Summary of Testing for Ignition Related Recalls

14V355

General Motors

2015/07/29

Abstract

In-vehicle testing was performed to provide data supporting the investigation of potential recall vehicles. This purpose of the testing was to demonstrate:

- Unintended key rotation could be replicated using the severe road surfaces at the Milford Proving Ground.
- Removal of all items from the key ring would eliminate unintended key rotation during severe road events.
- The recall repair would eliminate unintended key rotation during severe road events.
- That unintended key rotation would not occur due to contact with the driver's knee during vehicle operation (knee-key).

A combined total of over 400 on-road tests and knee-key evaluations were performed using 22 vehicles. The results demonstrated the Milford Proving Ground was an acceptable test site to replicate the issue, the temporary and permanent solutions resulted in zero unintended key rotations for any of the tested vehicles, and that no unintended key rotations occurred during normal operation due to contact with the driver's knee for any of the tested vehicles.

Theory: Removing Everything from Key Ring

With no weight attached to the key ring, the remainder of the system is symmetric; therefore, input torque due to jarring events in any direction is negligible. Vertical example below:

Sample Input torque calculations at rest: $\tau = F * d$

- *F* = Ring weight * g level = 0.031 Newtons * 1
- Slot length in key head = 2.2 cm
- *d* = Lever arm = ½ slot length * cos α = 0.95 cm
- τ = Static torque (F*d) = 0.031 N * 0.95cm = 0.03 N*cm

Input torque must exceed system resistance torque to cause rotation.

Vertical "g" level	Dynamic Torque (N*cm)
33	1
67	2
133	4
267	8
533	16

Table 1a: Dynamic Torque vs. Vertical "g"

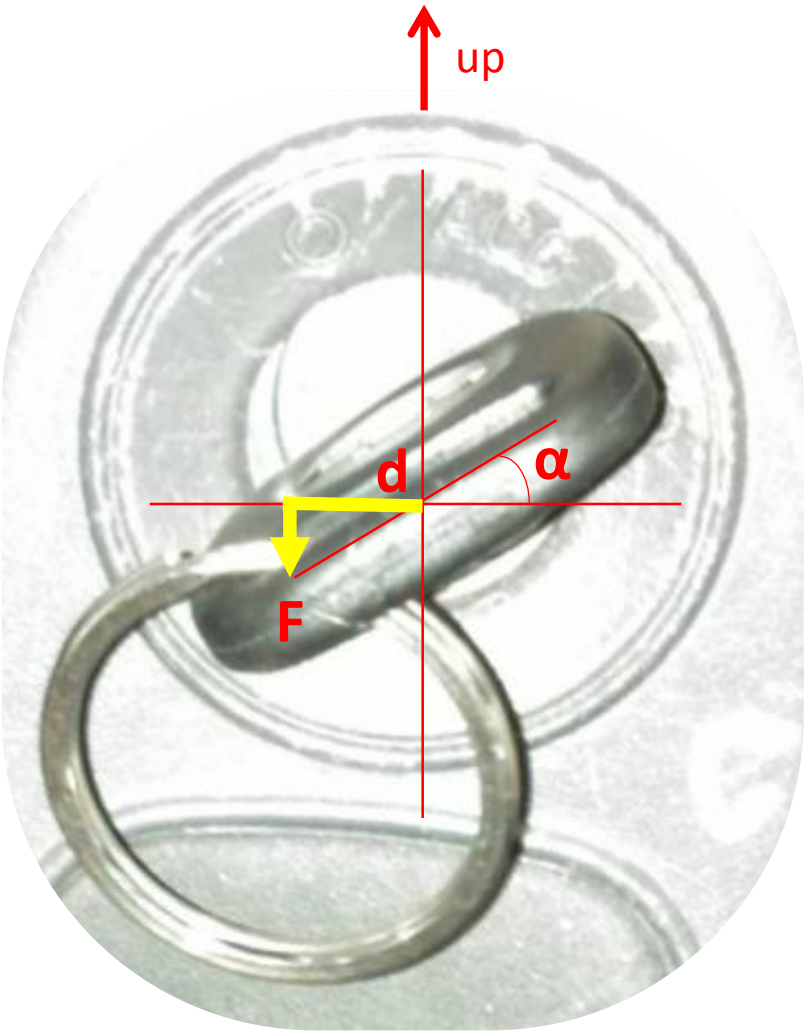


Fig 1a: Typical ignition key with ring attached

Theory: Replace Key Slot with Small Hole

The input torque due to jarring events in any direction is negligible due to small lever arm. Vertical example below:

Sample Input torque calculations: $\tau = F * d$

- *F* = 3.1 Newtons (with 0.7lb of keys added)
- Slot length in key head = 2.2 cm
- *d* = Lever arm = ½ slot length * cos α = .95 cm
- τ = Static torque (F*d) = 3.1 N * 0.95cm = 3 N*cm (@1g)

Input torque must exceed system resistance torque to cause rotation.

Lever Arm (cm)	Dynamic Torque (N*cm) at 12g with 0.7lb suspended from key ring
0.1	4
0.2	7
0.4	15
0.8	30

Table 1b: Dynamic Torque vs. Lever Arm Length

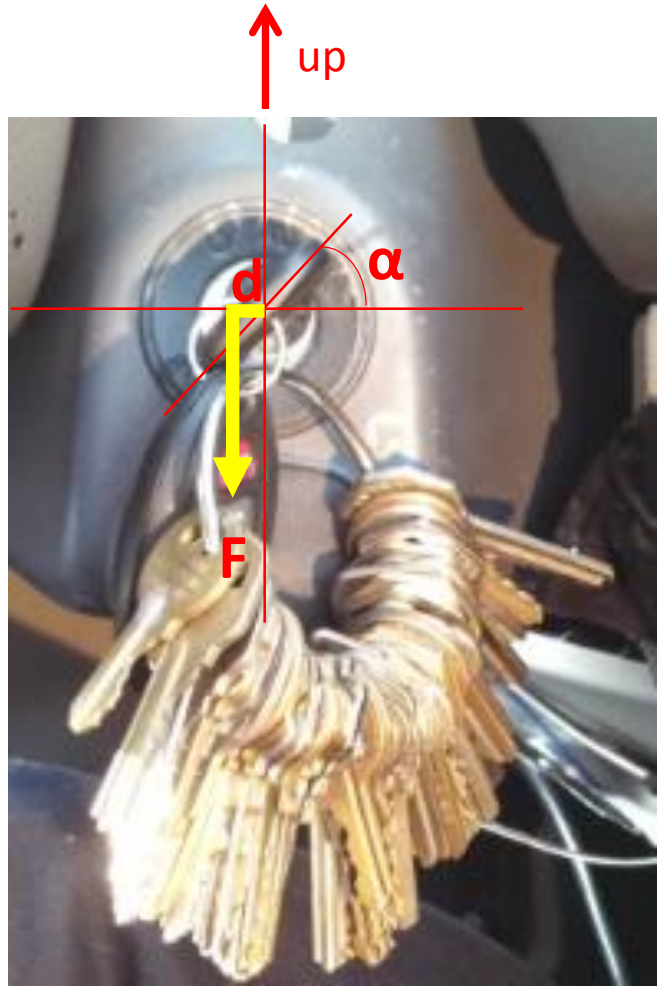


Fig 1b: Ignition key with 0.7lb of keys attached

Theory: Pre Recall System

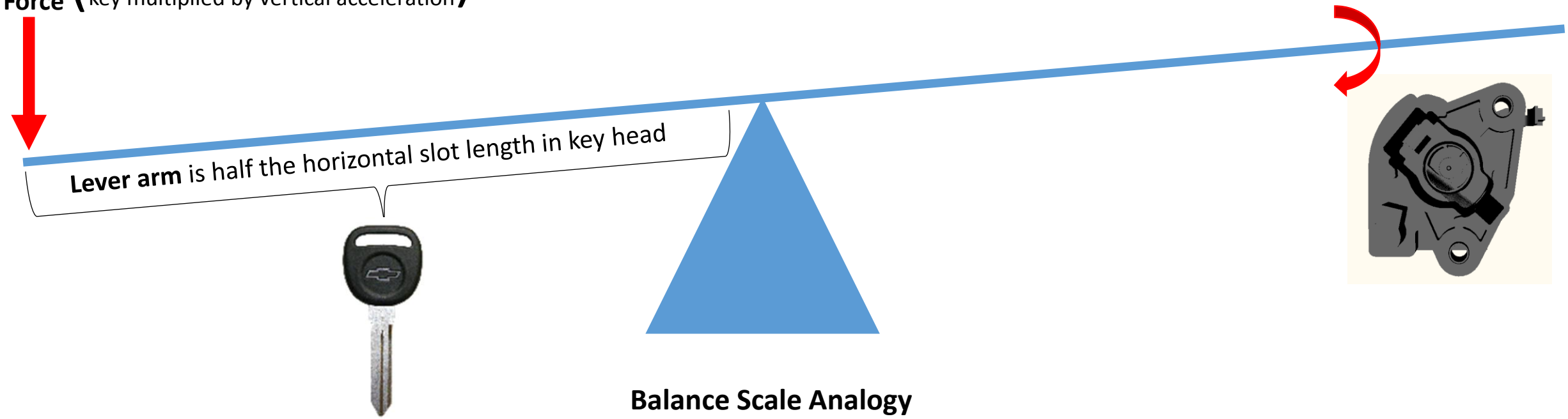
Input Torque =

Input Force * Lever Arm

System Resistance Torque =

Switch torque due to detent + torque caused by friction of rotating components

Input Force (Mass of items hanging from ignition key multiplied by vertical acceleration)



Balance Scale Analogy

Rotation occurs if Input Torque exceeds System Resistance Torque

Fig 2a: Moment comparison with slot

Why does removing everything from key ring prevent rotation?

Removing everything from key ring makes <u>input force negligible</u>

Input Torque =

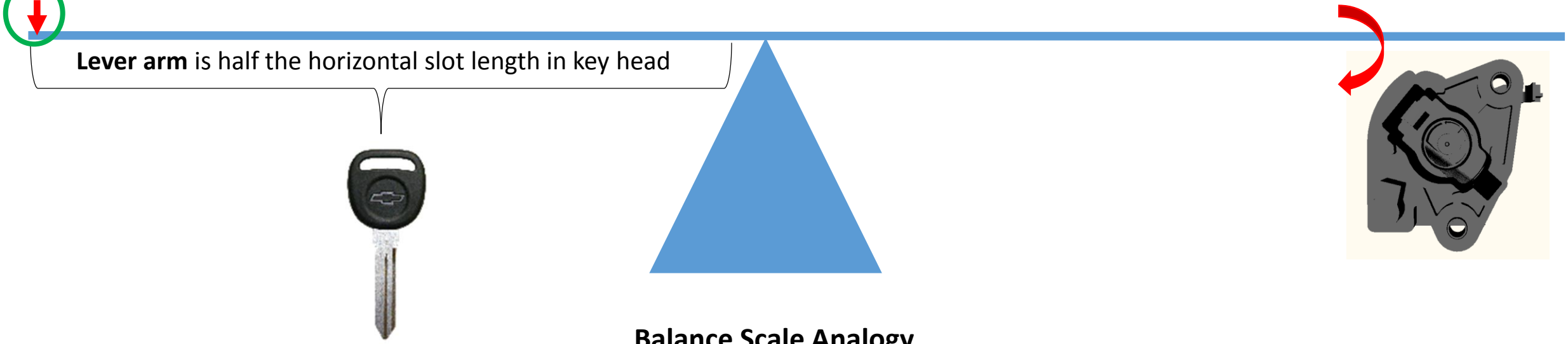
Input Force * Lever Arm

System Resistance Torque =

Switch torque due to detent + torque caused by friction of rotating components

Input Force (Mass of items hanging from ignition key multiplied by vertical acceleration)

Lever arm is half the horizontal slot length in key head



Balance Scale Analogy

Rotation occurs if Input Torque exceeds System Resistance Torque

Why does the small hole prevent rotation?

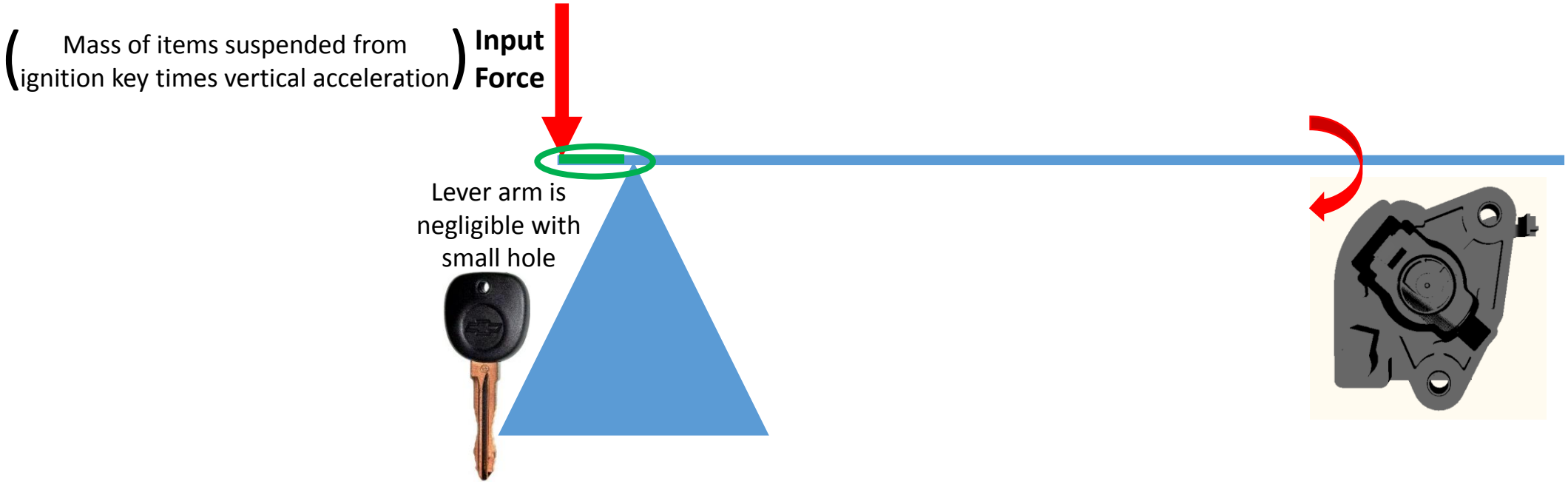
Input Torque =

Input Force * Lever Arm

Small hole <u>minimizes lever arm</u>; significantly reducing sensitivity to weight suspended, acceleration, and resistance torque.

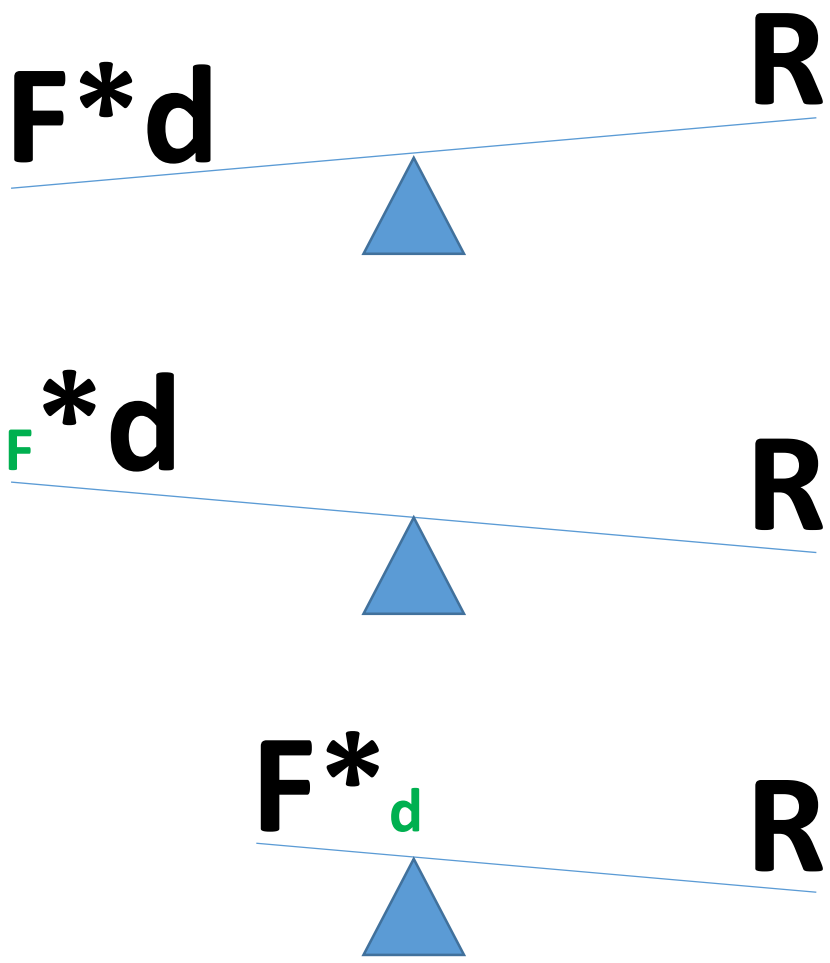
System Resistance Torque =

Switch torque due to detent + torque caused by friction of rotating components



Balance Scale Analogy

Rotation occurs if Input Torque exceeds System Resistance Torque



Pre Recall – Heavy objects (large **F**) hanging from slotted key (large **d**) can cause sufficient input torque to rotate key

Removing everything from key ring – Without significant weight (small **F**) hanging from key, insufficient input torque is generated to overcome the resistance torque

Recall – Changing from a slot to a small hole reduces the lever arm (small **d**) making system insensitive to weight or low switch torque

Fig 3

F = force due to mass hung from key and road input **d = lever arm from key slot** **R = system resistance torque**

Test Overview

- Inertial
  - Conducted full vehicle tests on severe road surfaces with 0.7 lb of keys attached to the key ring.
    - If rotation occurred, weight attached to key ring was incrementally reduced until rotation did not occur.
    - Also, if rotation occurred, an insert was added to the key effectively changing the slot to a small hole and the test was repeated with 0.7lb of keys.
  - Aggressive Road tests:
    - Ride and Handling loop @ posted speeds
    - Belgian Blocks durability schedule
    - Pothole #1 strikes
    - Pothole #2 strikes
    - Cubilete @ 10 – 15 MPH
    - Panic stop from 10 – 15 MPH
    - R&H Chatter @ 55 – 45 MPH
    - R&H Angled RR crossing @ 70 – 80 mph
- Unintended rotation due to driver's knee contacting key
  - Three evaluators representing the extremes of standing height (99th percentile male, 50th percentile male, and 5th percentile female) assessed their ability to rotate the ignition key away from Run with their knee.
    - If they were able to do so, they were asked to quantify the ease, and if they were in a normal driving position.

Overview of Data Collected

- Ignition State: Key position was monitored by the driver
  - Previous testing validated that driver observation of ignition key state correlates 100% with electrically monitored position.
- Dynamic Measurements:
  - Acceleration: A single DC Tri-axial accelerometer was mounted to steering column or dash in proximity of ignition switch
- Static Measurements:
  - Ignition System Torque from Run to Accessory
  - Ignition Switch Torque from Run to Accessory
  - Downward force required to rotate key away from Run

Belgian Blocks

A replica of Belgian granite block roads that are very rough, including dips and bumps.

Figure 4a

Figure 4b

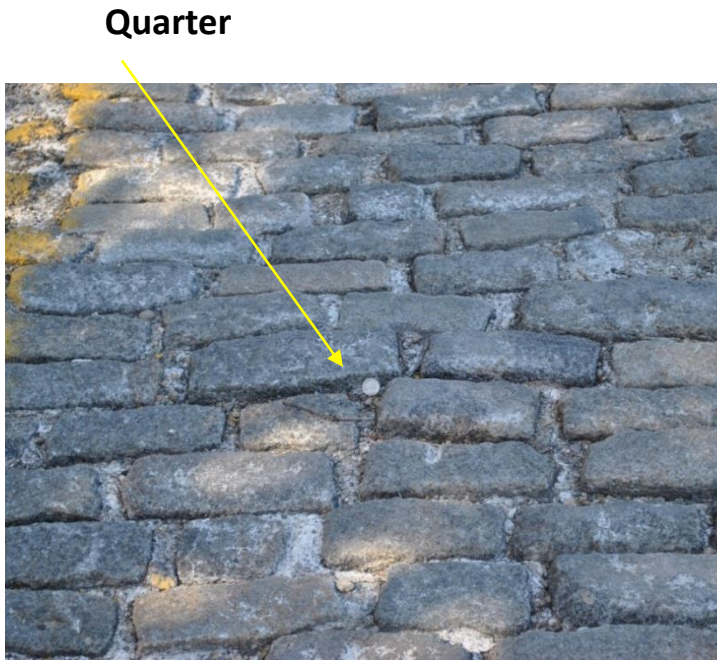


Figure 4c

Severe Pothole Strikes

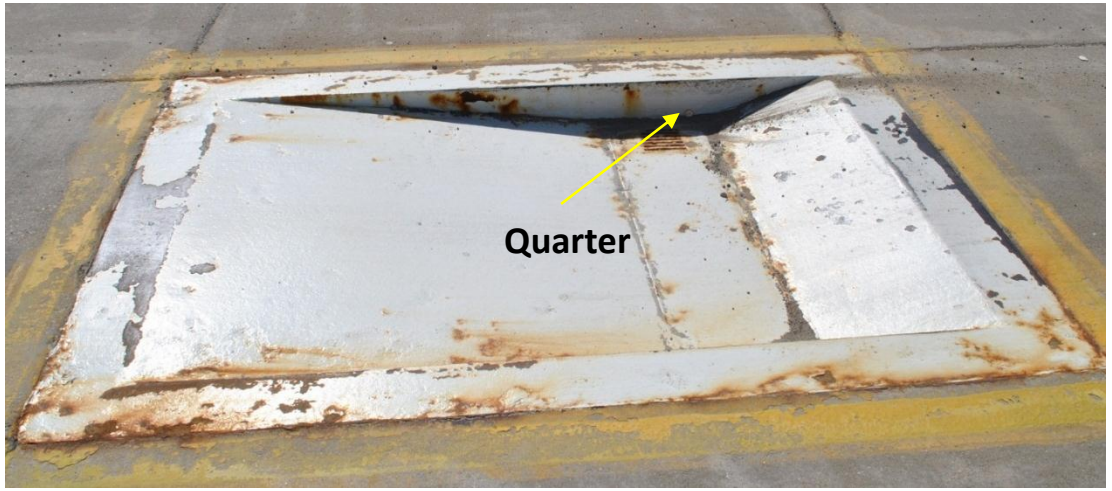


Figure 5a - Pothole 1

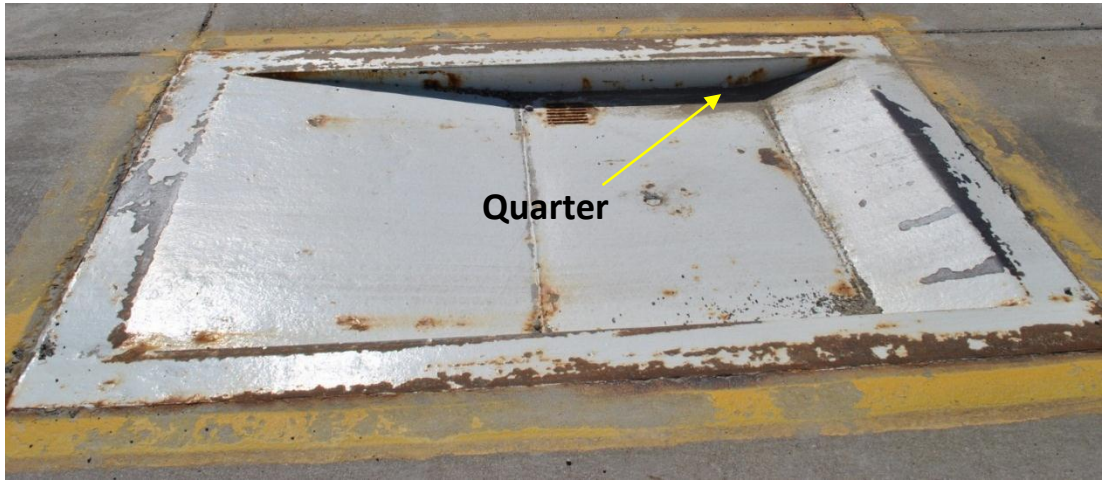


Figure 5b – Pothole 2

Cubilete

- A replica of a high severity rough road in Mexico, made of river rocks
- Driven at 10 - 15 mph

Figure 6a

Ride and Handling Loop

Figure 7a: Chatter Bumps from 55 – 45 MPH – A series of evenly spaced bumps that excite suspension motion. Frequency (cycles per second) = mph /3

Figure 7b: Ride & Handling Angled RR crossing @ 60 – 80 MPH - An elevated railroad crossing that is not perpendicular to the road direction

Panic Stops

- Panic stops conducted on a smooth and level road surface.
- Consisted of light acceleration to speeds of 10 to 15 mph, followed by a full and rapid brake pedal application.

Figure 8

Test Results

- Inertial
  - **Results:**
    - **Slotted Key - No rotation occurred on any vehicle when using a slotted key and weight was less than 0.2 lb.**
    - **Insert Key - No rotation occurred on any vehicle when the insert was installed in the key, even with 0.7 lb of keys.**
    - **No rotation occurred due to driver contact with key during any of these tests**

- Unintended rotation due to driver's knee contacting key
  - **Results:**
    - **None of the evaluators were able to rotate the ignition key away from Run in a normal driving position.**

Test Procedure and Results

- Inertial
  - Conducted full vehicle tests on severe road surfaces with 0.7 lb of keys attached to the key ring.
    - If rotation occurred, weight attached to key ring was incrementally reduced until rotation did not occur.
    - Also, if rotation occurred, an insert was added to the key effectively changing the slot to a small hole and the test was repeated with 0.7lb of keys.
  - Aggressive Road tests:
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    - Pothole #1 strikes
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    - Cubilete @ 10 – 15 MPH
    - Panic stop from 10 – 15 MPH
    - R&H Chatter @ 55 – 45 MPH
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  - **Results:**
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- Unintended rotation due to driver's knee contacting key
  - Three evaluators representing the extremes of standing height (99th percentile male, 50th percentile male, and 5th percentile female) assessed their ability to rotate the ignition key away from Run with their knee.
    - If they were able to do so, they were asked to quantify the ease, and if they were in a normal driving position.
  - **Results:**
    - **None of the evaluators were able to rotate the ignition key away from Run in a normal driving position.**

14V355 Vehicles

(Data arranged by platform)

MAKE	MODEL SERIES	MODEL YEAR	DESCRIPTIVE INFO. TO PROPERLY IDENT. VEH.
Buick	W	2005-9	LaCrosse
Chevrolet	W	2006-14	Impala
Chevrolet	W	2006-7	Monte Carlo
Cadillac	K	2000-5	DeVille
Cadillac	K	2006-11	DTS
Buick	H	2006-11	Lucerne

Table 1

2006-2014 Impala, 2006-2007 Monte Carlo, 2005-2009 LaCrosse, 2006-2011 Lucerne

VEHICLE TESTING

Vehicle	2007 Chevrolet Impala 107462 miles								2007 Chevrolet Impala 87057 miles					
Key	Overmold 1 - slot							Insert	Overmold 1 - Slot					Insert
Weight (lb)	0.7	0.63	0.55	0.4	0.4	0.3	0.2	0.7	0.7	0.63	0.55	0.4	0.3	0.7
Ride and Handling loop @ posted speeds	G							G	G					G
Begian Blocks RLDA schedule	G							G	G					G
Pothole #1 @ 25 MPH	R	R	R	R	G	G	G	G	G					G
Pothole #2 @ 25 MPH	R	R	R	R	R	R/G	G	G	R	R	R	R	G	G
Cubilete @ 10 MPH	G							G	G					G
Panic stop from 10 mph	G							G	G					G
R&H Chatter @ 45 - 55MPH Hz=MPH/3	G							G	G					G
R&H Angled RR crossing @ 70 mph	G							G	R	G				G
5% Female Knee Key Evaluation														
50% Male Knee Key Evaluation														
99% Male Knee Key Evaluation														

Legend:

- G - indicates ignition did not rotate
- R/G - indicates multiple tests with differing results
- R - indicates ignition turned out of Run
- Indicates driver was unable to rotate key with knee in a normal driving position

Table 2

Insert Key - No rotation occurred on any vehicle when the insert was installed in the key, even with 0.7 lb of keys.

2006-2014 Impala, 2006-2007 Monte Carlo, 2005-2009 LaCrosse, 2006-2011 Lucerne (continued)

VEHICLE TESTING

Vehicle	2010 Chevrolet Impala 109023 miles						2006 Buick Lacrosse 85704 miles						2007 Buick Lucerne 90051 miles				
Key	Overmold 1 - Slot					Insert	Overmold 1 - Slot					Insert	Overmold 1 - Slot				Insert
Weight (lb)	0.7	0.63	0.55	0.4	0.3	0.7	0.7	0.63	0.55	0.4	0.3	0.7	0.7	0.63	0.55	0.4	0.7
Ride and Handling loop @ posted speeds	G					G	R	R	G			G	G				G
Begian Blocks RLDA schedule	G					G	G					G	G				G
Pothole #1 @ 25 MPH	G					G	R	R	G	G		G	G				G
Pothole #2 @ 25 MPH	R	R	R	R	G	G	R	R	R	R	G	G	R	R	R	G	G
Cubilete @ 10 MPH	G					G	G					G	G				G
Panic stop from 10 mph	G					G	G					G	G				G
R&H Chatter @ 45 - 55MPH Hz=MPH/3	G					G	G	G	G			G	G				G
R&H Angled RR crossing @ 70 mph	G					G	R	R	G			G	G				G
5% Female Knee Key Evaluation																	
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Table 3

Insert Key - No rotation occurred on any vehicle when the insert was installed in the key, even with 0.7 lb of keys.

1998-2004 Deville

VEHICLE TESTING

Vehicle	2004 Cadillac DTS 90611 miles			2007 Cadillac DTS 86755 miles				
Key	Overmold 1 - Slot		Insert	Overmold 1 - Slot				Insert
Weight (lb)	0.7		0.7	0.7	0.63	0.55	0.4	0.7
Ride and Handling loop @ posted speeds	G		G	G				G
Begian Blocks RLDA schedule	G		G	G				G
Pothole #1 @ 25 MPH	G		G	G				G
Pothole #2 @ 25 MPH	G		G	R	R	R	G	G
Cubilete @ 10 MPH	G		G	G				G
Panic stop from 10 mph	R	G	G	G				G
R&H Chatter @ 45 - 55MPH Hz=MPH/3	G		G	G				G
R&H Angled RR crossing @ 70 mph	G		G	G				G
5% Female Knee Key Evaluation								
50% Male Knee Key Evaluation								
99% Male Knee Key Evaluation								

Legend:

G - indicates ignition did not rotate

R/G - indicates multiple tests with differing results

R - indicates ignition turned out of Run

Indicates driver was unable to rotate key with knee in a normal driving position

Table 4

Insert Key - No rotation occurred on any vehicle when the insert was installed in the key, even with 0.7 lb of keys.

Conclusions

- Over 400 tests were performed at GM's Milford Proving Ground involving extreme maneuvers on severe road surfaces. When sufficient weight was attached to the key ring the unintended key rotation condition was replicated. There were no instances of unintended key rotation due to contact with the driver in any of these tests.

- If unintended key rotation occurred with 0.7lb attached to the key ring, weight was incrementally reduced and the test was repeated until rotation did not occur. No vehicle test demonstrated unintended key rotation at or below 0.2lb. The key ring alone weighs several hundred times less than 0.2lb, therefore it will not cause unintended rotation due to severe road inputs.

- In any test event where unintended key rotation occurred, the test was repeated with a key insert that effectively changed the slot to a small hole. Every test with the insert demonstrated robustness to unintended key rotation with 0.7lb attached to the ignition key validating the effectiveness of the solution.

- Three evaluators representing the extremes of standing height assessed their ability to rotate the ignition key away from Run with their knee. None of the evaluators were able to rotate the ignition key away from Run in a normal driving position.

Note: As stated on NHTSA's website, safety belts should always be worn, even when riding in vehicles equipped with air bags. Air bags are designed to work with safety belts, not alone. By keeping drivers in a secure position, safety belts help all drivers maintain control of the vehicle in emergency situations.