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Dear Mr Foot,

Expert witness statement – case 'Z'

Thank you for instructing me in the case of Z. In your instruction letter of July 10th, you asked me to consider a listed document bundle; to consider whether the tag failure of December 2013 could have been caused accidentally or by wear and tear; and to address anything else I consider to be relevant.

You and I engaged Dr James Dean of Cambridge's Department of Materials Science and Metallurgy, who is an expert in the mechanics of solids and structures, including stress analysis, to perform the testing; his report is provided separately. My report is as follows,

1. I am Professor of Security Engineering in the Computer Laboratory and a Fellow of the Royal Society, the Royal Academy of Engineering, the Institute of Physics and the Institution of Engineering and Technology. I have thirty years' experience of the security engineering of a wide range of applications from payment systems through prepayment metering, vehicle tachographs and smartcards to electronic medical record systems. I have been an employee of IBM and Google, and consulted for a wide range of leading firms including Microsoft, Intel, Samsung and Matsushita. I am an author of a number of the highest-cited papers on the physical tamper-resistance of electronic devices, and of the standard textbook 'Security Engineering – A Guide to Building Dependable Distributed Systems'. A copy of my CV may be downloaded from my website, `http://www.cl.cam.ac.uk/~rja14`.

2. The court ordered that we get access to examine the curfew tag that forms the basis of the current prosecution against Z, the tag involved in an earlier 2011 case against him, and 25 new tags for testing. In addition I was tagged by G4S as were my colleague Dr James Dean and a student volunteer Mr Saad al-Oteibi.

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3. The main hypothesis we wished to test is that the clips used to attach curfew tags to ankle straps suffer fatigue failure. In a number of previous cases, prosecution experts (all from the same company, SureScreen Scientifics Division of Morley, Derbyshire) described clip cracks as having a conchoidal fracture surface with river markings, and argued that this indicated a sharp stress fracture. On consulting the relevant literature (as cited in Dr Dean's report) and discussing the matter with Dr Dean, I learned that such a fracture is often seen with a fatigue failure, rather than being evidence that fatigue was not involved. As fatigue fractures are merely within my general engineering knowledge rather than part of my specialist expertise, I advised you to engage Dr Dean as well.

4. In the current case, SureScreen's James Campbell produced a statement on tag PIDGC444467 recovered from the defendant "Special Z" dated 26th December 2013. The statement has much in common with SureScreen statements in previous cases including both text and argument. In section 10 he notes a conchoidal fracture with river markings and concludes that they indicate 'an overload applied to the strap or case substantially in the direction of the normal axis of the strap.' As noted above, such markings are also consistent with a fatigue fracture.

5. In the previous case involving the same defendant, where a tag raised a tampering alarm on June 2nd 2011, Z was subsequently convicted of tampering, yet continues to maintain his innocence. I have been supplied with Campbell's report in that case (tag PIDGCS341525) which is again very similar; one-sided fracture with a conchoidal fracture surface. In this case Campbell noted 'at least four distinct loading markings'. I see no sign that Campbell considered the possibility of fatigue fractures. In fact he states at section 15:

   > 'It is a misconception that something will be weakened by prior damage and will fail progressively, piece by piece. The idea that a heroine can be suspended over a pit by a rope that progressively frays until the last few fibres are holding her before she is rescued is pure fiction. In reality, the load that initiated the first signs of fracture then goes on to complete the break because the component is now progressively weakened so much that it cannot resist the applied load.'

6. In the present case, Campbell states at section 2 of his supplementary evidence that

   > 'The type of fracture seen on the device in question contains river marks (fanning out from the point of failure) and conchoidal fracture marks (radiating out from the point of failure) which indicates it is NOT due to stretching or fatigue.'

7. Both of these statements are incorrect. Fatigue fractures are pervasive in engineering, and the polycarbonate of which the clips are made does indeed suffer from them. According to the scientific literature, as cited for example in Dr Dean's expert report, conchoidal fractures are one of the telltales of fatigue fractures; the successive semicircles are the limits to which the crack propagated on successive stress loadings.

8. As a matter of fact, Campbell reports a fatigue test on a clip in his 26 December 2013 statement at section 18, page 10, where he reports cracking a clip by pulling on it about 20 times. This is a classic low-cycle fatigue test.

9. I thus formed the hypothesis that the defendant's tag may have suffered a fatigue fracture, and that a number of defendants in previous contested cases may also have been the victims of unrecognised fatigue fractures, including Z in his 2011 case. I argued that the matter should be properly tested, and the court accepted this argument.

10. In that argument, I proposed the following testing strategy following discussion with Dr Dean:

    (a) *We will start with clips loaded monotonically to find the breaking load and obtain samples of clips fractured in this way.*

    (b) We will then try torsion and shear of various kinds to see if that makes any difference.

(c) *We will instrument two or three tags for several days with strain gauges and acelerometers. One of them will be worn by a Muslim student who will pray five times a day. This will give us data on the loadings imposed in everyday use.*

(d) *We will use stress test rigs at the Department of Materials Science to replicate as closely as possible the loading types measured in service. The loading types may be complex, characterised by various (and superimposed) configurations of tension, shear and torsion (we will not really know until we collect the data). Some of these loadings will be much more difficult than others to replicate experimentally. Ordinary tension, shear and torsion tests are certainly expected, and some simple combinations of these loads are also possible. I will send separately a couple of photographs of the mechanical engineering lab that I took yesterday morning.*

(e) *We will see whether clips fracture under fatigue test; if so, how many cycles are needed to induce failure; and if not, then whether the breaking load on the clip is substantially reduced after the cycle equivalent of six months' or a year's normal wear and tear.*

(f) *If we get fatigue fractures or fatigue-enabled fractures, we will image the fracture surfaces using the wide range of microscopy facilities available in the department (optical, SEM, TEM, AFM, ...) and compare them with the fracture surfaces of monotonically fractured clips.*

(g) *In this exercise we will look for discriminating features that might enable a forensic examiner to tell clips that have been fractured by force apart from those that have been fractured by fatigue.*

(h) *If such features can be found, we will examine the fracture surfaces of the clip that is at the heart of this case.*

11. Dr Dean's report presents the test results in detail. Here I present my experience of having worn a curfew tag for three days, for part of which it was instrumented with strain gauges, an accelerometer and a gyro.

(a) It is easy to forget that you are wearing a curfew tag, particularly if you roll the top of your sock over it to stop it moving around. As a result, you catch it several times a day, whether on a radiator, or on your other leg, or some other object. In fact, catching it on a radiator at home ripped off the accelerometers from my tag, ending my data-collection run.

(b) The SureScreen expert Troy White confirms this snag hazard in the disclosed report on tag 499844: "Often the PID is snagged during use; such as when undressing, dressing or walking. This results in forces in the range of 6–8 kg with a large tug around 10kg."

(c) My earlier hypothesis, which was in fact originally suggested by a defendant in another case, that the tag clip is strained by Muslim prayer, seems less likely; squatting on the tag just causes it to slide round the leg. Our Muslim student volunteer confirmed that this design of tag, at least, was not troublesome during prayer, and the data bear this out. Cycling and football, which also formed part of the defendant's routine, impose substantially higher loadings.

(d) While discussing with Dr Dean the forces involved in straight and offset impulse loadings resulting from snags, I pulled the edge of my tag strap with a modest amount of force, perhaps 1kg or 2kg, while the tag was resting on my knee. There was an audible click from inside the clip. Dr Dean guessed that the arch connecting one lug to the clip had failed and we therefore decided to cut off the tag, so we could X-ray the damage, rather than pulling it off to measure whether it would break with less than the rated force following three days' wear and tear. (Dr Dean's had broken off easily following a game of football, as his statement explains.) It turned out that the lug arch was indeed cracked.

(e) This arch damage left no visible cracks or other damage marks on the visible surface of the clip. Perhaps it is only once at least one lug arch has broken, and the load is now borne by the end of the clip, that clip surface damage normally begins.

(f) A final point from experience is that the SureScreen experts give conflicting accounts of the loading per clip. At some places in some statements they argue that as a loading passes

through two clips, the breaking strain of the apparatus should be 50–70kg rather than the 25–35kg breaking strain for each individual clip. Elsewhere (e.g. D0369 on tag 473383) they correctly observe that the strap has a high coefficient of friction. The experience of wearing a tag teaches that it actually depends on the geometry. If I hold a tag in my hand and pull it directly away from my leg, then the force is indeed distributed more or less equally between the two clips, and if each of them can stand 25kg then the whole assembly might withstand almost 50kg. However if I hold the strap a quarter of the way round its circumference from the tag, and pull it quickly round my leg, then each clip is exposed initially to almost the full force of the pull because of the strap's friction on my leg, and both might break with an impulse load of about 25kg. Similarly. if a tag is snagged, the impulse will be borne largely by one clip because of the friction. Finally, if the snag results in an offset pull, failure might be progressive as the lug arch under most strain gives way first, followed by the most heavily-loaded clip hinge.

12. I now turn to the bundle of disclosed expert reports written by James Campbell and Troy White. These show further issues.

    (a) As already noted, arguments about load sharing between the clips are not consistent. It is repeatedly argued that applied loads are shared between the two clips and therefore 50kg of applied force is required to break one, yet we read for example in exhibit D0012 on tag 415025 'This clip has not been loaded nearly as much as the other one, which has failed'. Yet in D0200, on tag 434208, the same expert witness (Troy White) does not believe the defendant's story that the tag snagged, as one clip was undamaged while the other was broken in three corners and distorted in the fourth.

    (b) Also in exhibit D0021 we read that a clip 'has seen a force either greater than 250 Newtons (25kg) or for a longer period' despite the many claims that fatigue fractures cannot happen. or equivalently that a broken clip must have been loaded in excess of 25kg regardless of previous wear and tear, or equivalently as we read in D0164 on tag 414348 'Due to the brittle nature of the plastic clip and the stress/strain curve of these materials, the misconception that the strap could have been hanging on by a thread is not possible'.

    (c) The stress/strain curve of the polycarbonate is highly relevant to this case and I recommend that you seek disclosure of it.

    (d) Finally, I note that when a clip does come partially loose, as in exhibit C2515 on tag 406350, this is simply dismissed as a tag that was not properly latched in the first place. Yet field operatives use a special tool to attach tags and perform a tug test afterwards.

    (e) More generally there is the problem that in a system with no independent means of knowing the ground truth, it is difficult for experts to improve their expertise. It is perfectly possible that in some of the disclosed cases, the defendant did in fact tamper with their tag, while in others the SureScreen experts gave them the benefit of the doubt. Yet there are others with photographs of damage typical of fatigue fractures, while the SureScreen experts appear certain of the defendants' guilt.

13. Making reference now to Dr Dean's report, the evidence overall is mixed. On the one hand, the fracture surfaces in both clips (from the present case and the earlier 2011 case) are typical of fatigue fractures, both according to the literature and Dr Dean's expert opinion. That includes the analysis of the clip as a common polycarbonate plastic that is known to be vulnerable to fatigue failure.

14. In Dr Dean's words, '*Since the conchoidal marks and striations are numerous, it has to be assumed that a significant number of loading events occurred. This naturally implies that they occurred at a load that was insufficient to cause complete and immediate failure of the clip, although one could not say what loads exactly.*'

15. On the other hand, we have been unable to replicate the fracture surfaces seen on the 2013 and 2011 tags. The six full fatigue tests that we had the time to perform did not result in a clip break with an applied straight pull of less than the design minimum of 50kg.

16. It must be noted that we were required by the court to work under severe time pressure and that it takes about a day on a shaker to replicate six months' wear and tear (Z's 2013 tag was on his leg for about five months). No doubt once a crack starts to propagate, it takes less time than this, but we have been unable so far to discover the cicumstances required to repeatably initiate crack propagation. We were not able to test a clip with a broken arch; we did not have time to do thermal cycle tests; nor did we do enough controlled loading tests for them to detect a failure that occurs (say) in one out of ten clips at random. By the morning of July 25th, the deadline set by the court for service, we were only starting to come to grips with the problem.

17. Further salient factors in my opinion are:

    (a) the direct experience of Dr Dean's tag breaking easily after playing football;

    (b) the direct experience of my tag lug breaking easily in response to a light asymmetric tug;

    (c) the fact that the defendant voluntarily reported the tag failure to G4S and that no tamper event was initially recorded from the tag electronics.

18. Taking all these factors into account, it is my opinion that there is reasonable doubt about the assertions in section 19 of James Campbell's statement that the tag *'was deliberately tampered with by forcibly loading the clips in a manner which leaves no physical evidence'* and that *'such damage is indicative of a repeated, deliberate and premeditated effort to defeat the Tag'*.

19. You specifically asked whether the tag failure of December 2013 could have been caused accidentally or by wear and tear. In my opinion, it could have. Dr Dean's tag failed, and my tag partially failed, at significantly less than the 50kg design load. I cannot exclude the possibility that Z's tag similarly failed and I am not persuaded by Mr Campbell's arguments about the impossibility of fatigue in the face of strong visual evidence that it occurred in both the 2013 case and his earlier 2011 case. I hold this opinion despite our failure to duplicate the observed fracture characteristics in the time available to us.

I understand that it is my duty to help the court on the matters within my expertise and that this duty overrides any obligation to the person from whom I have received instructions. I have complied with that duty and will continue to do so. I have done my best to be accurate and complete.

I believe that the matters of fact stated in my report are true, and the opinions I have expressed represent my true and complete professional opinion.

Yours sincerely,

Ross Anderson