A SUMMARY OF THE WORK OF THE SAE ATD CHEST DEFLECTION TASK TEAM

John B. Athey
Joseph S. Balser
General Motors Corporation
United States of America
Paper Number 98-S9-W-27

ABSTRACT

This paper focuses on the work of the SAE ATD Chest Deflection Task Team, chaired by Mr. Joseph Balser. Data are presented, and discussed, on the most promising methods that were tried, as well as an examination of these methods.

An abbreviated version of their mission statement summarizes their work, "The ATD (Anthropomorphic Test Dummy) Chest Deflection Task Team will focus on the development and validation of a new transducer or transducers that will accurately measure ATD rib deflections and velocities in three axes when the ATD is exposed to belt and/or air bag testing. The first phase of work will be to improve and commonize deflection transducer hardware being used today. Phase two will be to develop and validate an advanced ATD chest deflection transducer that will effectively produce valid measurements at up to 18 meters per second at SAE filter class 600."

INTRODUCTION

The first meeting of the SAE ATD Chest Deflection Task Team, chaired by Mr. Joseph Balser, took place on September 13, 1995. This task team continued the work of the USCAR OSRP ATD Chest Deflection Task Team which first met on May 9, 1995, which was also chaired by Mr. Balser. The primary work of the SAE task team is not finished. The goal of this paper is to present the work that has been accomplished as of this writing, and to offer advice to users of ATD's as to how the work that this task team has accomplished can best be put to use. A secondary goal is to give some general direction that others can take in developing methods of making this very difficult measurement within the crash test environment.

DESIGN GOALS

At the first meeting of this task team chairman Balser had the task team define the goals of any new chest deflection transducers that they would be developing for use in ATD's. The task team used the term goals rather than requirements since some of the desired traits may be unattainable, or compromises may be necessary between two or more goals. The design goals that were agreed on for any transducers by the task team are listed below:

1. Accurately measure or compute rib deflections and velocities in the range of 0 to 18 meters per second, at SAE CFC 600, in the Hybrid-III 5th percentile ATD, with the plan to use the same basic device in all adult Hybrid-III ATD's.
2. Should be small, allowing multiple rib deflection transducers to be installed in the same ATD.
3. Must be easy to use and be compatible with standard data systems of either the onboard or off-board versions if transducers are to be used in high production testing facilities.
4. Ease and accuracy of calibration must be a major consideration.
5. Cost per channel must be considered.
6. Ease of installation and test setup must be highly considered.
7. Durability is a major consideration.

Most of the design goals were based on the combined experience of the task team. The exception to this was the first item which stipulates that rib velocities of up to 18 m/s must be able to be measured or calculated at SAE CFC 600. Dr. Rouhana suggested this number to the task team. He stated that he has seen driver air bags with membrane velocities of 100 miles per hour. Under certain conditions this can translate to a sternum velocity of about 8 m/s. Since passenger bags can have membrane velocities of approximately 200 miles per hour the task team agreed that it would be reasonable to infer a potential sternum velocity of 16 m/s with such an air bag. The task team agreed with Dr. Rouhana's recommendation. The additional 2 m/s (which yielded the 18 m/s value) was added to allow for some excess capacity.

MEASURING CHEST DEFLECTION

Traditional Methods of Measurement

Generally, frontal chest deflection measurements have been made using a rotary potentiometer. When rib deflection has been measured on side impact ATD's, a linear potentiometer or string potentiometer has typically been used. The problems of making the measurement with potentiometers are illustrated in Figures 1 and 2.

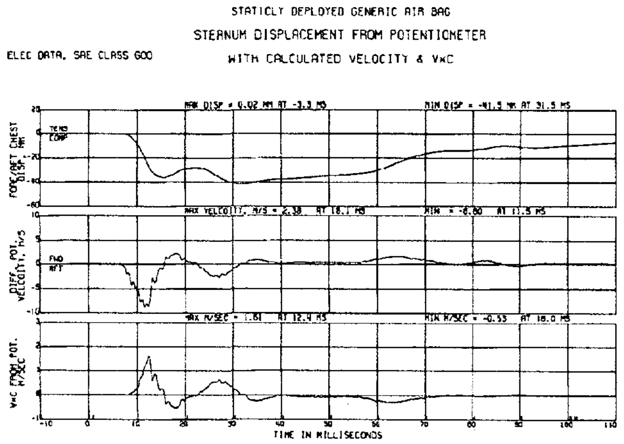

Figure 1. Data from a rotary potentiometer as used on a Hybrid III 5th percentile female.

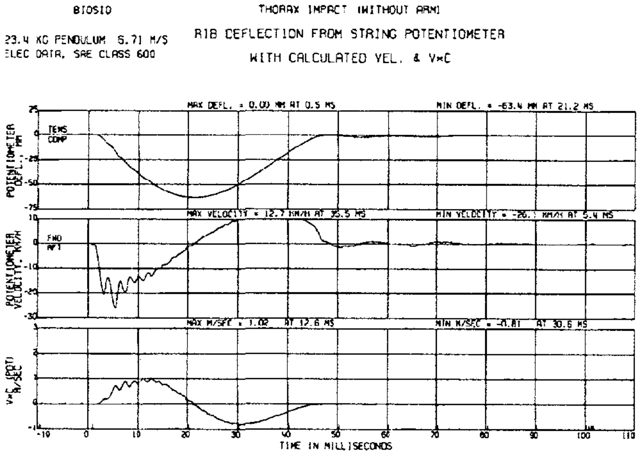

Figure 2. Data from a string potentiometer as used on a BIOSID.

Figure 1 shows three data traces, all from a Hybrid III 5th percentile female chest deflection transducer utilizing a rotary potentiometer. All three data traces are filtered at SAE CFC 600. The top trace is the chest deflection measurement. The second trace is the relative sternum velocity which was calculated by differentiating the deflection. The bottom trace is the Viscous Injury Criteria which basically is the deflection (top trace) multiplied by the velocity (middle trace) divided by a constant (this will be covered in detail later in this paper). As can be seen in all but the deflection (top) trace, there is an excessive amount of noise in the data.

The data from linear potentiometers generally display a similar type of noise, and they are frequently bothered by the vibrations which are in the crash test environment. Their data typically looks similar to that of the rotary potentiometer's data as described in the previous paragraph.

String potentiometers are often used to measure lateral rib deflection in side impact ATD's. String potentiometers have the problem of not being able to respond quickly enough to rapid increases in velocity, although they are not as sensitive to vibration. A sample of the data, at SAE CFC 600, from a string potentiometer is shown in Figure 2. Again, the top trace is the deflection, the second trace is the velocity (obtained by differentiating the deflection), and the bottom trace is the V*C data. The oscillations that can be seen in the velocity and V*C data are caused by small amounts of slack occurring in the string during periods of high rib acceleration when the potentiometer can not keep up with the rapid change in velocity.

The noise seen on these velocity traces could be smoothed out by filtering with a SAE CFC 60 filter. However, this filtering would also attenuate the peak velocity and distort the wave shape which are undesirable results. With the desire to produce meaningful velocity data at SAE CFC 600 it became necessary to find a method of making this measurement that would produce less noise.

Other Possible Methods of Measuring Chest Deflection

During the work of this task team, a number of different ideas and methods were mentioned and in some cases explored and tried. If desired, the reader may obtain information on these ideas by reviewing the minutes of the task team's work.

VISCOUS INJURY CRITERIA

In its simplest terms, for frontal ATD's, Viscous Injury Criteria (V*C) is determined by multiplying the sternum velocity by the sternum deflection. This product is then multiplied by the constant 1.3 and divided by the equivalent human chest depth. For side impact ATD's, the V*C is determined by multiplying the rib velocity by the rib deflection. This product is then divided by one-half of the equivalent thorax width.

Previously V*C was calculated with data filtered at 60 Hz (SAE CFC 60). When it was determined that air bags generate high thoracic velocities, it became necessary to make V*C calculations at 600 Hz (SAE CFC 600). Generally, in order to minimize the risk of thoracic injury, a maximum V*C value of up to 1.0 is allowed. As will be shown, at SAE CFC 600, there are significant difficulties to be overcome before meaningful data can be provided.

A Basic Method of Calculating Viscous Injury Criteria

This method utilizes only the chest deflection potentiometer data filtered at CFC 600 and is typical of methods that are widely used independent of the ATD type. The constant used in the following V*C calculation is specific to the Hybrid III 50th percentile ATD.

1. Filter the chest deflection data at SAE CFC 600.
2. Differentiate the data (this yields velocity). Convert to meters per second (m/s) if necessary.
3. If necessary, convert the filtered chest deflection data, from step 1, to meters (m).
4. Multiply the velocity (m/s) by the deflection (m).
5. Multiply this product by 1.3 and divide by the constant 0.229 meters (the chest depth). This result is the V*C data. Only the positive peak value is typically of interest.

Justification of SAE CFC 600 V*C Data

While it is beyond the scope of this paper to fully explain the justification of increasing the channel filter class to 600 for Viscous Injury Criteria data it can be seen from the data in Figures 3, 4 & 5 that there is a significant change in the amplitude, as well as the wave shape, of the data at 60, 180 and 600 Hz. The plots in Figure 3 are all of V*C data from a standard rotary potentiometer in a Hybrid III 5th percentile female; they are at SAE CFC 600, 180 & 60 from top to bottom.

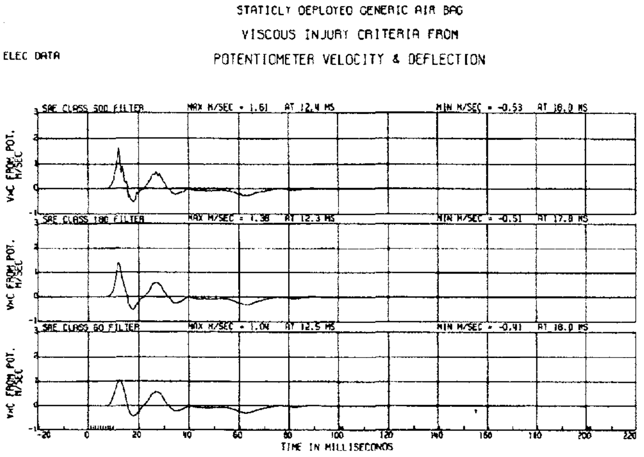

Figure 3. Viscous Injury Criteria data from a rotary potentiometer that has been filtered at SAE CFC 600, 180 & 60.

The ATD used on this test also had upper, mid and lower sternum, as well as corresponding upper, mid and lower spine accelerometers installed in the longitudinal axis. The three traces in Figure 4 are data from the upper sternum and upper spine accelerometers which were used to measure V*C. The use of accelerometers for measuring V*C will be covered later in this paper. The accelerometer data are used here to illustrate that even when V*C data are produced without noise, there is still a high enough frequency content to justify using SAE CFC 600 filters for the Viscous Injury Criteria data. Although on this test there is little change in the data at SAE CFC 180 and 600, other tests have demonstrated that larger differences exist as the sternum velocity increases -- such as in out of position air bag testing. Also, the three traces in Figure 5 show that the relative sternum velocity data from these accelerometers, which are used to produce the V*C data, show a significant difference in wave shape at SAE CFC 180 and 600. This indicates that there is a faster rise time in the velocity data than the SAE CFC 180 filter can capture.

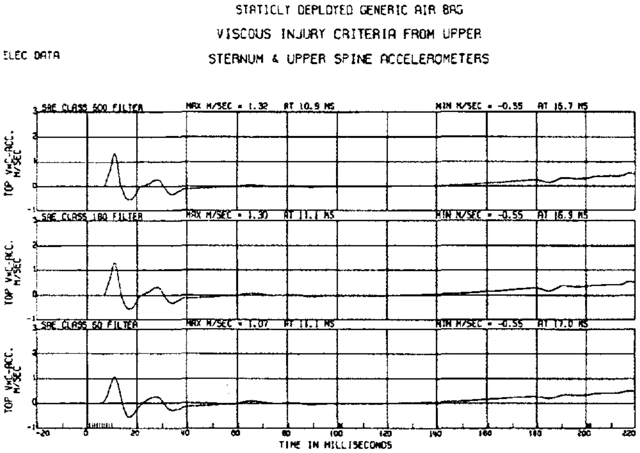

Figure 4. Viscous Injury Criteria data as calculated from integrated accelerometer data at SAE CFC 600, 180 & 60.

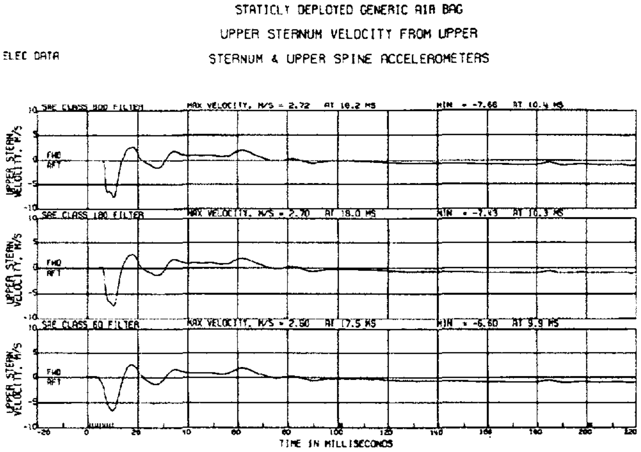

Figure 5. Relative sternum velocity as calculated from the first integral of the difference in sternum and spine acceleration at SAE CFC 600, 180 & 60.

RECOMMENDED METHODS OF MEASURING VISCOUS INJURY CRITERIA

This paper will focus on the most promising methods that have been evaluated up this point. Many of the methods that were not pursued further may be potentially workable, but the task team had limited resources and funding available so they focused their resources in the areas that they had expertise in and that they believed showed the most promise.

Dr. Steven W. Rouhana is writing and presenting a paper for this ESV Conference titled, "A High Speed Sensor for Measuring Chest Deflection in Crash Test Dummies." Since his paper completely describes a sensor that he and his team developed, his work will not be explored in this paper. All readers of this paper are encouraged to read his paper (paper number 98-S9-O-15).

The Standard Potentiometer Method

This method has been used in the Hybrid III 50th percentile male since the ATD was introduced in 1975. A rotary potentiometer is mounted on a bracket to the upper lumbar area of the ATD, and a shaft connects the potentiometer to the sternum. This transducer and hardware are shown in drawing #78051-317 in the Hybrid III drawing package. The task team explored numerous ways of minimizing the noise in the data that is typically inherent with this method. The suggested enhancements are listed below:

1. Eliminating excessive clearance and binding between the ball and slider of the chest deflection transducer assembly.
2. Using a Hall Effect Potentiometer instead of a resistive element potentiometer.
3. Using sealed instrumentation grade bearings.
4. Eliminating stress on the bearings.

Eliminating Excessive Clearance and Binding - Although the noise generated by the mechanical linkage from the potentiometer to the sternum is not repeatable it was shown that the level of noise can be decreased by making certain that there is a good fit between the slider and the ball. It is not uncommon for the ball to bind in certain areas of its travel in the slider or for the clearance between the ball and slider to be sufficient in some areas as to allow actual rattling.

The easiest method for checking the fit of these items is to hold the slider in one hand and the transducer arm and ball assembly in the other hand while the ball is within the track of the slider. By moving the ball slowly through the slider one can feel any areas where there is excessive friction or excessive clearance. Generally, if there is excessive friction or clearance it is best to replace the slider with a new part, although the ball should also be inspected for any flat spots, burrs or foreign materials on its surface. In some instances, such as a nick on the slider, it may be possible to locate and correct the problem when there is excessive friction on a portion of its travel.

Hall Effect Potentiometers - In some instances data could be shown where there was less noise on the velocity data when a Hall Effect Potentiometer was used than with a resistive potentiometer. However, this was not always true. It appears that when the data were improved by replacing the resistive potentiometer with a Hall Effect Potentiometer that the resistive potentiometer had exceeded its useful life. Although the deflection data from it were still acceptable, the differentiated deflection data (velocity) had become noisy.

One of the primary advantages of using Hall Effect Potentiometers is that there are no wiper contacts that can lift off the resistive element or become oxidized causing intermittent contact. A new high quality resistive potentiometer, with an infinite resolution resistive element will generally give data comparable to that of Hall Effect Potentiometers. Eventually the data from a resistive element potentiometer will normally degrade and become more noisy over time.

Instrumentation Grade Sealed Bearings - The standard bearings for the chest deflection transducer assembly are neither sealed nor of instrumentation grade. One of the task team members had considerable success with improving the data by replacing the standard bearings with high quality instrumentation grade sealed bearings. The task team member explained that over a period of time particulate matter can accumulate on the bearing surfaces which creates enough friction where the roughness can be felt when the bearing is turned by hand. This will show up as significant spikes in velocity data (differentiated deflection). By using sealed instrumentation grade bearings the data will be improved and also should not deteriorate since particulate matter will not be able to get into the bearing to damage the machined surfaces. The reason for using instrumentation grade bearings is due to the tighter tolerances that they are machined to which eliminates clearances than may lead to mechanical noise and data noise.

Eliminating Bearing Stress - It was also mentioned that the data had been improved in some instances by mounting the bearings within a custom made transducer bracket with RTV adhesive/sealant. This would eliminate any stresses placed on the bearing by manufacturing tolerances causing the bearings to not be accurately aligned. It was believed that this may no longer be necessary since manufacturing methods have been improved over the last two decades when this ATD was initially designed. However, since the transducer bracket is not typically replaced this is a significant issue to be aware of when searching for the cause of noise in the data.

Summarizing the Potentiometer Method - One of the main advantages of this method is that the technology has been in place for decades without significant change and in general it works quite well. If 60 Hz data was adequate, there would be no need to improve on this method. By utilizing the above steps as a guide, significant steps can be made in improving the data provided by the standard hardware at SAE CFC 600.

The Accelerometer Method

This method uses the data from accelerometers to calculate both the velocity and deflection. Depending on the test conditions, this method can work anywhere from extremely well to very poorly. Some of the issues can be improved, but others appear to be permanent issues that make this method less than ideal for many situations. However, there are enough advantages to this method to make it a valuable tool for the additional information that it provides.

The primary advantage of the accelerometer method is that the data it produces are extremely smooth and free of noise. Samples of these data (at SAE CFC 600) were shown previously in Figures 4 and 5. The disadvantage of this method is that the deflection (second integral of the acceleration) drifts further and further from the zero level as the test progresses from time zero. This can also be seen in the velocity (first integral of the acceleration) data, although to a much lesser extent. The drifting of the deflection and velocity data will also cause drifting of the V*C data when it is calculated using this method.

The traces shown in Figure 6 demonstrate this problem toward the right side of the plot; as the test progresses the traces are moving further from zero rather than approaching zero which is typically what is really happening. The data shown in Figures 4, 5 & 6 are from an out-of-position test with a staticly deployed airbag. Sled testing will usually produce data that has this problem to a greater extent, occasionally the drifting problem in the second interval (relative deflection) of the accelerometer data is so severe that the real peak sternum deflection can not be located or determined from it. This is likely only when the maximum deflection is very small or when the peak deflection occurs more than approximately 50 ms after time zero (this is typically the case on standard sled & barrier tests -- not out-of-position tests).

There are many factors that contribute to the drifting problem that cannot be easily controlled. Frequently either the ATD undergoes rotation during the test or the sternum is deflected inward at an angle. Either of these will cause the accelerometer to move differently than what its single channel of data can indicate. To overcome this would require numerous additional data channels and complex processing. Some other causes of drifting are the hysteresis of the accelerometer beam and the zero level noise integration. Although the problem of the deflection and, to a lesser extent, the velocity data drifting cannot be readily eliminated, there are steps that can lessen the drifting. The following steps will help to minimize this problem:

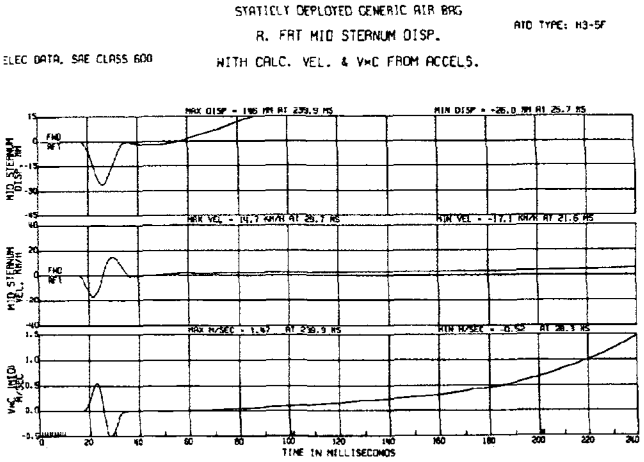

Figure 6. Mid Sternum deflection, velocity and V*C all calculated using accelerometers.

1. Use a full scale value that is not drastically higher than the maximum acceleration that is likely to be observed when the data system (for the accelerometers) is being calibrated. This will increase the resolution of the data and help minimize the drifting. This step is widely recognized as good laboratory practice.
2. Do not start the integration process of the accelerometer data until the chest potentiometer begins showing chest deflection. This will cut down on the total time that the accelerometer's data need to be integrated which will lessen the drifting problem. This can be especially useful on sled or full scale testing; it will be less helpful on out-of-position testing.
3. If possible, reset the integrals to zero at known points. At some point while the data is still being collected the sternum will have returned to its initial relative velocity of zero. For example, the potentiometer data shown in Figure 7 (2nd trace from the top) indicate that the ribs settled to a final zero velocity by approximately 100 milliseconds after time zero. This can be deduced by noting that at this point the deflection is no longer changing; if the deflection is

not changing, the relative sternum velocity is zero. The time that the relative sternum velocity returns to zero can also be determined from the differentiated potentiometer deflection. If the processing software allows the integration to be set to zero at both the beginning and ending points (using 100 milliseconds as the ending point in this example) the accuracy of the data in between these areas can be dramatically improved. This would cause the other data shown in Figure 7 to not drift off of the plot as they do now.

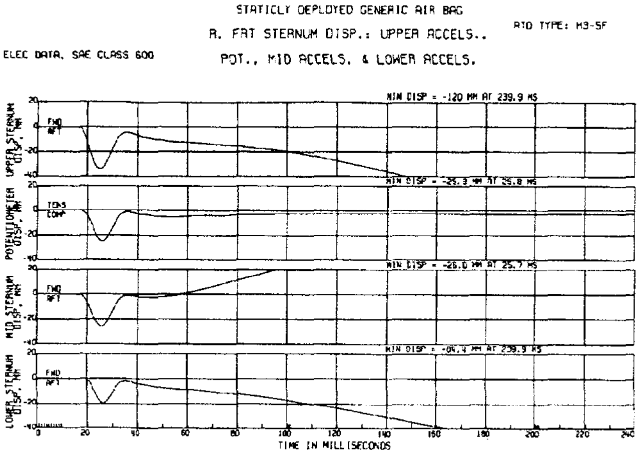

Figure 7. Sternum deflection from upper accelerometers, potentiometer, mid and lower accelerometers.

Summarizing the Accelerometer Method - Due to the inherent drifting that exists in this method, it is recommended that this method be used to supplement (not replace) the deflection data that is available from the potentiometer. At the time of this writing, the Hybrid III 5th percentile, 3 & 6-year-old child ATD's come with the accelerometer mounts necessary to install accelerometers to record this information. The user needs to instrument the ATD, record and process the data accordingly. The user does need to be aware of the drifting problems that occur and examine the data carefully. This method is capable of providing far more information than is available from only the potentiometer; most notably the relative velocity, deflection and the V*C of the top and bottom of the sternum.

The Combination Method

This method uses the velocity as calculated from the first integral of the acceleration and the deflection as measured by the potentiometer for calculating V*C. The V*C data from this method tend not to drift away significantly from zero due to the deflection from the potentiometer being used in the calculation. Any drifting that does occur will be caused by the integrated accelerometer velocity, and this is not usually significant enough to be troublesome. It is highly recommended that this method be used for side impact ATD's provided the ATD is capable of measuring the lateral acceleration of each rib and the lateral spine acceleration at each point opposite the rib. This method is also recommended for frontal ATD's, but only for the mid sternum -- not the upper and lower sternum.

The problem with using this method for the upper and lower sternum of frontal ATD's is that the deflection is not being measured from the same location as the velocity. This can cause misleading V*C information. Figure 8 shows the V*C calculated at SAE CFC 600 using the accelerometers only (traces 1, 3 & 4), and the potentiometer only (trace 2). Figure 9 shows the V*C calculated using the combination method. Traces 1, 3 & 4 were calculated using the upper, middle and lower sternum relative acceleration respectively for velocity and the potentiometer for deflection. The 2nd trace was calculated using the average of the upper and mid sternum relative acceleration with the potentiometer used for deflection. The average of these two locations was used because this is equivalent to the approximate location of the point that the standard chest deflection transducer measures when the ribs are compressed significantly. As the data demonstrate the V*C, using the combination method, disagrees substantially with the accelerometer data in this instance. The reason for this can be seen by looking carefully at the data in Figures 10 & 11. Figure 10 shows the relative sternum deflection as calculated by the sternum and spine accelerometers (traces 1, 3 & 4), as well as the sternum deflection measured by the potentiometer (2nd trace). Figure 11 shows the relative sternum velocity as calculated from the sternum and spine accelerometer data (traces 1, 3 & 4), and the sternum velocity as calculated by the potentiometer data (2nd trace). As can be seen from Figure 10, the upper sternum compresses to a greater magnitude, and it reaches its peak deflection sooner than the lower sternum. As can be seen from Figure 11, the upper sternum compresses with a higher relative velocity than the lower sternum, and it reaches its peak velocity sooner than the lower sternum.

The reason the data in Figures 8 & 9 are different can be seen by looking carefully at the data in Figures 10 & 11. For the combination method, the relative sternum deflection data of the potentiometer (2nd trace from the top in Figure 10) is multiplied by the relative sternum velocity data (Figure 11) to yield the V*C data as shown in Figure 9 (after multiplying by a constant). The peak velocity and its time for the upper, mid and lower relative sternum velocity are shown in Table 1. The relative sternum deflection (from the potentiometer) is multiplied for the combination method with the relative sternum velocity (from integrated acceleration) for the upper, mid and lower sternum. The purpose of including the peak values and times as listed in Table 1 is to clarify what is happening. The same deflection data is used for each sternum location in the combination method. The time of the peak deflection in relation to the time of peak velocity of each sternum location that it is multiplied with needs to be emphasized as an indication of how the different sternum locations are moving in relation to each other at different times.

Table 1.

Peak Velocities & times for Figure 10 (traces 1, 3 & 4)

Location	Peak Relative Velocity	Time of Peak Vel.
Upper Sternum	23.5 km per hour	20.6 milliseconds
Mid Sternum	17.1 km per hour	21.6 milliseconds
Lower Sternum	15.5 km per hour	23.2 milliseconds

The peak sternum deflection was 25.3 millimeters at 25.8 milliseconds as measured by the potentiometer. As we move down the sternum the time of the peak velocity approaches the time of peak deflection (as measured by the potentiometer), this causes the resulting V*C number to be higher. The peak velocity of the lower sternum took place at 23.2 ms. This is only 2.6 ms before the peak deflection. As can be seen from the deflection trace (Figure 10, second trace from the top), the deflection is approximately 20 mm at this time (23.2 ms). The upper sternum reaches its peak velocity of 23.5 km per hour at 20.6 ms. This is 5.2 ms before the peak deflection. When the upper sternum is at its peak velocity the deflection that it is being multiplied by is less than 10 mm. For this test, the combination method caused the V*C to be low for the upper sternum and high for the lower sternum. This is shown by the data in Figure 9 (combination method) as compared to the data in Figure 8 (traces 1, 3 & 4 calculated using the accelerometer method; trace 2 calculated using the potentiometer method).

As has been shown, the combination method caused the V*C to increase as we went from the top of the sternum to the bottom of the sternum. The potentiometer makes its deflection measurement near the center of the sternum. The measuring point rises as the ribs are compressed, and the measuring point will also change if the rib cage is forced up or down by the restraint system. The upward and downward motion of the rib cage is limited in the latest version of the Hybrid III 5th, 3 and 6-year-old ATD's, but can still occur to a limited extent. Each measured location on the sternum reached its maximum velocity prior to the time that the same location reached its maximum deflection (this is always the case since at maximum relative deflection the relative velocity is zero). The higher portions of the sternum reached each of their peak deflections and velocities before the lower portions (this can vary with different test conditions). These issues will cause erroneous V*C calculations to be produced when the combination method is used for frontal ATD's if it is used at all sternum locations (top, middle and bottom). When the lower sternum relative velocity

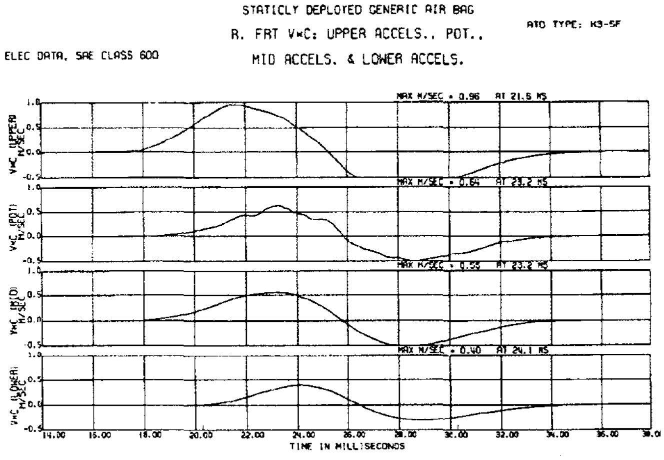

Figure 8. V*C from upper accelerometers, potentiometer, mid & lower accelerometers.

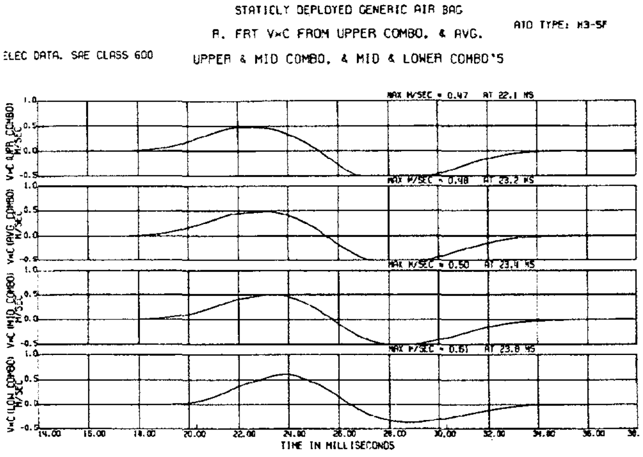

Figure 9. V*C from upper sternum combination method, average upper & mid sternum combination method, mid and lower sternum combination method.

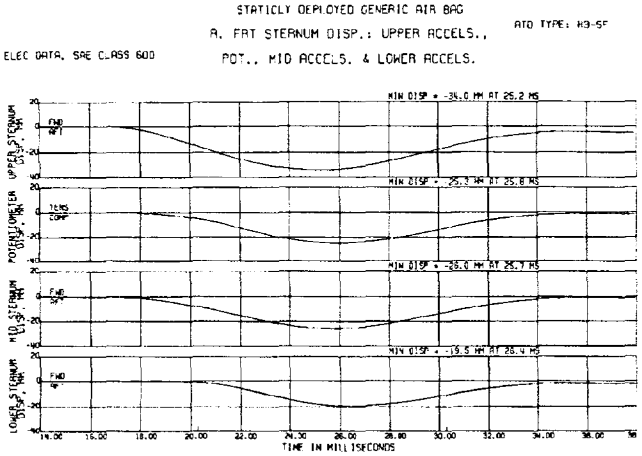

Figure 10. Relative sternum deflection from the upper accelerometers, potentiometer, mid & lower accelerometers.

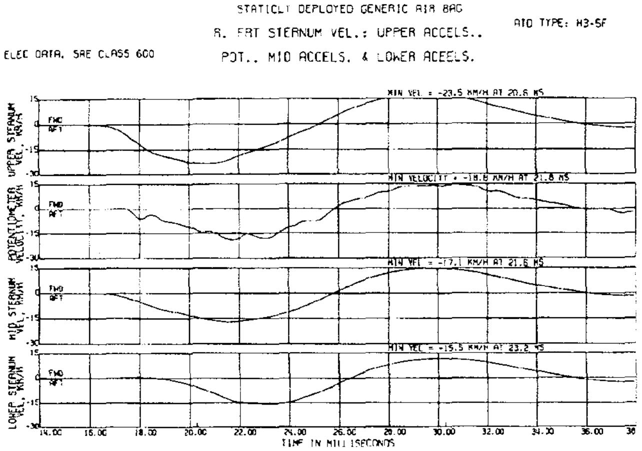

Figure 11. Relative sternum velocity from upper accelerometers, potentiometer, mid & lower accelerometers.

was multiplied by the potentiometer deflection the resulting V*C is higher because the peak velocity (even though it is lower) took place later in time, at which point the deflection is higher -- the end result is that the lower sternum V*C is shown to be incorrectly higher when calculated by the combination method on this test.

However, if the combination method is used on the mid sternum location only, the results obtained are comparable to the V*C calculation from the potentiometer if one visually averages out the noise of the potentiometer's data at SAE CFC 600. This can be seen by comparing the third trace of Figure 9 (V*C Mid Combo) with the second trace of Figure 8 (V*C Pot). The potentiometer's data is higher than it should be because of the fairly high frequency noise content in its data (note that the time base on this plot is stretched out to 2 milliseconds per division). The combination method provides reasonably accurate data only for the center portion of the sternum; it does not provide useful data for the top or bottom of the sternum. For ATD's without the mid sternum accelerometer, the combination method can be used by first averaging the upper and lower sternum acceleration, and subtracting the average of the upper and lower spine acceleration to determine the relative mid sternum acceleration. The relative mid sternum acceleration can then be integrated to obtain the relative mid sternum velocity.

It needs to be acknowledged that there is a ten percent difference between the V*C result from the combination method (0.50) and the result from the accelerometer method (0.55). Much of the reason that the V*C number from the combination method is lower is from the phase shift as discussed previously in this section. This will cause differences because the potentiometer does not measure the sternum deflection at the same point on the sternum though out the test.

When drifting of the data are excessive the data provided by this method can be improved by utilizing the same three items methods mentioned in the Accelerometer Method section.

<u>Summarizing the Combination Method</u> - The combination method is not recommended for all sternum locations for frontal ATD's because of the erroneous V*C data that it produces. This is caused by the deflection (from the potentiometer) being measured at a different location than the velocity (calculated by integrating the accelerometer data). For frontal ATD's it is recommended that the combination method be used to determine the mid-sternum V*C only. The results from this should be comparable to the V*C determined from the potentiometer if the noise on the potentiometer's data is visually averaged. It should also be comparable to the mid sternum data from the accelerometer method (in this test there was a 10% difference).

The combination method is being recommended as the preferred method for side impact ATD's provided that the relative rib acceleration can be determined. On side impact ATD's, determining the relative rib acceleration requires two lateral accelerometers per rib. One accelerometer to measure lateral rib acceleration, and one accelerometer to measure the spine acceleration at a point opposite of the rib accelerometer. The relative rib acceleration is determined by subtracting the spine acceleration from the rib acceleration. The combination method works well for side impact ATD's because, unlike the frontal ATD's, the accelerometer and the potentiometer are both taking their data from virtually the same location.

CONSTANTS USED FOR CALCULATING V*C

The following tables (2 & 3) show the constants that were mentioned in the previous sections for calculating V*C. The constants have the unit of "meters" in the denominator with the numerator having no unit. Since this is confusing it is left out of the "constant" column. For frontal ATD's the constant is obtained by dividing 1.3 by the corresponding human percentile chest depth. For side impact ATD's the constant is obtained by dividing 1.0 by 1/2 of the corresponding human percentile thorax width. Most people typically do not include the units (meter per second) when discussing V*C data but just mention the peak positive value reached without units.

Table 2.

V*C Calculation Constants for Frontal ATD's

ATD Type	Human Chest Depth	Constant
Hybrid III 3-year-old	0.122 meters	10.656
Hybrid III 6-year-old	0.143 meters	9.091
Hybrid III 5th percentile	0.187 meters	6.952
Hybrid III 50th percentile	0.229 meters	5.677
Hybrid III 95th percentile	0.254 meters	5.118

Table 3.

V*C Calculation Constants for Side Impact ATD's

Side Impact ATD Type	1/2 Chest Width	Constant
SID-IIs (5th percentile)	0.138 meters	7.246
BIOSID (50th percentile)	0.175 meters	5.714
EUROSID-1 (50th percentile)	0.140 meters	7.143

RECOMMENDATIONS

This paper has discussed, in detail, three methods. The recommended methods are shown in Table 4 for making the velocity and deflection measurements and in Table 5 for the V*C measurements.

Table 4.

Recommended Measurement Methods

Measurement	ATD Type	Method
Deflection	All	Potentiometer
Deflection	Frontal*	2nd Integral of Accel.
Velocity	Frontal**	Differentiated Pot.
Velocity	All	1st Integral of Accel.

* It is recommended that this deflection measurement be made on frontal ATD's in order to provide additional measurement locations (upper, mid & lower sternum), to the single deflection measurement made from the potentiometer.

** It is recommended that this velocity measurement be made on frontal ATD's to use as a supplement to the velocity measurements made from the accelerometers.

Table 5.

Recommended V*C Measurement Methods

ATD Type	Method
Frontal	Potentiometer *
Frontal	Accelerometer *
Frontal	Combination *
Side Impact	Combination

* It is recommended that all three methods be used on frontal ATD's so that they can be used as a supplement to each other as described previously. In some instances the accelerometer method may drift too much on some sled and barrier test to be of significant value. In these instances, the combination and potentiometer method must be relied on. The accelerometer method is of most use for out-of-position testing.

The Potentiometer Method

This is the oldest method. It is recommended that the data from this method always be recorded for the deflection data and differentiated to provide velocity data even though it is likely to be somewhat noisy. By providing this data there is more information to check either the accelerometer or the combination method for their accuracy. As has been mentioned earlier in this paper, even when there is excessive noise in the data, one can usually read through the noise to obtain a realistic approximation of the true velocity value. The deflection data that it gives is accurate and doesn't drift and is seldom noisy. The velocity data that this method provides is noisy, but does not drift. This makes it useful for correctly interpreting the data provided from the other methods.

Recommended Processing Procedure for the Potentiometer Method - Since there are so many possibilities of the order that many of the processing steps can be performed in while still meeting the requirements of J211, it was believed advantageous to specify one method of processing so that all people involved would be handling the data the same way. The suggested method is outlined below:

1. Filter the chest deflection data at SAE CFC 600. The units should be in millimeters.
2. Differentiate the filtered chest deflection to get the sternum velocity. The velocity should have the units of meters per second.
3. Multiply the chest deflection by .001 to convert the deflection from millimeters to meters.
4. Multiply the sternum velocity by the deflection. The result will be data that have meters squared per second as the unit.
5. Obtain the final V*C result by multiplying this data by the appropriate constant for the ATD type. The constant is the number 1.3 (1.0 for side impact ATD's) divided by the depth of the chest of the corresponding percentile human (or 1/2 of the human thorax width for side impact ATD's) measured in meters. This constant has meters as its unit in the denominator. After multiplying the constant and the result in step 4 you have the V*C (Viscous Injury Criteria) values with meters per second as the unit. Only the positive peak value is typically of interest.

This method of processing the data meets all of the requirements of J211; most notably not filtering digitally more than once, and filtering before any nonlinear operations.

The Accelerometer Method

This method is recommended for frontal ATD's, and is especially useful for out-of-position testing. The user must use caution when examining the data. The data from the accelerometers will not usually be valid for the entire duration of the test, but will typically be valid (with only a small error) through the time of peak deflection. The data should be compared to the potentiometer's data to confirm that it made sense and that it compliments rather than contradicts the potentiometer's data.

Recommended Processing Procedure for the Accelerometer Method -
Since there are so many possibilities of the order that many of the processing steps can be performed in while still meeting the requirements of J211, it was believed advantageous to specify one method of processing so that all people involved would be handling the data the same way. The suggested method is outlined below:

1. Subtract the spine acceleration from the sternum acceleration. This gives the acceleration of the sternum relative to the spine. This is the same acceleration that the chest deflection transducer would see. Filter this result at SAE CFC 600.
2. Integrate the result to get the relative sternum velocity. This is the same velocity that the chest deflection transducer would see. The velocity should have the units of meters per second.
3. Integrate the relative sternum velocity to get the relative sternum deflection. This is the same deflection that the chest deflection transducer measures. The deflection should have the units of millimeters.
4. Multiply the deflection by 0.001 to convert the calculated deflection from millimeters to meters. This may be different depending on what constants you use when doing your integration.
5. Multiply the relative sternum deflection (in meters) by the relative sternum velocity (in meters per second). The result will be data that has meters squared per second as the unit.
6. Obtain the final V*C result by multiplying this data by the appropriate constant for the ATD type. This constant is the number 1.3 (1.0 for side impact ATD's) divided by the depth of the chest of the ATD (or 1/2 of the thorax width for side impact ATD's) measured in meters. This constant has meters as its unit in the denominator. After multiplying the constant and the result in step 5 you have the V*C (Viscous Injury Criteria) number with meters per second as the unit. Only the positive peak value is typically of interest.

This method of processing the data meets all of the requirements of J211; most notably not filtering digitally more than once, and filtering before any nonlinear operations.

The Combination Method

On frontal ATD's, this method is recommended only for the mid sternum. This is the preferred method for side impact ATD's. Although the possibility still exists for an occasional test where the velocity data will drift off excessively causing the V*C data to show an ever increasing or decreasing number as the test progresses. This is the exception and is not likely to be a problem until well after the region of interest in the test data.

On side impact ATD's, the combination method can only be used when the rib acceleration relative to the spine can be determined. This requires an accelerometer on the spine opposite from the one on the rib.

Recommended Processing Procedure for the Combination Method - Since there are so many possibilities of the order that many of the processing steps can be performed in while still meeting the requirements of J211, it was believed advantageous to specify one method of processing so that all people involved would be handling the data the same way. The suggested method is outlined below:

1. Subtract the spine acceleration from the sternum acceleration. This gives the acceleration of the sternum relative to the spine. This is the same relative acceleration that the chest deflection transducer would see. Filter this result at SAE CFC 600.
2. Integrate the result to get the relative sternum velocity. This is the same relative velocity that the chest deflection transducer would see. The velocity should have the units of meters per second.
3. Filter the chest potentiometer deflection data at SAE CFC 600. The units should be in millimeters.
4. Multiply the filtered deflection by 0.001 to convert the measured deflection from millimeters to meters.
5. Multiply the sternum deflection (in meters) by the sternum velocity (in meters per second). The result will be data that has meters squared per second as the unit.
6. Obtain the final V*C result by multiplying these values by the appropriate constant for the ATD type. The constant is the number 1.3 (1.0 for side impact ATD's) divided by the depth of the chest of the corresponding percentile human (or 1/2 of the human thorax width for side impact ATD's) measured in meters. This constant has meters as its unit in the denominator. After multiplying the constant and the results in step 5 you have the V*C (Viscous Injury Criteria) values with meters per second as the unit. Only the positive peak value is typically of interest.

This method of processing the data meets all of the requirements of J211; most notably not filtering digitally more than once, and filtering before any nonlinear operations.

CONCLUSION

The work of this task team is not completed. The task team hoped to develop a single transducer that could provide both deflection and velocity data that could be used for determining V*C. As of yet they have not developed this transducer. Chairman Balser plans to resume the task team work when more data is available or a new technology is developed that shows promise of making this measurement in an improved fashion beyond what is currently available.

ACKNOWLEDGMENTS

Chairman Balser would like to thank all the members of the task team for their participation in their work which was summarized in this paper. The only data published in this paper was produced within General Motors. Many other individuals and companies submitted data and information that appears in the SAE published minutes of this task team. All members of the task team expended valuable time, energy and input into the yet uncompleted, but valuable work of this task team.