of the bumper beam
- On this basis there is benefit associated with extending the test area
- Cars could collect stiff components just beyond current test area
  - Feasibility of moving these parts?
- Vehicle 1 met requirements

# Legform tests – Round 2

Comparison with EEVC results

## Rotation of legform

- EEVC legform rotates substantially in oblique impacts (fired straight)
- Didn't see 'odd' injury metric results
  - Not obviously over-reading
  - Not obviously under-reading

## Rotation of Flex-PLI

- Obvious rotation shown via video analysis of Flex-PLI tests
  - Seeing 30 to 50 degrees at end of bumper beam
  - Similar to EEVC legform
- Tests at end of bumper beam with car rotated to give normal impact give lower values than straight test (with oblique contact)
  - May support the notion of over-reading knee metrics
    - Some difference in profile
  - Not such an obvious feature with the EEVC legform

# Legform tests – Round 2

Comparison with EEVC results

## Practicality

- Tried rotating vehicle
- Reduced test speed to match 'normal' velocity
- Seemed to produce sensible peak values without large rotation
- Don't know whether vehicle rotation is a viable solution for Test Services

## Rotation of vehicle solution?

- Need to keep incident angle below 30 degrees
  - Large legform rotations at 30 degrees!
- To test end of bumper beam with less than 30 degrees incident angle – might need to go to > 15 degrees
  - Example from our three vehicles
  - 45° – 30° = 15° vehicle rotation
- Concern that rotated vehicle tests give lower Flex-PLI results
  - Over-reading in oblique impacts
  - Manufacturers likely to opt for easiest solution

# Conclusions and options – for discussion

**Tests from end of bumper beam and accident analysis show benefit to extending test area**

- **Option 1 – No change**
- **Option 2 – Extend to bumper beam**
  - Adopt a 'Euro NCAP'-like procedure?
- **Option 3 – Extend to 45 degrees**
  - With or without 66 mm
- **Option 4 – Remove bumper corner limits**
  - Allow testing across full width of vehicle

# Conclusions and options – for discussion

**If bumper test area extended – consider rotation of legform in oblique impacts**

## Option A – No change – longitudinal test

- Any over-reading may be negligible *vis-à-vis* repeatability, reproducibility, etc.
- Assume it is still feasible to meet injury metric thresholds

## Option B – Allow rotation of the vehicle

- Need to write test speed calculation into regulatory text
- Flex-PLI results suggest option to test at 'normal' angle to vehicle is best
- Can all Test Services accommodate this?

## Option C – Force rotation of vehicle

- To keep incident angle at a consistent level around the bumper

# Thank you…
# Questions?

Prepared by Brian Hardy & Jolyon Carroll
30 January 2014

Contact;
Tel: +44 1344 770564
Email: jcarroll@trl.co.uk