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BLAST SURVIVABILITY AND SEAT DROP TOWER TESTING

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ABSTRACT

The inclusion of energy-absorbing (EA) seats in combat vehicles has been shown to greatly reduce the likelihood of upper-body injuries during mine blast events. A drop tower is one of the common low-cost methods of testing an energy-absorbing seat to determine the vehicle acceleration and associated level of blast that it can protect against. However, the lack of a standard drop tower test procedure for mine blast purposes means that different facilities perform tests and analyze and report results in an inconsistent manner. As a consequence, the reported performance of any given seat tested in a drop tower may not accurately reflect the degree to which it would protect a soldier during an actual blast event. This paper describes the nature of the problems associated with current drop tower testing, and proposes a solution to eliminate much of the ambiguity surrounding test results. We will describe proposed test and analysis methods that can lead to a more accurate and conservative estimate of EA seat performance during an underbody blast event, resulting in better seat designs and increased soldier survivability.

INTRODUCTION TO MINE BLAST AND SPINAL COMPRESSION

Many of the injuries that occur as a result of underbody blast events are associated not with blast overpressure or fragment impact, but arise from whole-body acceleration. As the blast lifts the vehicle off the ground, the seated occupant suffers spinal compression forces that can lead to severe upper-body injuries. One measure of spinal compression is the Dynamic Response Index, or DRI. This is proportional to the compression calculated using a simple spring-damper model of the human spine. The input to the model is the vertical acceleration measured in the pelvis, which arises due to the motion of the vehicle following the blast event.

$$\frac{d^2 s}{dt^2} + 2\zeta\omega \frac{ds}{dt} + \omega^2 s = \frac{d^2 z}{dt^2} \qquad (1)$$

In this equation, d^2z/dt^2 is the input shock acceleration, s is the resulting spinal compression, and ζ and ω are values which characterize the response of the human spine – ζ=0.224 and ω=52.9 rad/sec.

For no spinal incapacitation, the limiting value of DRI is either 17.7 [1] or 18 [2], which corresponds to a spinal compression of about 62 or 63 millimeters. It turns out that for short-duration input shocks (less than about 15 msec), the value of DRI is insensitive to the actual shape of the shock pulse. In this case, it can be shown that the value of DRI is very close to 3.96 times the integral of the shock input d^2z/dt^2 over the duration of the event. This integral is simply equal to the change in velocity of the spine during the blast. Briefly, this is the velocity at which the occupant is lifted off the ground. If the occupant is sitting in a rigid seat attached to the vehicle structure, this velocity is close to that at which the entire vehicle is lifted off the ground. We refer to this velocity as ΔV, so we have in the case of a rigid seat:

$$DRI = 3.96 \cdot \Delta V \qquad (2)$$

where ΔV is measured in meters per second.

As it happens, almost all blast events in combat vehicles deliver the shock pulse to the seat mount over a very short duration, so the approximation in equation (2) is accurate for a rigidly mounted seat. Also, the value of ΔV for a given vehicle is strongly related to the size of the mine blast (measured in kilograms of TNT) at a certain location under the vehicle. As a consequence, survivability against a given size of mine blast can be stated as follows: the seat should mitigate the DRI such that it drops below the survivable limit (17.7 or 18) for a blast input that produces a specified value of ΔV.

Because blast survivability is specified in terms of ΔV, we can simulate the blast performance of any given seat design using a simple drop tower. The seated crewman is placed in the sled, which is raised to a given height and then dropped. Upon impact, he experiences a sudden change in velocity very similar to that which occurs during a blast event. Again, the precise profile of the shock input is not the same, but the overall integrated ΔV can be easily controlled by adjusting the height of the tower and the characteristics of the programmer (as described in the next section), and the resulting spinal compression and DRI should be comparable.

DROP TOWER TESTING – BLAST SIMULATION

The essential elements of a drop tower test include the tower itself, the sled to which the seat under consideration is attached, the anthropomorphic test dummy (ATD) belted into the seat, the instrumentation (principally accelerometers and load cells) on the ATD and on the sled, the programmer (typically a crushable disk) that adjusts the shock profile when the sled strikes the bottom of the tower, and the high-speed video that records the entire event.

The figures below show a few frames from the high-speed video of a drop test. The top two photos show the ATD in the sled as it falls to the bottom of the tower. The bottom two frames show the moment of impact, followed by the rebound of the sled. Note that the height of the rebound depends on several factors, including the nature of the programmer that shapes the impact shock, the weight of the sled and occupant, and the type of seat (rigid or energy-absorbing). However, in our experience it is unusual for the rebound height to be more than a few percent of the drop height. So, for example, a drop from a height of 1.30 meters might result in a rebound of about 0.030 meters (30 mm).

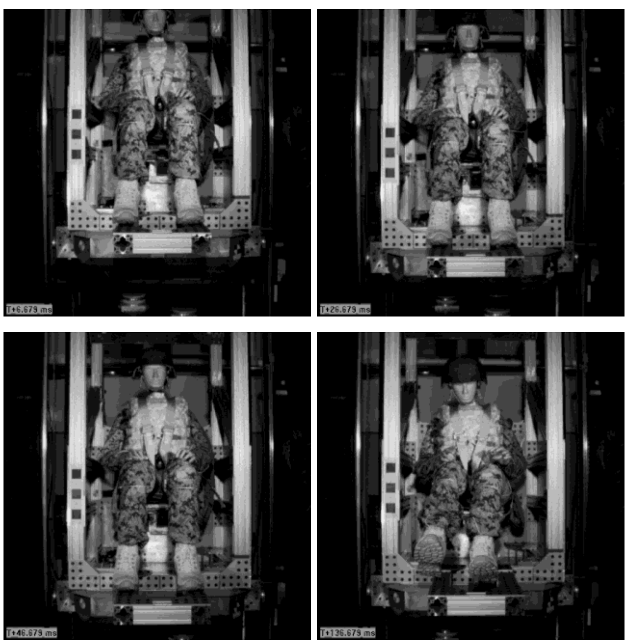

Figure 1. Video frames from drop tower testing.

The key data needed for computing both the DRI and the value of ΔV in the drop tower test is normally acquired from accelerometers located both on the sled and within the ATD. The accelerometer on the sled is used to compute the value of ΔV, while the accelerometer in the pelvis of the ATD provides the shock input used to compute the DRI from equation (1) – it provides the right-hand side.

The figures below show an example of the data provided by these accelerometers for a given drop test. The duration of the data is only ¼ of a second (250 msec). The event is largely completed long before that time, at least in terms of potential injury to the occupant. The top figure shows the acceleration profile of the sled and the pelvis. The bottom figure shows the same data integrated up to provide the velocity profile of the sled and the pelvis.

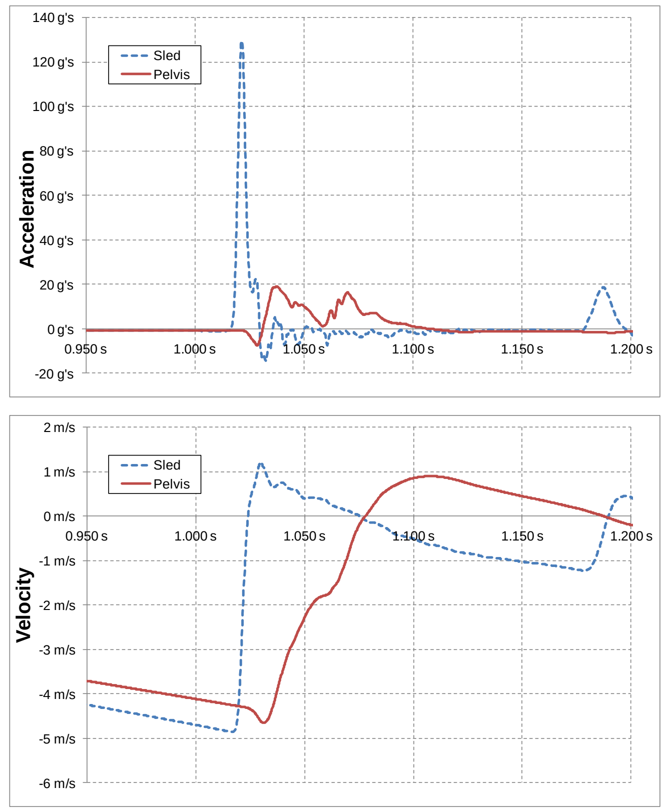

Figure 2. Acceleration and velocity of the sled and the ATD during a drop test.

The goal of an energy-absorbing seat is to take the total integrated shock input produced by the event (the ΔV), and transmit it to the seated occupant over a longer period of time. This can be seen in the figure above, where the velocity traces show how the sled reacts on impact over about 10 msec, while the ATD reacts over about 70 msec. This is accomplished through the action of a mitigation system in the seat that typically employs either energy-storage devices (springs) or energy dissipation devices (shock absorbers) or both. In any event, these devices can only work if the seat is allowed to move relative to the fixture. That is, the seat needs to have some amount of stroke in order to mitigate the effects of the shock. And the more stroke that the seat has available, the more shock the seat can attenuate.

As it happens, the equation that describes the motion of an energy-absorbing seat has exactly the same form as the DRI equation which describes the compression of the spine. This is not surprising, since the DRI equation is a model of the spine in terms of a simple spring and shock system. This equation can be easily solved analytically for a number of shock inputs. As a consequence, it is a simple matter to relate the characteristics of the seat's energy-absorption system to the spinal DRI and the initial blast shock loading, ΔV. One of the key results of this analysis is a specification of the optimum EA seat attenuator characteristic for any given weight of occupant and blast load. Another key result is the specification of the minimum seat stroke needed to attenuate a given shock load to a survivable DRI level, regardless of the weight of the occupant [3,4].

DROP TOWER TESTING – DATA ANALYSIS

One of the essential elements in drop tower testing is the calculation of the value of ΔV. Again, for any given vehicle and shot location, this number represents the blast load in kilograms of equivalent TNT, and is the number generally used to specify survivability requirements. In the drop tower, this number represents the velocity change to which the seated occupant is exposed during the test. It would seem to be a simple number to compute, given the instrumentation available on the tower. However, it turns out that there is no specification that describes exactly how to compute this value. Also, because of the great variety of instrumentation, it is possible to compute this value any number of ways, and in general, the different methods produce different answers.

One simple way to calculate the value is to examine the integrated signal from the accelerometer attached to the sled. This is the velocity profile, and it is a simple matter to compute the difference between the minimum and maximum values and call that ΔV. Unfortunately, there are a number of reasons why this may not be appropriate.

First, the sled accelerometer is subjected to some fairly high loads during the event, and may not respond in the same way following impact as before. That is, although the accelerometer may measure the impact velocity accurately, there is no guarantee that it is still measuring the bounce velocity correctly.

Second, the location of the accelerometer on the sled and the structure of the sled itself may lead to a "ringing" effect, in which the accelerometer indicates a higher transient velocity that is not representative of the actual sled velocity at the site of the seat mount.

Third, the interaction between the ATD in the energy-absorbing seat and the rebounding sled may reduce the overall load on the seat below that which is indicated by the sled velocity alone. For example, if the sled is not a great deal heavier than the ATD, the force of the falling ATD will serve to reduce the rebound of the sled. As a consequence, the instantaneous maximum sled rebound velocity would overestimate the effective load on the ATD. This would not happen, for example, in an actual vehicle where the mass of the occupant has very little effect on overall vehicle motion.

Finally, the structure of the sled and the tower itself can serve to absorb energy during the rebound. If the sled and tower undergo sufficient vibration due to the violence of the impact, this can also reduce the rebound, in which case the instantaneous change in velocity is an overestimate of the true ΔV experienced by the ATD.

Consider, for example, the following integrated accelerometer trace. It shows data from a drop test using an energy-absorbing seat which exhibits a number of anomalies.

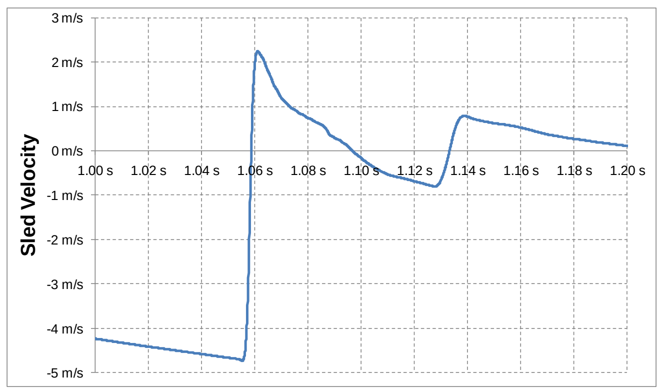

Figure 3. Velocity trace from the sled of a drop tower showing anomalies.

First, consider the basic structure of the velocity signal – the integrated accelerometer response from the sled. It shows an initial ramp of negative 1 G, as expected, up to the point of impact, which occurs at about -4.6 m/sec. The sled then bounces up to a maximum velocity of about 2.2 m/sec, giving an apparent ΔV of 6.8 m/sec. However, at that point, the sled begins falling again at a rate far in excess of 1 G. In fact, the effective deceleration of the sled is about 4.7 G. Moreover, when the sled finally makes contact with the bottom of the tower on the second bounce, the accelerometer indicates that the impact velocity is only about -0.7 m/sec, despite the fact that it apparently bounced up at more than three times that rate. Also, the time duration between the initial impact and the second impact is 70 msec, which is consistent with a liftoff velocity of only 0.34 m/sec. All of these factors lead to the conclusion that the data from the sled accelerometer alone is not a good method for calculating the effective value of ΔV.

CALCULATION OF ΔV

As mentioned above, there are a number of alternative ways of extracting the value of ΔV from the instrumentation, besides looking at the simple difference between minimum and maximum sled velocity from the accelerometer. All of these methods focus on the same problem – determining the actual impact velocity and an effective bounce velocity that is consistent with the forces experienced by the seated ATD.

The impact velocity is not, in general, subject to much uncertainty. It can be determined from the height of the drop, or from the integrated accelerometer trace on the sled, or from the high-speed video of the event. In our experience, the high-speed video and accelerometer data generally match very closely, and produce a value a few percent lower than the theoretical value calculated from the height of the drop. This is not surprising – we would expect a small frictional loss in the tower, and the accelerometer should produce very accurate data prior to the shock of the initial impact. The only important factor to consider is that the sled accelerometer should be a piezoresistive type that provides a signal all the way down to DC (a piezoelectric accelerometer will not work for this purpose). Also, the maximum G-level should be low to allow for higher resolution at low acceleration (during the drop), and the accelerometer should be mounted so as to mechanically filter the high-frequency shock.

The calculation of the bounce velocity, on the other hand, is subject to much greater uncertainty. Besides using the integrated accelerometer trace, we could calculate the bounce velocity using any of the following methods:

1. Use the second impact velocity of the sled, rather than the initial bounce velocity. Since this occurs long after the initial impact, any transients induced by the initial impact should have died out.

2. Use the video to follow the sled after impact and determine the bounce velocity digitally.

3. Use the time between the first and second impacts of the sled and calculate an effective bounce velocity consistent with this time interval.

4. Use the video to follow the sled after impact and determine the height to which the sled rises (the bounce height) and calculate a liftoff velocity consistent with this height.

We have examined these different methods of calculating the bounce velocity on a number of different drops. The second method is not, in general, practical. This is due to the fact that the bounce is typically not very high, and there is insufficient resolution on the video to get an accurate measurement of bounce velocity. On a typical high-speed video, the difference in bounce height over 5 msec might only measure 2 or 3 pixels. This provides only a very coarse measure of ΔV. As a consequence, we will focus our attention on the other three methods (second impact velocity, duration between bounces, and bounce height).

As an example of the variation in ΔV calculation from these different methods, consider the table below. It shows the value of ΔV calculated in different ways from a number of different drop tower tests. These include two different types of energy-absorbing seats tested at two different drop towers.

Table 1. Values of ΔV calculated using different methods for four different drop tower tests.

Drop ID	ΔV V_{max}	ΔV V_{2nd}	ΔV Δt	ΔV Height
CV-G	1.7 m/s	1.1 m/s	0.88 m/s	0.78 m/s
Driver-G	2.1 m/s	0.4 m/s	0.88 m/s	0.70 m/s
Shock-A1	1.7 m/s	0.8 m/s	0.73 m/s	0.75 m/s
Shock-A2	2.2 m/s	0.7 m/s	0.34 m/s	0.60 m/s

As already mentioned, the use of V_{max} for the bounce velocity cannot, in general, be justified in the face of experience showing that this value generally overshoots the effective value. For example, a bounce velocity of 2.1 m/s should make the sled rebound to a height of nearly 9”, whereas the sled typically rebounds less than 1.5”.

Similarly, the second impact velocity is unreliable as well. Even though the transients have generally died out by the time the sled impacts the second time, the fact is that the velocity trace is an integrated signal. As a consequence, any transients that occurred during impact are still present in the integrated velocity trace. This means that although the sled accelerometer can still provide useful data following the impact, the integrated signal probably should not be used at this point.

Considering the last two methods, they show values that are fairly close to each other and also fairly consistent across drops. This consistency is important. The bounce height of a given drop tower should not vary greatly from one drop to another, provided the drop height and impact programmers are similar.

However, the last value in the table under the Δt heading shows an anomaly associated with the duration calculation. This value of 0.34 m/s is much lower than the other values, which range from 0.7 to 0.9 m/s. There are several possible reasons for this, but one important reason has to do with the nature of the programmers and the impacted mass. When the sled initially strikes the bottom of the tower, the impact is moderated through the use of a programmer that sits between the two. This consists of a pliant material (rubber, plastic, wood) that adjusts the impact pulse into the desired shape and duration. Also, the bottom of the drop tower may not itself be rigid, but may consist of a heavy shock-mounted mass that reacts slowly to the impact from the sled. The initial impact can potentially deform, destroy, or dislocate the programmer, as well as moving the impacted mass at the bottom of the tower. As a consequence, the second impact may not correspond exactly to the initial impact – the sled may have to fall a little further to strike the displaced mass, or a little less far because the programmer is now out of alignment. As a consequence, there is potential for variation in the calculation of the bounce velocity using the time duration method.

The method using a video analysis of the bounce height of the drop tower has a lot to recommend it. First, in our experience it appears to be fairly consistent for a given set of drop conditions, which is what we expect for a drop tower. Second, it forces the analyst to conduct a detailed frame-by-frame examination of the tower in the moments immediately following impact. While this is necessary in order to determine the bounce height, it is also possible to notice features of the experiment that might not otherwise be obvious. For example, any potential anomalies in the event such as excessive wobble in the drop tower, or deflection of the sled.

More importantly, the bounce height method is physically reasonable at the limits of any given drop tower. As a consequence, the value of ΔV produced by this method cannot be far off from the actual effective value. As an example, consider the case of a perfect drop tower where the sled is very much heavier than the occupant and there is no friction, so that the movement of the occupant in the EA seat has virtually no effect on the dynamics of the sled following the impact. In this case, the sled will bounce to the natural height consistent with the bounce velocity, and the resulting ΔV will be consistent with the effective ΔV. Now consider the other extreme, where the sled is extremely light compared to the occupant. In this case, the motion of the ATD following impact will continue to push the sled downward so that the bounce height will be close to zero, as will the ΔV calculated from drop height, which again accurately represents the effect of the bounce velocity on the seat's EA mechanism.

In fact, the bounce height mechanism even accounts for the case where the tower has frictional losses that make the sled decelerate faster than it should during the bounce. For example, suppose that the guide rails in the drop tower start to wobble following the shock of the initial impact, and this wobbling leads to binding of the sled during the bounce. This additional force on the sled will reduce the bounce height at the same time that it reduces the effective force of the sled on the EA mechanism of the seat. This is true whether the force is accidental, as just described, or intentional, in the case of a braking force on the sled.

Finally, as the previous table shows, the bounce height method of calculating the bounce velocity is generally conservative, especially compared to the V_{max} method of integrating the accelerometer signal.

TESTING RECOMMENDATIONS

Accelerometers

Because mine blast testing specifies a ΔV to correlate with a specified blast load, the drop height and pulse width must be carefully controlled and monitored to achieve the required change in velocity. Accelerometers for drop testing must have a frequency response and range that allows for accurate measurement of the drop, impact, and bounce. They must be accurate at very low amplitudes (less than one G) and must have a static (DC) frequency response. This allows the signal to be integrated in order to calculate drop velocity based on an acceleration signal on drop tower floor/seat/etc.

The most common IEPE type accelerometers, with instrumentation industry names like Deltatron and ICP are not recommended for use in this type of testing. This is because they do not have a DC frequency response. While some of them do dip below 1 Hz in frequency response, they still will not yield accurate measurements at DC.

Charge amplifier accelerometers, while providing a DC frequency response, do not work well for this type of testing because the long distance that the accelerometer must travel causes DC offset changes in the signal due to changes in the cable position and other factors in the environment around the accelerometer. Typically these accelerometers are better suited for short-travel tests where the test specimen is not required to fall several feet.

Piezoresistive (PR) accelerometers work very well for this application. They have a DC response, very accurate output at all amplitudes, and are not impacted by long-travel measurements. While temperature has an effect on the DC offset of PR accelerometers, it changes very slowly when compared to the duration of the test, which allows any thermal shift in the output to be zeroed out of the data during post-processing.

Many types of PR accelerometers exist on the market, and some are much better suited to this type of testing than others. A risk when using PR accelerometers, especially in shock situations, is excitation of the accelerometer's own resonant frequency leading to spurious data. Accelerometer manufacturers have implemented a few solutions to address this. First, PR accelerometers have been manufactured that have a very small seismic mass and/or a stiff beam, driving the resonant frequency of the device above that of the object to which it is mounted. Second, some PR accelerometers have been "gas-damped". The gas damping acts as a mechanical filter, eliminating high frequency content to prevent the accelerometer from ringing, but effectively lowering the bandwidth of the accelerometer. Third, Sandia Labs has designed an accelerometer (built by Endevco) that has a mechanical filter built into packaging for the instrument. This, like the gas-damped accelerometer, prevents ringing by not allowing high-frequency components to be transmitted to the seismic mass in the first place. All three of the above solutions can effectively eliminate concerns with accelerometer resonance. At GDLS, both gas-damped and mechanically-filtered accelerometers that do not respond above 2 kHz have worked well.

Fixturing and Accelerometer Placement

The goal of measuring drop tower acceleration is to capture global movement of the sled, which simulates the hull in a blast event. Ideally, the drop tower sled will respond to the shock event exactly like the hull to which the intended seat will eventually be mounted. For this reason, the sled structure should be rigid enough that the shock input on the floor of the sled is transmitted efficiently to the seat mounting point. Once rigidity has been established (for example, by comparing the measured response at different locations on the structure), accelerometers can be mounted in the desired locations. It is preferable to mount the accelerometers that measure tower acceleration as close to the seat as possible, in order to measure the input as accurately as possible.

In addition to being rigid, the sled itself should be much heavier than the seat and occupant. This is the case in the event of an occupant in a real vehicle during a blast, and the tower should attempt to simulate this. By making the sled heavy, the effect of the seated occupant on the test is minimized, and the data will show the effect of the shock transmitted from the sled through the seat to the occupant, rather than the other way around.

A final note to the placement of accelerometers is that it is always preferable to use multiple accelerometers or other required instrumentation at the locations where data is most crucial. For instance, placing a second drop tower accelerometer or lumbar vertical accelerometer very close to the first decreases the risk of losing acceleration data during the event due to failure of the test article or damage to the accelerometer cable due to moving parts. Having a secondary measurement also allows for a sanity check – by looking at the two signals on a graph, they should lie very close to each other. If they do not, there may be reason for concern that at least one of them is not operating properly.

Pulse Programmers

In order to achieve the correct pulse shape, iterative testing must be done to find the proper material to adjust the shock input when the sled strikes the bottom of the tower. This cushioning material is referred to as a programmer. There are many possibilities where this is concerned, but to make a half-sine pulse at the correct impact velocity and pulse width, elastomer programmers, particularly polyurethane disks, have produced desirable results. Drop or shock tower manufacturers like MTS and Lansmont have used shaped polyurethane programmers for decades. These are usually round, with the thickness, hardness, and diameter adjusted to provide the pulse width, and the contacting surfaces shaped in a convex manner to for a half-sine pulse. The GDLS drop tower, for instance, uses two sets of three elastomer programmers. Each set is comprised of a six inch diameter disk, one inch thick, of polyurethane with a durometer of roughly eighty, and two convex contactors, six inches in diameter and one-half inch thick, with a durometer of ninety to one hundred. The figure below shows one set of elastomer programmers.

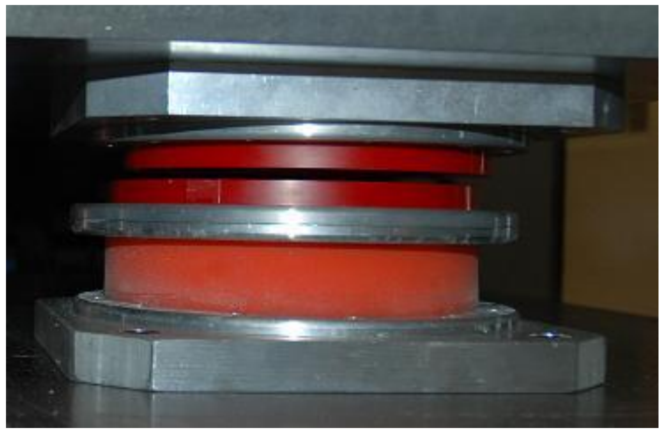

Figure 4. Elastomer programmer used for pulse shaping on the GDLS drop tower.

When selecting the appropriate elastomer programmers, it is important to recognize that softer materials of similar diameter and thickness, i.e. lower durometer polyurethane, will increase the pulse-width. Increasing the thickness or decreasing the diameter of the programmers will also increase the pulse-width. All of these factors must be considered, as well as the weight of the drop-tower sled and all of the attached test instrumentation, fixturing, survivability of the programmers, and test articles. Properly sized and selected elastomer programmers should yield very repeatable results for years.

The convex shape of the contacting programmers is extremely important. If two flat surfaces contact each other, the effect is similar to a belly flop into a pool. This inputs a much higher bandwidth impulse into the system, potentially exciting undesirable resonances in the structure. The programmers slow the tower down in a more controlled manner, effectively eliminating these resonances.

The method of specifying the pulse width is also important. One widely accepted method to measure a shock pulse width, which is also used by GDLS, is “projection”. To use this method, simply follow a straight line down the sides of the pulse to where the line crosses zero. This avoids confusion as to where the pulse begins or ends. Below is an illustration of this method of measuring the width of a smoothed pulse with a nearly triangular shape. Alternatively, the pulse width could be specified as full-width at half-maximum (FWHM). In any case, it should be defined and controlled in order to prevent ambiguity and variation in test results.

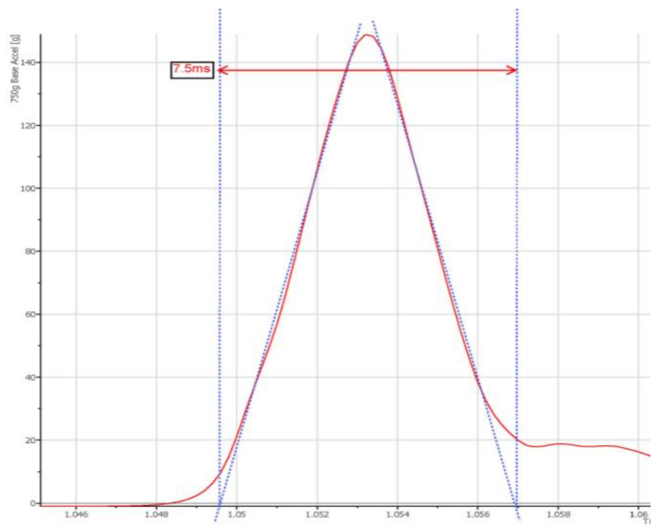

Figure 5. A measure of pulse wide for drop tower impulse testing.

Data Acquisition and Processing

First, as a starting point for setting the speed of the acquisition system, the sampling rate must be such that the alias-free bandwidth of the data is greater than the highest frequency at which filtering has been specified for the test. A good starting point is a sample rate at least double the required filter frequency. This means that if the accelerometer has a 2 kHz mechanical filter, the data must be acquired at a rate of no less than 4 kHz. This will most likely be adequate, but if there is a large quantity of high frequency content in the signal the sampling rate should be increased.

Another key consideration in data acquisition is the time of pre-trigger acquisition. Typically, the impact event is a fraction of a second, yet the drop tower may be falling for a half of a second or more. Recording a full second of data before the drop and after the impact will ensure that the entire event is captured. This is important for several reasons, including:

- Recording the entire drop allows integration of the acceleration signal to produce a velocity plot. This should show a negative 1-G fall, a peak velocity at impact consistent with the drop height, a second fall at negative 1-G, and allow for other consistency checks on the data.
- Having many samples before the release of the tower (while no acceleration is occurring) allows this block of data to be averaged and subtracted from the signal, which mathematically nulls any offsets in the accelerometers and load cells. Subtracting out the offset in this manner assists in integration of the signals to produce an accurate velocity.
- Collecting data following the event allows for further consistency checks. For example, the integrated velocity should return to zero. Any permanent offset is an indication of problems.

Digital filtering may be required for each test, but since our accelerometers are designed to mechanically filter out the high-frequency input, the signal should look very similar after filtering to what it looked like originally. Note that, for DRI and velocity integration calculations, raw data should not yield significantly different results than filtered data. For peak acceleration and force measurements, filtering will usually decrease peak values slightly. However, unfiltered data should be preserved in case there is any question that the filtering process significantly changed the results. If this is in fact the case, it is evidence of a questionable experiment (i.e., badly mounted accelerometers, lack of programmers, insufficiently rigid sled).

IMPLICATIONS AND RECOMMENDATIONS

One of the important implications of this work is that a number of drop tower tests may have over-reported the protective capability of the EA seats. Consider, for example, a test which quotes a ΔV of 5.6 m/sec due to an impact velocity of 3.8 m/sec and a bounce velocity of 1.8 m/sec calculated using the V_{max} approach. If the actual bounce velocity is only, say, 0.7 m/sec (equivalent to a bounce height of about 1”), the test was actually conducted with a ΔV of about 4.5 m/sec. By examining equation (2), it’s clear that even a rigid bench seat could potentially provide a survivable DRI at this load. As a consequence, passing such a test could lead to an overestimation of the actual benefit of the EA seat in protecting occupants from blast injuries.

This potential for misleading performance estimates points out the need for a standard in drop tower testing to simulate blast-resistant seating. This standard should address some of the issues raised in this paper, including drop tower configuration, mass, instrumentation, programmers, strapping of the ATDs to the seat, and procedures for data analysis. The main issue raised in this paper has to do with the calculation of ΔV. However, there are other issues associated with testing. For example, in a drop tower the ATD is in a state of zero-G just prior to impact, whereas in an actual vehicle his weight holds him down to the seat. Also, foot position should be controlled so as to ensure that the posture of the ATD in the drop tower reflects the actual seating posture in the vehicle. Normally, the feet should be taped down to prevent them from lifting off the floor during the drop and subsequently slamming down at impact. Again, a standard for drop tower testing that addresses these issues would remove much of the ambiguity surrounding testing and make possible more accurate comparisons of data from site to site.

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