Implications of Snell M2000 Testing Policy

By

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Abstract

The policies, methods and procedures used in the Snell Memorial Foundation's current motorcycle helmet certification program are presented and discussed. These are of particular interest to Snell certified helmet manufacturers in that they describe the processes by which new helmet models are evaluated and certified and by which units of certified models may later be determined non-compliant. The presentation includes the description of an analytical technique which is then applied to actual test data taken from the Foundation's testing of currently certified helmets.

Executive Summary

The Snell Memorial Foundation tests crash helmets for two different purposes: Snell certification testing is performed to demonstrate whether a helmet demonstrably meets Snell requirements and, conversely, the Snell random sample test (RST) program seeks among currently certified headgear to identify those that demonstrably do not meet requirements. Certification testing must demonstrate, beyond a reasonable doubt, that the helmets perform as specified. Effectively, the burden is on the manufacturer, any uncertainty is grounds for rejection. But for RST testing, the Foundation assumes the burden. Action will be taken against a helmet model only if the testing clearly demonstrates that the helmet no longer performs to the Snell requirements.

Snell impact tests apply impacts of a specified severity to a helmet and measure the peak shock transmitted through the helmet wall to a headform placed inside. So long as this peak shock does not exceed 300 g, the helmet is considered clearly to meet the test requirements. However, there is an irreducible uncertainty associated with these tests that complicates any clear finding that the helmet does not meet requirements. It seems intuitive that establishing some slightly higher peak acceleration might suffice for this purpose, for example: any peak acceleration exceeding 330 g will be taken as a clear demonstration that the helmet does not meet requirements. However, for the most common failure mode, merely tinkering with the test criterion will not be useful.

The Foundation has established a second test protocol for determining whether a helmet sample clearly does not meet impact test requirements. This protocol maintains the same 300 g peak acceleration criterion but applies a moderately lower test impact to the helmet. If the helmet response exceeds the criterion for this lower impact severity, there is a reasonable basis to require corrective action.

The basis for this second protocol rather than merely setting a second peak acceleration criterion is discussed in terms of cross plots of the helmet's acceleration response versus the calculated deformation of the helmet wall which is, essentially, a double integration of the acceleration response versus time.

Introduction

The Snell Memorial Foundation conducts three stages of testing in the administration of its motorcycle helmet programs. The first stage is certification. Manufacturers submit helmet samples for certification testing. If the samples meet all test requirements the model is admitted to the program and the manufacturer is encouraged to begin Snell labeled production of units for distribution and sale.

The second stage is random sample testing or RST. The Foundation purchases units from retailers and distributors and brings them into the laboratory for testing. If the samples meet test requirements, all is considered well and the matter rests until the next round of RST. If a sample fails in RST, however, a third stage of follow up testing is scheduled.

In this third stage, three more samples of the same model and size are acquired, from the same source if possible so that there is a reasonable chance of getting units made at about the same time as the one that failed. The three samples are then subjected to the same tests that produced the RST failure although by a different technician whenever possible. If all three samples pass this follow up testing no further action is deemed necessary. Snell labeled production may continue uninterrupted and all will be considered well until the next round of

RST. However, if any of the three samples fails, the matter is referred to a board member, the Director for Standards Enforcement for action under the standard Licensing Agreement.

The first and second stage testing, certification and RST, are conducted to the same protocols. However, the demands are eased for the third stage, follow up testing. Instead of testing at the standard levels of impact energy, the follow up impact tests are conducted at 90% of those energies. The basis for this difference is that the certification test levels have been set to identify those helmets that comply with the Foundation's M2000 and SA2000 standards but the third stage test levels have been chosen for another purpose: to identify those units that <u>do not</u> comply.

The third stage takes the existing procedural and transducer tolerances into account. These tolerances are best understood as testing uncertainties. Much of the Foundation's effort as an quality laboratory certified by A2LA to ISO/IEC 17025-99 is devoted to quantifying and controlling these uncertainties. The nature of these uncertainties is that a single test will not properly distinguish between compliance and non-compliance. Instead, one test must be used to identify helmets that certainly comply while a second test will identify those helmets that certainly do not. The higher level set for certification testing eliminates any reasonable uncertainty whether a passing model is fit for admission to the Snell program. Similarly, the lower level set for third stage testing eliminates any reasonable uncertainty whether a failing model should be removed from the program.

The difference between the certification and third stage tests is in impact severity. The third stage imposes less severe impacts on the helmets but requires that the peak shock transmitted to the headform meet the same criteria as in certification. An alternative approach might be to apply the same levels of impact but to permit a moderately greater peak shock to be transmitted. The Foundation's directors considered this method of dealing with test uncertainties but rejected it because the overwhelming majority of impact failures was seen to be in impacts against the hemispherical anvil. Impact performance against the hemispherical anvil is almost completely determined by the total impact energy applied. If the energy applied is less than some specific amount determined by the structure of the helmet and the point on the shell at which the impact is applied, most helmets will easily satisfy any reasonable limit on peak transmitted shock. However, as the energy applied in the test is increased to this limit and slightly beyond, the peak transmitted shock will skyrocket. Since the uncertainties governing passing and failing against the hemispherical anvil spring overwhelmingly from uncertainties in the energy applied, the directors have chosen to resolve them by modifying the energy of the test rather than the criteria.

The following sections present, first, an analytical technique for studying helmet impact and then applies this technique to several sets of results obtained for various Snell certified helmet models. The material presented demonstrates the soundness of the energy based approach to understanding hemispherical anvil impacts, the nonlinear behavior of peak shock for this impact variety and, ultimately, the basic fairness and practicality of the methods by which the Foundation identifies new models for certification and eliminates certified models that have become non-compliant.

Analytical Technique: Acceleration versus Displacement

This discussion relies on two different means of presenting the acceleration response of helmets tested in impact: the familiar acceleration versus time plot and a second format showing acceleration versus helmet wall deformation.

The acceleration versus time plot in Figure 1. shows the results of an actual helmet impact. The arrows indicate the left to right flow of events. That is: the trace starts on the left, the acceleration builds to the 292 g peak and then falls back to zero as the event progresses. The horizontal line at 300 g indicates the Foundation's test criterion. Had the acceleration exceeded this criterion at any point, the helmet would have failed the test.

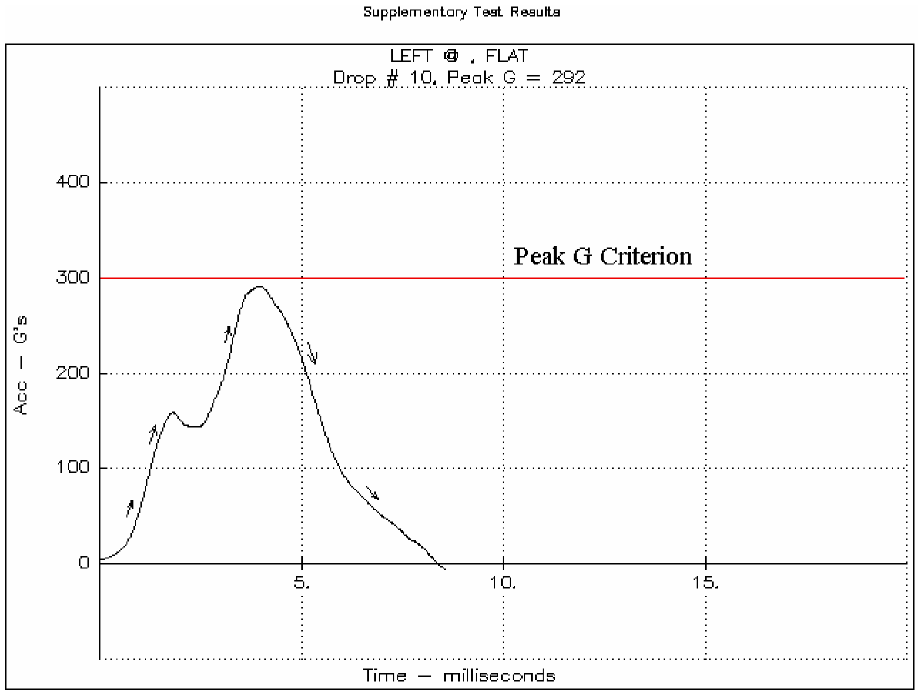

Figure 1 Acceleration versus Time

Figure 2. is the same acceleration response plotted versus the position of the falling headform. The zero position at the left side of the plot represents the point where the helmet first contacts the anvil. Delta X increases as the headform continues to move downward crushing the helmet wall between itself and the unmoving anvil. Unlike the first plot, this trace folds back on itself. The event proceeds from left to right on the plot until a maximum Delta X and then goes back, right to left until the end of the event. The left to right arrows represent the loading curve, the portion of the trace in which the helmet wall is being crushed, and the right to left arrows show the unloading curve, the portion representing the helmet rebounding away from the anvil.

The Snell Impact test criterion is the same as for the first plot but this format allows the inclusion of a second bound on helmet performance. Delta X at any given impact site may not exceed a certain value depending on the structure and materials of the helmets. That is: the helmet wall cannot be crushed past a certain minimum thickness. The thick blue vertical line represents an absolute bound that Delta X will never exceed. Instead, when the helmet deformation gets close to this limit, the material properties of the helmet wall begin to change. The crush resistance suddenly begins to increase super-exponentially with further deformation so that the forces and accelerations applied to the test headform or a wearer's head spike sharply upwards. The trace will never reach the limit but it will curve dramatically upward, through the 300 g criterion, beyond the measuring range of the transducers perhaps until the test headform and guidance hardware themselves begin to fail.

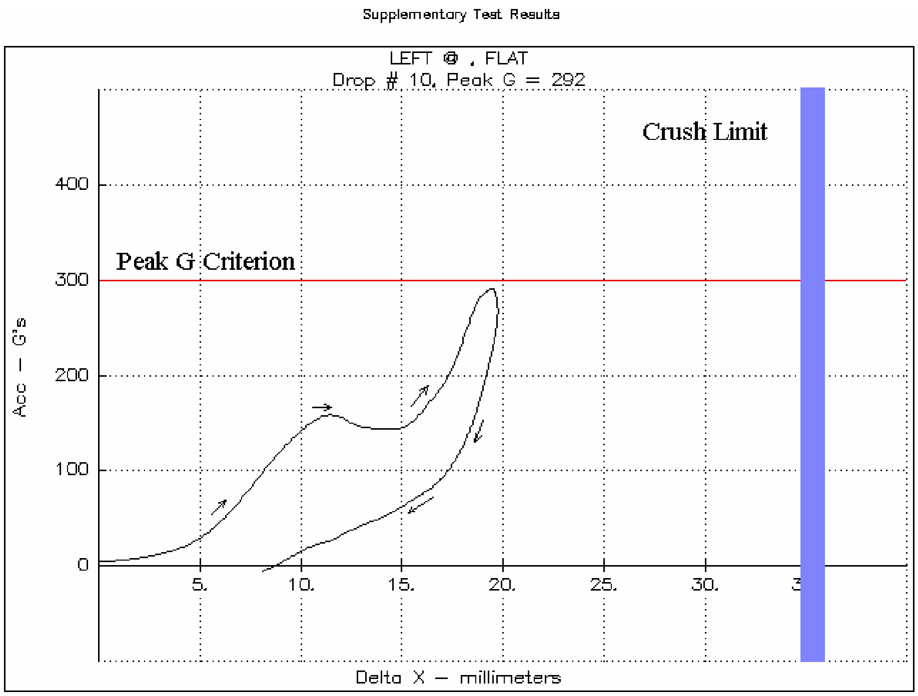

Figure 2 Acceleration versu Delta-X (cross-plot)

These acceleration versus displacement plots are based on the same information in the acceleration versus time plots and on the measured impact velocity of the falling headform. The acceleration is integrated with respect to time and subtracted from the impact velocity to obtain the headform velocity at each instant during the impact. Then this velocity is integrated over time to obtain displacement as a function of time. Finally, the acceleration at each instant in time is plotted versus the corresponding displacement yielding a curve appears very similar to a materials properties curve such as stress versus strain or a spring function.

One of the problems of this analysis is the correct identification of the instant at which the helmet first touches the anvil. If the analyst misidentifies this instant, the entire acceleration versus displacement trace will be shifted right or left. The other problem is that the integration operation propagates and compounds measurement errors so that, after two integrations, the displacements in these plots are a good deal less precise than the times in the acceleration versus time plots. However, these plots may yield useful insights into the impact event and, particularly, impact energy management.

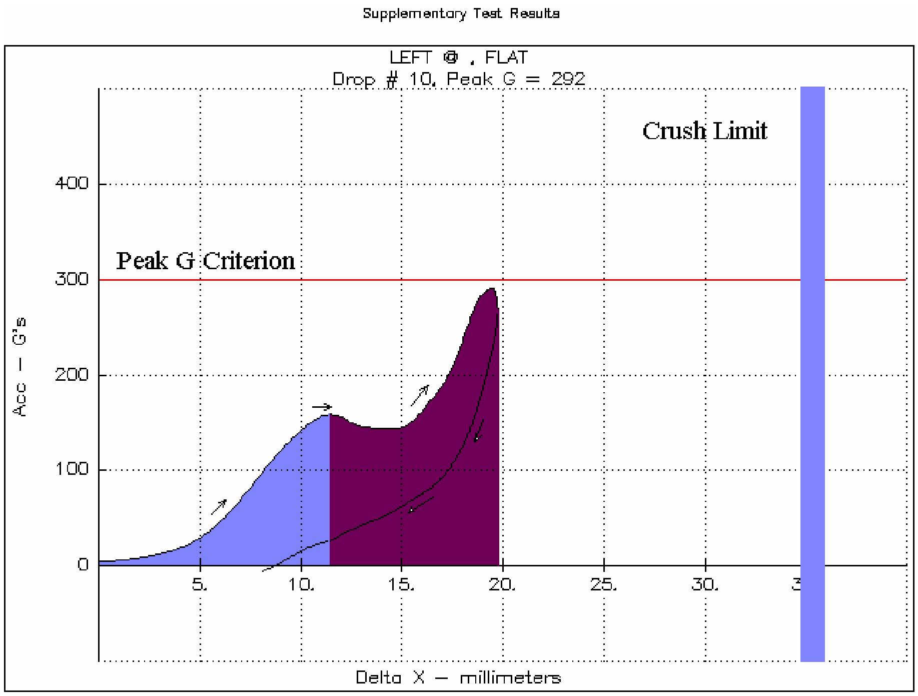

Figure 3 Cross-plot

The area under the loading curve in this acceleration versus displacement plot multiplied by the drop mass is equal to the energy managed. The leftmost (blue) filled in areas on the trace in Figure 3. correspond to the energy managed when the acceleration reaches its first peak and the sum of all the filled in areas is corresponds to the total impact energy applied in the test. The area under the unloading curve is of less interest but actually corresponds to mechanical energy stored elastically in the helmet shell and liner and that is returned to the helmet during unloading causing it to rebound away from the anvil.

One of the potential uses of this acceleration versus displacement presentation is predicting helmet performance for different drop masses and energy levels. The assumption here is that most of the impact performance is determined by a force versus deformation response that is

Delta X — millimeters

essentially fixed by the impact site and the anvil surface. That is, if an identical sample of the model in the test shown above were impacted at the same site against the same anvil, the loading curve would follow the same track. If the impact energy was lower, the trace would depart a little earlier from the above and follow an unloading curve roughly parallel to the one above but shifted a little to the left. If the impact mass were a little different, the entire trace would be shifted higher or lower in inverse proportion to the mass difference.

This presentation may also yield some insights into helmet performance for subsequent impacts. The unloading portion of the trace indicates that some portion of first impact was managed elastically. That is, a portion of the total kinetic energy was stored in the helmet shell and liner and then returned to the system as rebound velocity. The implication is that this elastic component remains available for subsequent impacts. Furthermore, the rebound curve may understate the size of this residual management capacity because of dynamic effects.   The effect is that a helmet may be able to manage noticeably more energy in two impacts than in one. There is also a suggestion that a reduction of the energy applied in the first of two impacts will be compounded in the increase of energy management available to a second impact. That is: if a helmet impacted at 150 j can just manage a second 110 j drop, the same helmet when first impacted at 135 j may be able to manage noticeably more than 125 j in a second drop.

Of course, there is more to impact response than this simple force versus deformation paradigm. The helmet shell has appreciable mass and will almost certainly flex and vibrate, particularly in impacts against the hemispherical anvil. Further, the shell and the liner are likely to have some velocity sensitive aspect to their force versus deformation behavior. At best, these acceleration versus displacement traces reflect the force versus deformation response but with an overlay of dynamic effects that could confound any predictions based on them. Even so, force versus deformation is likely to be a fundamental property of the helmet and is likely to yield useful insights into impact response and into material differences between units of the same helmet model.

Examples

Figures 4 and 5 are acceleration versus time traces from first and second round tests of a Snell certified motorcycle helmet. They show the first and second impact results for right side impact against the hemispherical anvil respectively. The traces in red are results taken from a first round RST test. The traces in black are from three follow up tests on the same model. Although all four traces from the first impact are roughly similar, the first round result from the second impact is very different from the others, Instead of a well behaved response peaking at about 150 g, this trace spiked sharply upward and peaked above 450 g, well above the test criterion.

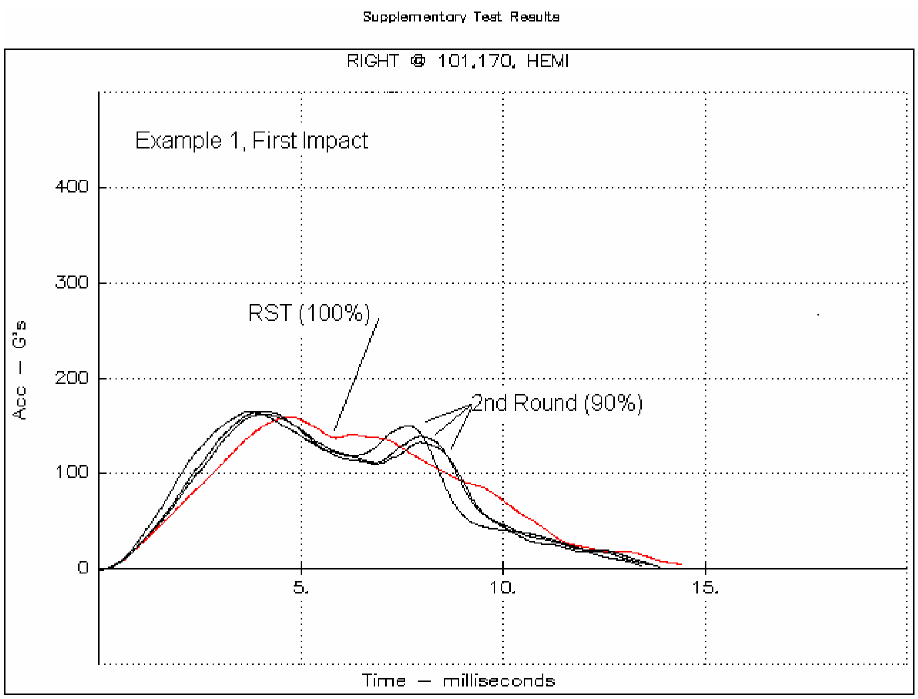

Figure 4

It was as a result of this RST failure that the three additional samples were purchased for follow up testing. The results of these follow up tests were all within the test criteria so no further action was deemed necessary. However, the follow up tests differ procedurally from the first round testing. It is not immediately apparent in the acceleration versus time traces but the impact energies used in the follow up tests are only 90% of those in the first round. This difference is more easily seen in cross plots of acceleration versus displacement.

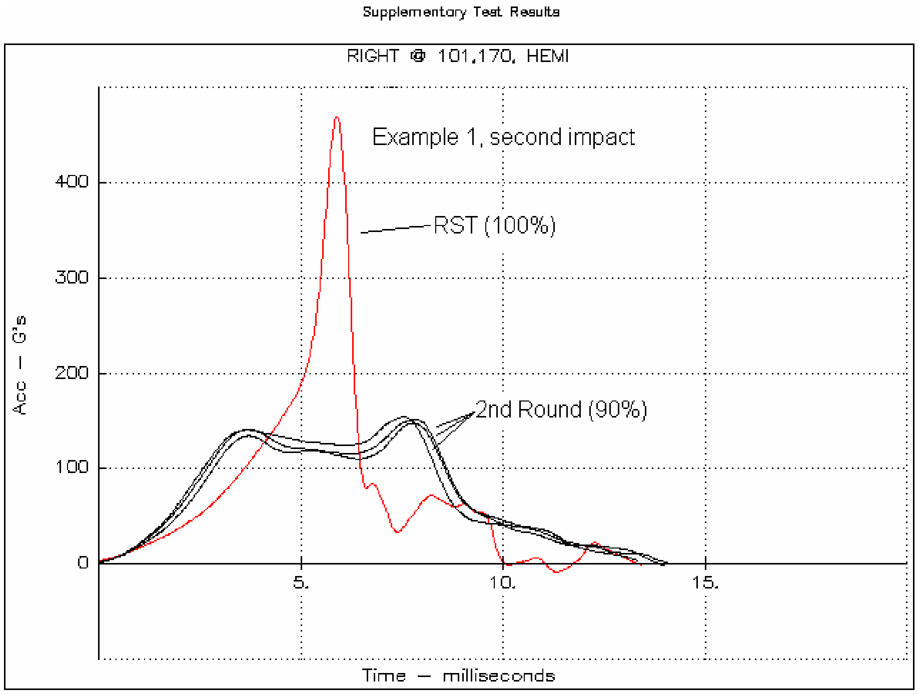

Figure 5

Figure 6. plot shows a dramatic difference between the RST and follow up results. There seems to be a five to seven millimeter difference in the peak intrusion into the helmet. In fact, with 10 % more energy, one would expect more intrusion. Figure 7. is even more dramatic. The red trace from the first round RST test seems to reach an absolute limit of deformation. The accelerations seem to suddenly start climbing as the deformation approaches 30 mm and it appears as if there is some asymptotic limit just beyond 30 mm that is the maximum compressibility of the helmet wall at the site being impacted. That is, in this test, the impact was sufficient to collapse the helmet wall completely so that the remainder of the shock was transmitted almost directly to the headform.

A calculation similar to one yielding deformation versus time indicated that in this particular impact, the helmet sample managed 97 j of the 110 j of energy applied before the acceleration trace exceeded 300 g. The implication is that if the impact severity had been 97 j or less, the cross plot would have followed essentially the same curve as observed until the energy under the curve equaled the impact energy at which point the curve would have broken away following an unloading path roughly parallel to that observed. The peak g would have been 300 g or lower. By extension, since the two impacts at this site totaled to 260 j, the helmet sample managed a total of 247 j before it failed. Since the follow up tests are performed at 90% of the RST energies, the follow up samples were only required to manage 234 j which they did quite easily. In fact, it seems quite reasonable that the original sample would also have passed at these reduced energy levels.

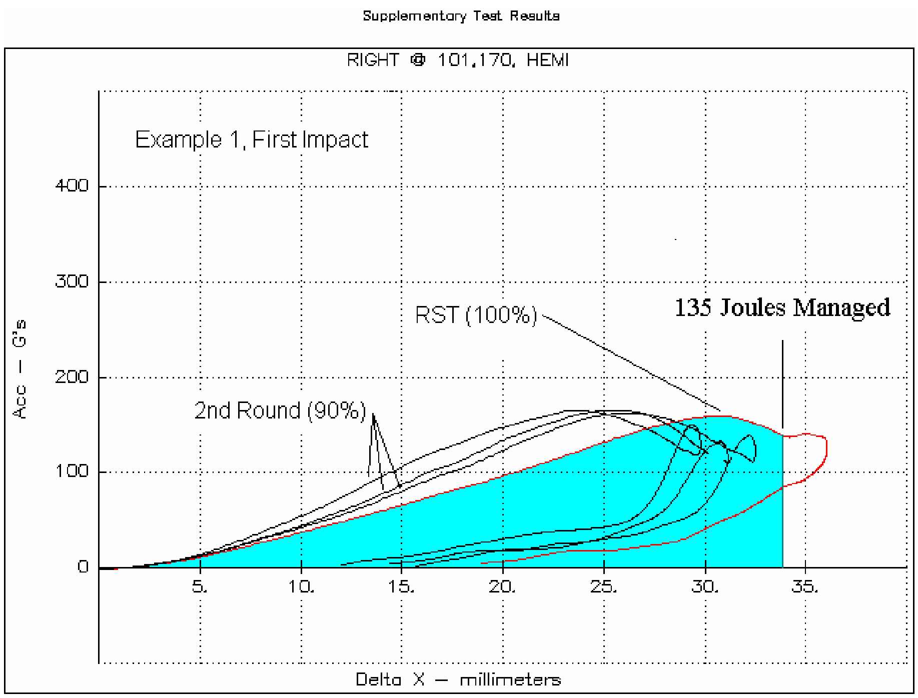

Figure 6

These traces also suggest a difference between the structures of the RST helmet and the three follow up helmets. The slope of the acceleration versus displacement trace for the RST helmet is markedly lower than for the three follow ups. Some of this difference may be due to dynamic effects, the impact velocity was about 5% greater and there could be some velocity sensitivity in the helmet materials properties. It is also possible that a slight variation in the impact site caused the difference in response. However, I suspect that some variation in the helmet itself, whether in the liner density, shell lay up, or assembly produced this difference in slopes and was ultimately responsible for the test failure.

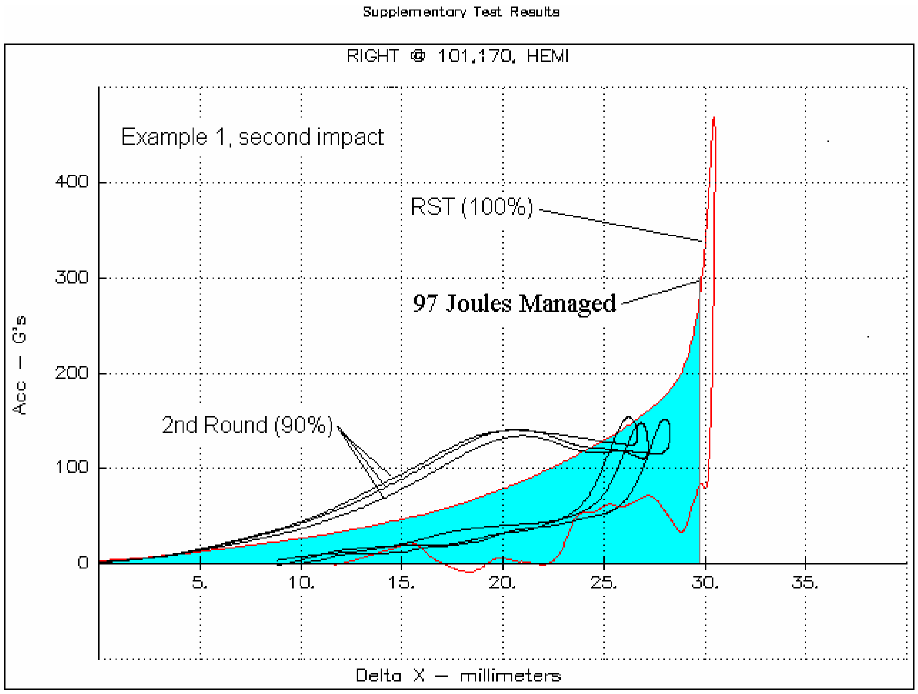

Figure 7

The traces for a second set of helmets, Figures 8 through 11, are similar. These results are for hemispherical impact at the rear of the helmet on the test line. The RST sample failed the second impact managing about 92 j of the 110 j applied or a total of 242 j over the two impacts. As can be seen, the follow up samples managed the 236 joules applied in two impacts without any difficulty. As with the previous example, the acceleration versus displacement traces suggest that the RST sample differed from the follow up samples. However, it seems reasonable that samples identical to the RST sample would also have passed had they been tested at the reduced energies of the follow up test protocol. This conclusion seems particularly remarkable when considering that the peak acceleration recorded for the second impact conducted at the 100% level exceeded 500 g.

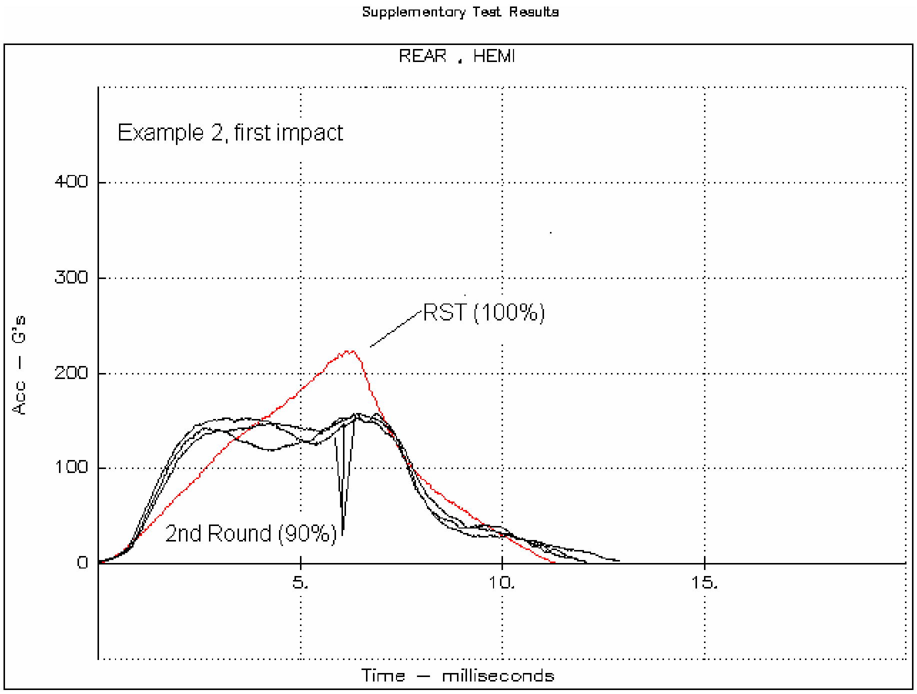

Figure 8

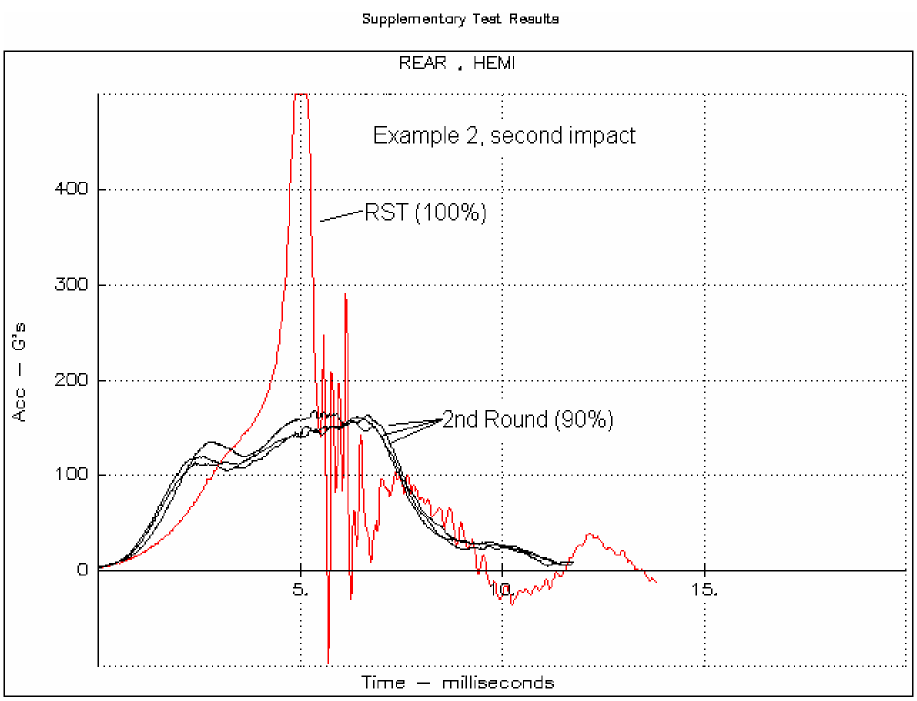

Figure 9

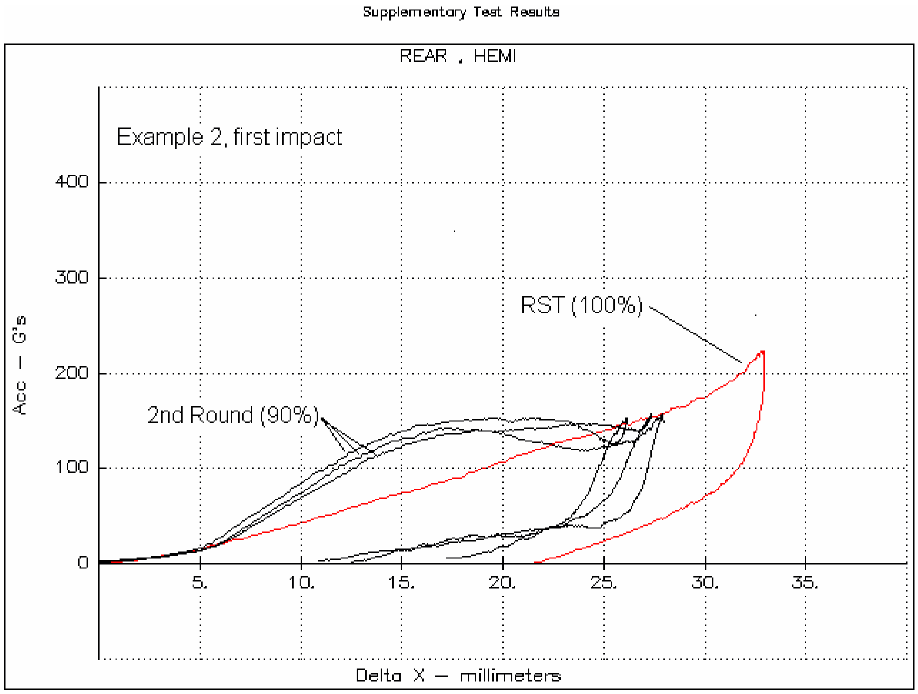

Figure 10

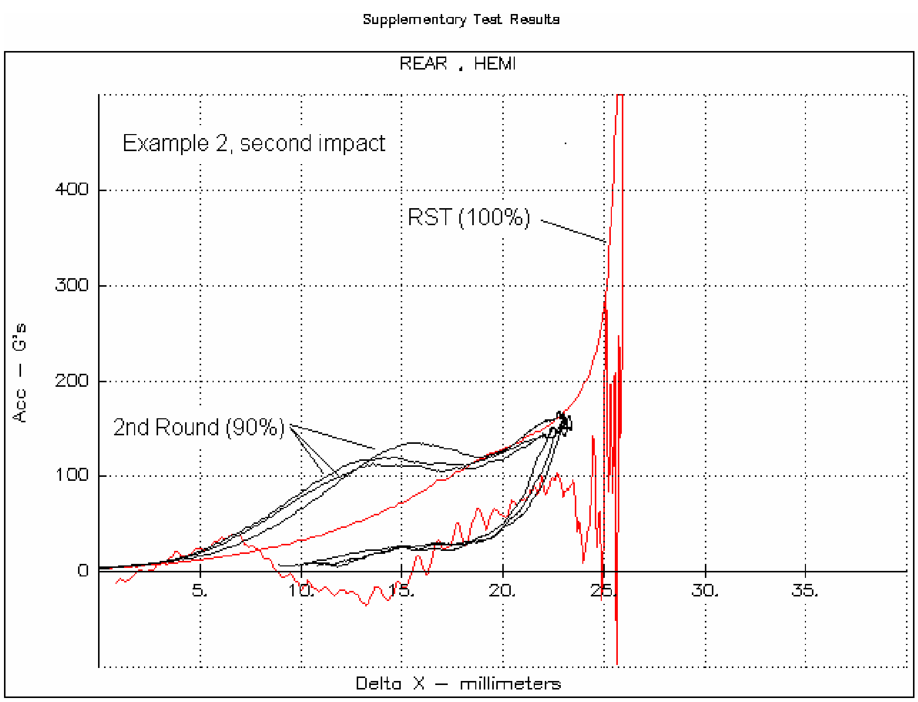

Figure 11

The third set of traces, Figures 12 through 15, show a more serious problem. There were two right side hemispherical impact failures noted in RST testing. One sample had been conditioned hot and the other cold and had been tested simultaneously. The cold conditioned sample passed the first impact but failed the second and the hot conditioned sample failed both impacts exceeding the accelerometer's measurement range in the second. All the follow up samples were tested in the hot condition and one of those failed the second impact with a peak acceleration of 312 g.

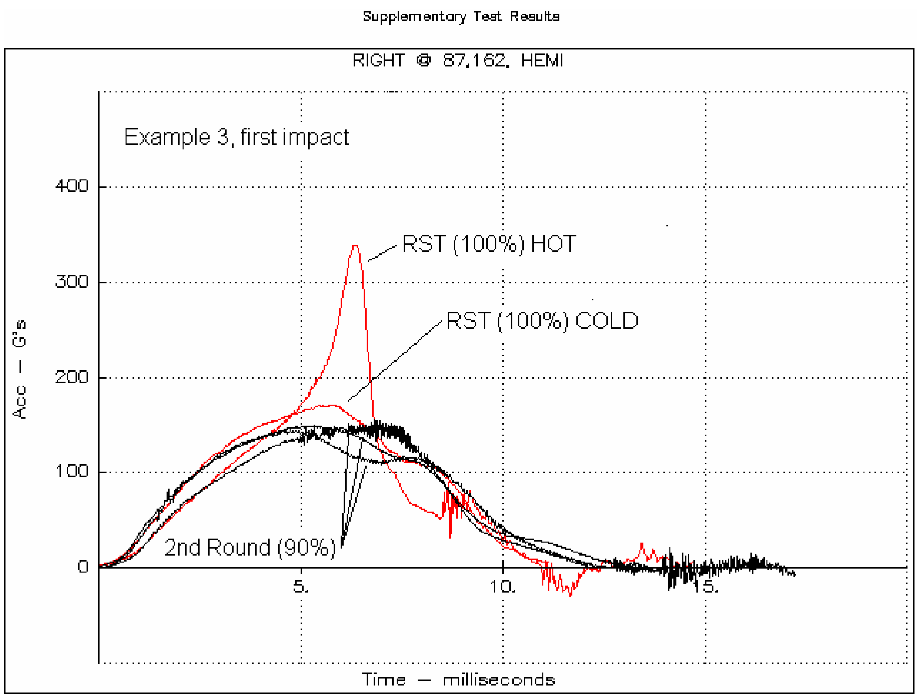

Figure 12

The cross plots reveal a number of interesting features. In the first of the two plots, two of the follow ups and the cold conditioned RST sample have the same acceleration versus deformation slopes while the hot conditioned RST sample and the third follow up sample have another lower slope. The hot conditioned RST sample trace seems to start to break upward after 32 mm of deformation and approaches an asymptote located at about 35 mm but the corresponding follow up sample reaches 34 mm of deformation with no sign that it may be approaching an asymptote. In the second plot, the asymptote for the cold conditioned sample appears to be 2 to 3 mm in front of the other asymptotes. The slope characteristics noted in the first plot are duplicated here but one of the two follow up traces with the higher slope seems to break upward as if nearing an asymptote while the other does not.

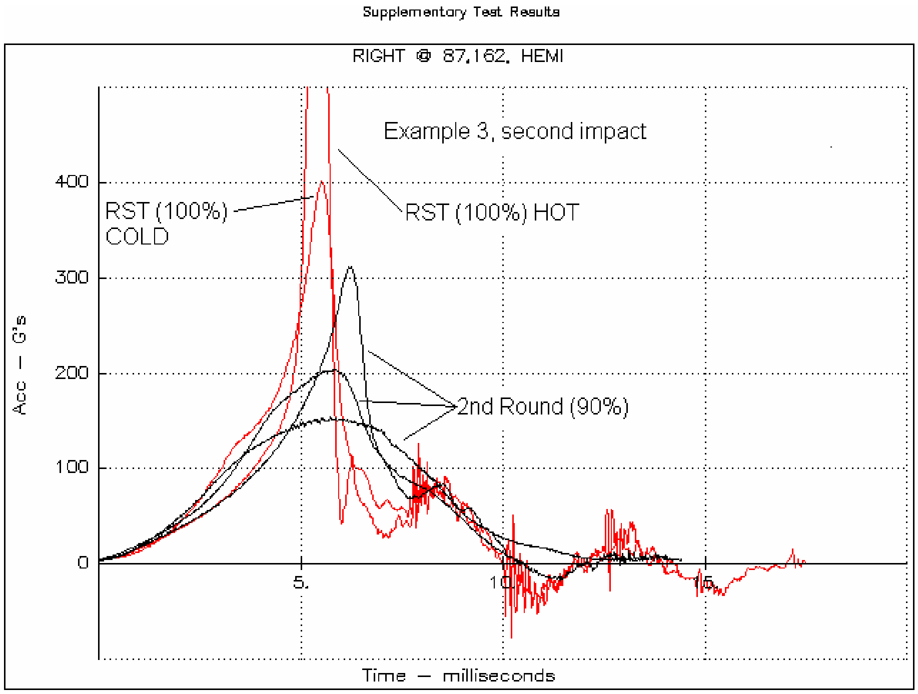

Figure 13

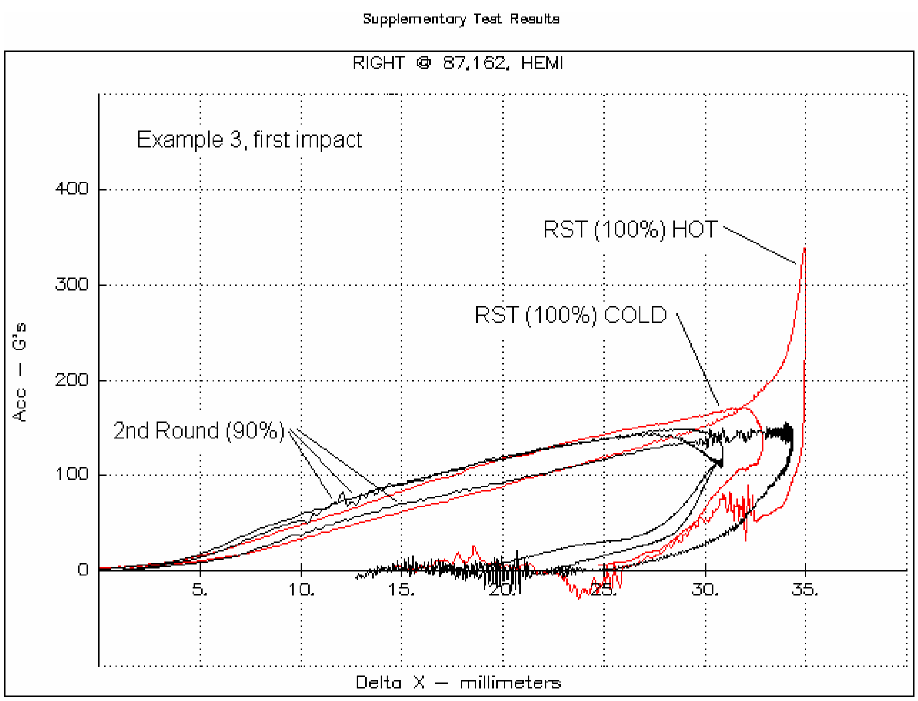

Figure 14

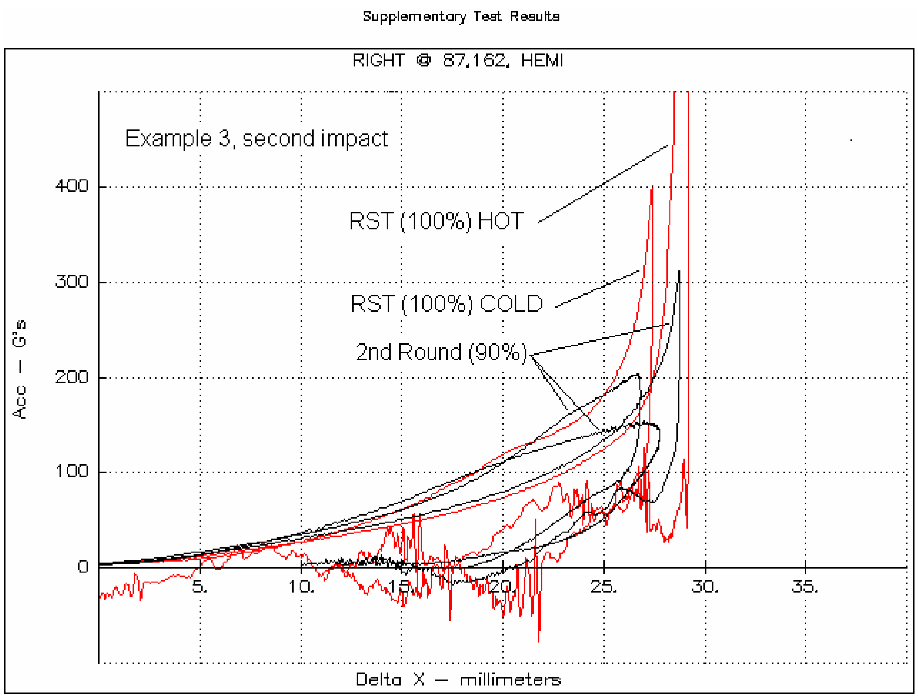

Figure 15

The slope anomalies suggest differences in the shell lay up or in the liner density. The differences in asymptotes, at least in the first plot, may be differences in liner thickness. Pleases note, this difference need not be differences in the liners themselves. Since the liners taper in that area, slight differences in the way the liner is inserted into the shell, or in the thickness of the edge beading or even inaccuracies in the determination of the impact site could shift the impact to thinner portions of identical liners. The asymptotes in the second plot are likely most affected by the nature of the damage done in the first impact. The extent of shell delamination and the amount of liner recovery are likely to vary even in seemingly identical units. These factors and the additional uncertainty in identifying the instant when the helmet contacts the anvil in second impacts suggest that comparisons may be misleading.

The energy calculations indicate that the cold conditioned RST sample managed all of the first impact and 99 j of the 110 j applied in the second for a total of 249 j over two impacts. The hot conditioned RST sample managed 145 j of the first impact before exceeding 300 g and 83 j of the second for a total of 228 j. The single failure noted in the follow up tests managed all 135 j of the first impact and 97 j of the 99 j applied in the second impact for a total of 232 j. The hot conditioned sample might have failed even at the follow up test energies. The follow up failure indicated that the test results could not be reasonably attributed to testing uncertainties but instead showed a definite deviation from the standards. The test results did demonstrate levels of protective performance well above other commonly accepted standards so the only corrective actions deemed necessary were to stop Snell labeled production, identify and correct technical problems and then submit samples of the improved headgear for certification testing. Once

samples of the corrected headgear had been tested and found to meet all requirements, the Foundation was pleased to authorize the resumption of Snell labeled production of this headgear.

Conclusions

In each of these three examples, there is a suggestion of material differences in the helmet samples that may have produced the failing observations. However, for the first two samples, the observations were ultimately dismissed as anomalous. In the case of the third example, the observations led to the conclusion that model was, indeed, non compliant. Therefore, the Foundation imposed corrective action upon the manufacturer according to the terms of the Licensing Agreement.

Each of these three examples also shows the abrupt transition in helmet behavior that is particular to impact failures against the hemispherical anvil. When the helmet deformation begins to approach some asymptotic limit, the helmet stiffness starts to rise sharply resisting further deformation and transmitting sharply increasing levels of shock to the headform. The limit on deformation is effectively a limit on the impact energy that the helmet can manage in hemispherical impact at the given site on the helmet surface. If the energy applied is within this limit, the helmet will respond with a peak level of shock well within a reasonable criterion. If the energy is beyond this limit, the peak shock will skyrocket to levels beyond any reasonable criterion causing deformation not just in the helmet but in the headform, anvil and guidance hardware. For hemispherical impact, the clearest difference between a qualifying and a non-compliant helmet is whether the helmet can manage the required impact energy.

To separate qualifying helmets from all those submitted for certification, Snell policy requires that they manage 100% of the energies called out in the standard. Any uncertainty weighs against the helmet. If the samples pass, the Foundation can state with confidence that the model complies with all the performance requirements of the standard. Later, to determine whether a certified helmet has become non compliant, policy calls for testing at 90% of the energies called out in the standard. Effectively, the benefit of any uncertainty lies with these proven models. Should a sample of a certified helmet fail to meet the test criteria at this lower level of impact, it is compelling evidence that the model is, indeed, non-compliant.