

Memorandum by Dr A. F. Anderson CEng FIEE March 2012 : Re the Tanya Spotts EDR results.

1 Background.

In an ODI Report attached at the end of this memo, Mrs Spotts describes a sudden acceleration incident that she experienced on 26th December 2011 in a 2011 Model Year Lexus ES350. See also <http://edition.cnn.com/2012/03/01/us/toyota-memo-acceleration-concerns/> for her interview with CNN.

The essence of her description of the incident is as follows:

While parking in a public covered garage, Mrs Spotts turned into the parking space, positioned her car¹ and was about to turn off the engine when the car lurched forward, hitting the concrete wall in front of her. She says that she had reached a good parking position and is certain that she had her foot on the brake. She suffered a sprained right ankle which she attributes to hard braking.



Fig 1 Damage to driver's foot claimed to be caused by hard braking

2 Toyota's Claim regarding the EDR Data

Toyota examined the Spotts vehicle and downloaded data from the Event Data Recorder on January 24th 2012. Toyota have subsequently made the Bosch EDR Crash Data Download report available. This report is in standardized format that makes no attempt to infer anything from the data downloaded. We must presume that Toyota analysed the EDR Data and reached certain conclusions, because in their letter to CNN of 22nd February 2012 they say:

“The Event Data Recorder (“EDR”) in her vehicle establishes irrefutable evidence that it was not an electronic defect that caused her low speed event while parking her vehicle..... we have evaluated the Spotts vehicle; this evaluation included a download of the pre-crash data from the EDR. The pre-crash data from the EDR establishes that Mrs Spotts was travelling at approximately 9 mph at the time of impact. The EDR download also establishes that she applied

¹ CNN quotes her as saying she was “covering the brake” as she positioned the car.

the accelerator pedal multiple times in the seconds before impact. Moreover, the circumstances of Mrs Spotts’ event – a low speed collision while parking – are entirely consistent with pedal misapplication as confirmed by numerous studies of cases in which drivers have complained of unintended acceleration...”

However, it should be noted that at the time of writing this memo Toyota have not declared, as far as I am aware, the assumptions and reasoning by which they reached their conclusions.

I note that Toyota projects a sense of absolute authority and certainty in their letter to CNN by careful choice of expression:

- “irrefutable evidence”;
- application of the accelerator pedal “multiple times” in the seconds before impact;
- circumstances being “entirely consistent with pedal misapplication as confirmed by numerous studies of cases in which drivers have complained of unintended acceleration”

Toyota imply that the EDR data points conclusively towards pedal misapplication. There are no half measures in their claim. However it is important to remember that unless and until Toyota produce the reasoning by which they reached their conclusions, these conclusions cannot be assumed to be more than bold, unsubstantiated assertions. In the absence of Toyota publishing their reasoning on the matter, I will now examine the EDR Data and try to establish whether or not it supports the case that Toyota appears to be making so emphatically. How irrefutable is Toyota’s “irrefutable evidence”?

3 De-mystifying and making sense of the EDR Data

Pre-Crash Data, -5 to 0 seconds (Most Recent Event, TRG 1)

Time (sec)	-4.4	-3.4	-2.4	-1.4	-0.4	0 (TRG)
Vehicle Speed (MPH [km/h])	3.7 [6]	3.7 [6]	3.7 [6]	3.7 [6]	5 [8]	8.7 [14]
Brake Switch	OFF	OFF	OFF	OFF	OFF	ON
Accelerator Rate (V)	0.94	0.98	0.78	0.78	1.37	0.78
Engine RPM (RPM)	400	800	400	400	1,600	1,200

Fig 2 EDR Data Table

Fig 2 above shows the EDR pre-crash data table for Mrs Spotts’ vehicle. There are five rows for the variables recorded, namely: Time, Vehicle Speed, Brake Switch ON/OFF, Accelerator Rate, Engine RPM. There are six columns for recording the variables at times of -4.4 sec, -3.4 sec, -2.4 sec, -1.4 sec, -0.4 sec and 0 Sec (Trigger point) before the crash. No post-crash data is presented.

Please note that the matrix of data is sparse and the resolution of each data item is low. With a sampling rate of once per second, events lasting for say half a second or less may well not be recorded accurately, if at all.

- Vehicle speed resolution is 1.2 mph and the value is rounded down and recorded. Thus any speed slightly less than 9.9 mph would be rounded down to 8.7 mph.
- The brake switch is either ON or OFF and gives no idea of brake force.

- The Accelerator Rate has two recording specifications: Percentage of accelerator pedal depressed (recorded as 0 – 100%); Output voltage of accelerator pedal module (recorded as 0-5v). **Note that in the case of Fig 2, Percentage of accelerator pedal depressed has been omitted.** Toyota provide no reason for this omission.
- Engine RPM resolution is 400 RPM and the actual value is rounded down and recorded. For example, if the engine speed is 799 RPM this will be rounded down to 400 RPM. This is well below the low idle speed, a point that I will come to shortly.

Toyota assert that Mrs Spotts “**applied the accelerator pedal multiple times in the seconds before impact**” but they fail to say which data items provide the supporting evidence for this assertion. Nor do they declare how many times in the seconds before impact they believe “**multiple times**” to be. Toyota appear to be suggesting that the EDR data provides evidence that Mrs Spotts was repeatedly pumping the accelerator pedal instead of the brake.

Looking at the first four EDR data sample points from -4.4 seconds to -1.4 seconds shown under the grey background:

Time (Sec)	-4.4	-3.4	-2.4	-1.4	-0.4	0 (TRG)
Vehicle Speed (MPH [km/h])	3.7 (6)	3.7 (6)	3.7 (6)	3.7 (6)	5(8)	8.7(14)
BRAKE SWITCH	OFF	OFF	OFF	OFF	OFF	ON
Accelerator Rate(V)	0.94	0.98	0.78	0.78	1.37	0.78
Engine RPM (RPM)	400	800	400	400	1,600	1,200

It is clear that all the recorded values remain the same between -4.4 and -1.4 seconds except for the two Accelerator Rate values and one Engine RPM value marked above in red. Since the changes in red are small, this suggests that prior to the -0.4 second point the vehicle was mainly coasting.

- **Vehicle Speed.** From a consideration of elementary machine dynamics, the expected result of hypothetically applying an accelerator pedal “multiple times” in a given period of time would in this case be to increase the vehicle speed between the -4.4 seconds and the -1.4 seconds point.
- However, as the table shows, the vehicle speed remains constant at 3.7 mph. **There is no indication of a significant speed change prior to the -0.4 second point.** This demonstrates, in my opinion, that there is no evidence of any acceleration during that period of 3 seconds that could be construed as evidence of “applying the accelerator pedal multiple times in the seconds before impact”.
- It is not until the -0.4 second point that the speed increases to 5 mph followed by a further increase to 8.7 mph at the 0 secs point. On the assumption that the acceleration from 3.7 to 8.7 mph was linear, the start of the acceleration from 3.7 mph would have been between -0.5 to -0.6 seconds before impact. I fail to see how acceleration in the last 0.6 seconds before impact could be construed as evidence of “multiple times” application of the accelerator pedal.
- **Brake Switch.** This appears to be ON at the 0 secs point but not before that.

- Accelerator Pedal Sensor Voltage.** This starts at 0.94 v at -4.4 seconds, rises to 0.98 v at -3.4 seconds and drops to 0.78 v at -2.4 seconds and remains there at -1.4 seconds. Is it this apparent sensor voltage change that Toyota consider to be of “irrefutable evidence” of “application of the accelerator pedal multiple times”? If so, are not the changes rather small?
- Recorded Engine RPM.** The recorded engine RPM is “400 RPM” at -4.4 seconds, rises to “800 RPM” at -3.4 seconds and then drops again to “400 RPM” until -0.4 seconds. This speed excursion has to be interpreted extremely carefully. “400 RPM” actually means a speed between 400 and 799 RPM because the engine speed resolution is only 400 RPM. It has to be noted that a typical engine idle speed lies in the region of 600 – 1000 RPM. Thus it seems very unlikely that “400 RPM” is actually less than 650-700 RPM, otherwise the engine would have stalled. Consequently, the apparent speed excursion would appear to be of the order of 150 RPM and, in my opinion, provides no kind of “irrefutable evidence” of “application of the accelerator pedal multiple times”. At the -0.4 sec point the engine RPM is “1,600 RPM” which drops to “1,200 RPM” at the 0 seconds point. These are actually not very high engine speeds.

Let us look at the accelerator pedal sensor voltage in greater detail.

Time (Sec)	-4.4	-3.4	-2.4	-1.4	-0.4	0 (TRG)
Accelerator Rate(V)	.94	.98	.78	.78	1.37	.78

Three of the six data points record a voltage of 0.78 v and the other values are 0.94v, 0.98v and 1.37 v. What we now have to establish, because they have not been included in Fig 1, is what sort of “Percentage of accelerator pedal depressed (0-100%)” these voltages might correspond to.

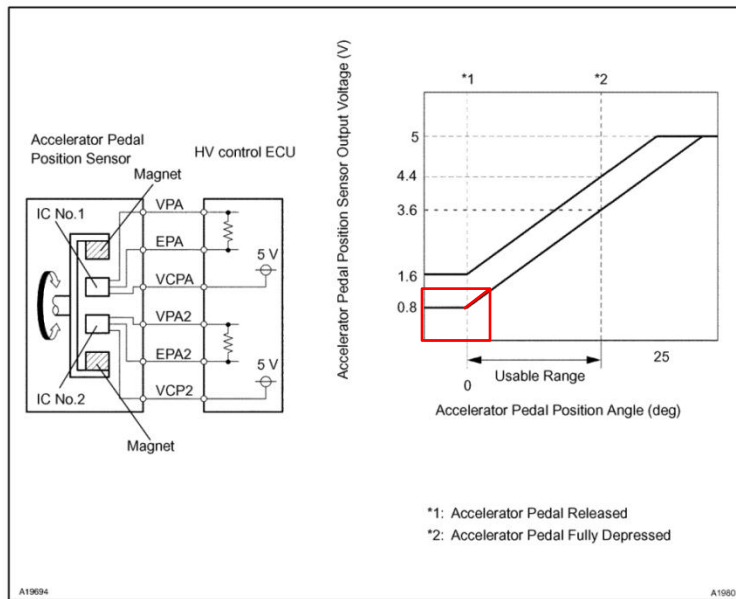


Fig 3 Voltage Output Characteristic for Pedal Sensors A and B

Fig 3 shows the typical voltage characteristics of the two pedal sensors A and B².

- The A sensor (higher characteristic) ranges from 1.6 v to 4.4 v in its usable range, corresponding, respectively, with closed and wide open throttle (WOT)
- The B sensor (lower characteristic) ranges from 0.8 v to 3.6v in its usable range, corresponding, respectively, with closed and wide open throttle (WOT)

The voltages of 0.78v and 1.37 v, minimum and maximum voltages recorded by the EDR are below the usable range of sensor A, but within the usable range of sensor B. Thus it is clear that it is sensor B that has been monitored by the EDR. It would appear that 0.78 corresponds, more or less, with the lower end of the usable range (0.8 v) and represents somewhere near the closed throttle position.

Time (Sec)	-4.4 sec	-3.4 sec	-2.4 sec	-1.4 sec	-0.4 sec	0 sec
Accelerator Rate(V)	.94	.98	.78	.78	1.37	.78
Increase in V	.16	0.20	0	0	0.59	0
Estimated Percentage of Accelerator Pedal Depressed % of WOT called for	.16/2.8=6%	.2/2.8=7%			.59/2.8=21%	

We can see from the above calculations:

- initially the accelerator pedal sensor voltage does not exceed a value that would call for more than 7% of WOT .
- At the -0.4 second point, the sensor voltage does not exceed 21% of the voltage required to call for WOT.

Toyota claim: “The EDR download ... establishes that she applied the accelerator pedal multiple times in the seconds before impact and that she did not apply the brake pedal until approximately 0.4 seconds prior to impact.” It is clear that the EDR data does not support this assertion in any way. Besides which, **there does not appear to be any evidence that the pedal sensor voltage ever reached a value anywhere near that calling for a wide open throttle.**

Had the Estimated Percentage of Accelerator Pedal Depressed values been included in the EDR data disclosed, it would have been immediately obvious that the EDR data did not provide evidence of multiple application of the accelerator pedal, or that the accelerator pedal had ever been depressed beyond the 21% mark. It would therefore be interesting to hear Toyota explain why they left the Estimated Percentage of Accelerator Pedal Depressed values out of the data table.

Fig 1 shows a picture of Mrs Spotts’ foot taken after the accident. As I understand it, her doctor has attributed the sprain to excessive force on braking. I assume that Toyota are claiming either (1) that it is

² As far as is known, the pedal sensor characteristics are the same for all Toyota vehicles irrespective of whether they use Denso or CTS accelerator pedal sensors.

evidence of Mrs Spotts pressing pedal to metal on the accelerator, imagining it to be the brake, or (2) as evidence of her heavy braking having first made a “pedal error”.

- If (1) then Toyota would have to explain how the injury could be obtained without pressing accelerator pedal to metal, since there is no evidence from the EDR record of the accelerator pedal ever having been depressed to more than 21% of the WOT position.
- If (2) Then Toyota would have to explain how Mrs Spott managed to get her foot off the accelerator pedal and fully depressing the brake pedal in less than 0.4 seconds.

These are matters which lie properly within the remit of an accident reconstructionist.

4 Interpreting the EDR Results

I established in the previous section that the claims made by Toyota concerning the EDR results are without foundation. I turn now to considering whether or not the EDR results correlate with the incident experienced by Mrs Spotts.

From what Mrs Spotts has said, it would appear that she moved into the parking space and was about to switch off the engine when the vehicle suddenly accelerated. It seems reasonable to suppose that she was covering the brake with her foot at that time and may even have had her foot actually on the brake to finally stop the vehicle, as would any other driver carrying out a similar manoeuvre. It is clear that she then experienced a full-blown sudden acceleration from near standstill that was terminated only by hitting a concrete wall. She says that she braked very hard and the evidence of damage to her foot would suggest that this was indeed the case. We have no idea how long it was between the time when she sensed the vehicle starting to accelerate and when she began to apply the brakes. However, it is reasonable to suppose that she applied the brakes rapidly by reflex action rather than as a result of thinking what to do first.

Looking at the EDR data, in the final 0.4 seconds, we get an apparent rise in speed from 5 mph to 8.7 mph, or a rise of 3.7 mph in 0.4 seconds which corresponds to an acceleration of 6.25 mph/second, which is equal to 9.17 ft/sec² or 0.28g. Yet this appears to be being achieved (a) with the brakes on and (b) with the accelerator pedal position moving back from about 21% of WOT back to fully closed throttle (c) with the engine speed reducing from an apparent 1600 RPM to 1200 RPM.

In my opinion, this suggests that the downloaded EDR data is inconsistent. This I take to be a possible indication that the Engine ECU/Electronic throttle ECU were subject to some kind of electronic upset that resulted (a) in an uncommanded sudden acceleration and (b) in corresponding errors arising in the data downloaded to the EDR.

The only way of exploring this matter further would be to establish from the extent of the vehicle damage and the distance moved during the sudden acceleration incident what the vehicle acceleration must have been and how well the crash reconstruction correlates with what might be expected from a wide open throttle event in a confined space.

5 Conclusions

I have examined the downloaded EDR data for the time between -4.4 seconds to 0 seconds and have reached the following conclusions.

1. There is no indication of significant speed change prior to the -0.4 second point. The speed would appear to have remained in the region 3.7 to 4.9 mph during that time.
2. A possible engine speed excursion with an increase in recorded RPM from “400 RPM to “800 RPM” at -3.4 seconds should not be interpreted as an actual engine speed change of 400 RPM. In my opinion, it is largely an artifact of the speed resolution of 400 RPM being rather crude. Since the engine low idle speed is likely to be somewhere in the range 600 to 1000 RPM, possibly about 650 RPM, the speed excursion is unlikely, in my opinion, to have been greater than perhaps 150 RPM. This in turn implies very modest changes in accelerator pedal position
3. The accelerator pedal sensor voltage appears to have called for 6% WOT at the – 4.4 second point and 7% at the -3.4 second point and then called for the closed throttle position until the - 0.4 second point. These changes would appear to be consistent with the minor excursion in engine speed mentioned under point 2 above. Toyota’s claim that “The EDR download... **establishes that she applied the accelerator pedal multiple times in the seconds before impact**” is here totally out of step with the evidence from the EDR data. In my opinion, the EDR download does not establish any such supposed multiple application of the accelerator pedal. The onus here lies with Toyota to demonstrate how, in their opinion, the data in Fig 1 supports their claim.
4. At the -0.4 second point, the accelerator pedal sensor voltage appears to have called for 21% WOT before returning to a voltage calling for the closed throttle position at the time of the crash.
5. **From points 1 to 4. There does not appear to be any evidence to suggest that the pedal sensor voltage ever reached a value anywhere near that the ECU would consider to be a request from the driver calling for WOT.**
6. **In my opinion, the EDR data does not provide a scintilla of evidence supporting Toyota’s case that Mrs Spotts “applied the accelerator pedal multiple times in the seconds before impact.”** Toyota appears to be making claims that bear no relation whatsoever to what may reasonably be deduced from the EDR data.
7. Mrs Spotts seems to have experienced a full blown, if short lived, sudden acceleration. On this everyone appears to be agreed, even though they disagree on cause. However, the downloaded EDR data appears to show a much milder event. This apparent discrepancy demands an explanation.
8. One possible explanation of the apparent mismatch between the actual event and the EDR data is that there was some kind of electronic upset that (a) caused the sudden acceleration and (b) caused inconsistent EDR data. It should be remembered that the EDR only records values stored in ECU memory and transmitted over the CAN bus. Thus the accelerator pedal sensor voltage recorded is not the actual sensor value, as would be measured at the sensor terminals,

but the value used for computation. There can be no guarantee that these two will always be the same and they most certainly will not be in the event of any kind of ECU malfunction.

9. It is generally agreed that it is not advisable to rely solely on the EDR when explaining a sudden acceleration incident. At best EDR data may provide supporting evidence confirming the crash analysis. At worst, the EDR data may be self-evidently unreliable. One problem is that if one of the ECUs should malfunction this may well upset the EDR data rendering it meaningless. Another is that during the crash itself electrical transients may be induced that upset the data stored in the EDR itself. The only real way of avoiding this problem would be to have a completely independent automobile monitoring system that did not use the main engine ECU as its computing engine.

The Spotts incident illustrates not only the shortcomings of the present EDR systems, but also what may happen if the analysis of the results, by default, is left to the manufacturer.

In this case Toyota downloaded the EDR Data, Toyota analysed the data and Toyota then told CNN in authoritative tone:

- Firstly, that “The Event Data Recorder (“EDR”) in her vehicle establishes irrefutable evidence that it was not an electronic defect that caused her low speed event while parking her vehicle...”
- Secondly that “The EDR download also establishes that she applied the accelerator pedal multiple times in the seconds before impact.”
- Thirdly that “... the circumstances of Mrs Spotts’ event – a low speed collision while parking – are entirely consistent with pedal misapplication as confirmed by numerous studies of cases in which drivers have complained of unintended acceleration...”

As I have shown in this memo, not one of the above claims can be justified from an analysis of the EDR Data. If Toyota had been required, as a matter of agreed good practice, to publish not only the EDR Data Report, but the chain of reasoning by which they reached their conclusions, then they would have been much less ready to make assertions of the above kind. In this case Toyota have been allowed to forcefully assert via their PR Department that the EDR data points towards pedal misapplication, when in fact that assertion appears to be completely groundless. Bearing in mind the forcefulness of the claims made by Toyota in this instance, they should, in my opinion, even now, be required to produce and place in the public domain their internal report on the EDR results upon which, presumably, their public claims are based. Failure to do so should be deemed as an implicit admission that in fact, as I believe this memo shows, their assertions are groundless.



Antony Anderson
March 8th 2012

ODI Report

Make : LEXUS Model : ES Year : 2011 Manufacturer : TOYOTA MOTOR CORPORATION Crash : Yes Fire : No Number of Injuries: 1 ODI ID Number : 10441934 Number of Deaths: 0 Date of Failure: December 26, 2011 VIN : JTHBK1EG7B2... Component: VEHICLE SPEED CONTROL Summary:

AT ABOUT 2:00 PM ON DEC 26, 2011, WHILE PARKING IN A PUBLIC COVERED GARAGE, I TURNED INTO THE PARKING SPACE, POSITIONED MY CAR, AND WAS ABOUT TO TURN OFF THE ENGINE WHEN THE CAR LURCHED FORWARD, HITTING THE CONCRETE WALL IN FRONT OF ME. THE PASSENGER IN MY CAR, MY 21 YEAR OLD DAUGHTER, ALSO A LICENSED DRIVER, FELT THE CAR LURCH AND ACCELERATE FORWARD. SINCE I HAD REACHED A GOOD PARKING POSITION, I AM CERTAIN THAT I HAD MY FOOT ON THE BREAK AND WOULD NOT HAVE BEEN TRYING TO ACCELERATE. THE INJURY TO MY FOOT, FROM ALL INDICATIONS, SHOWS THAT MY FOOT WAS ON THE BREAK. I HAD IT X-RAYED ON DEC 27 AT A PATIENT FIRST MEDICAL FACILITY AND ALSO WAS SEEN ON DEC 28, BY MY FAMILY PHYSICIAN. HE EXAMINED MY FOOT AND INDICATED THAT MY ANKLE SPRAIN WAS INJURED AS I WAS BREAKING; IT WOULD NOT HAVE SUSTAINED THAT INJURY IF MY ANKLE WOULD HAVE BEEN ON THE ACCELERATOR.
