Crush Analysis Considerations

Use of Crush in Vehicle Accident Reconstruction for the Purpose of Determining Impact Speed

Crush Analysis Considerations

presented by

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Crush Analysis Considerations

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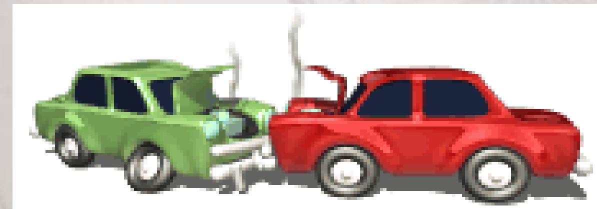
- ACTAR # 484
- EIT
- Involved in AI/AR work since 1976



 # 484

Speed from Crush

Background - Measurement -History - Calculation

Overview

Objections to using crush

- One of the stumbling blocks to using crush often cited by people is that the measurements take too much time
- Other objections to using it are -
- No class in crush (yet)
- Don't need it with now having CDR
- Inaccurate
- Don't like it - Prefer Momentum

Measurement

Background

- "Standard" Measurement protocol says 2,4, or 6 equally spaced measurements

- Referred to as the "Tumbas Protocol"

- Outlined in SAE # 880072 "Measuring Protocol for Quantifying Vehicle Damage from an Energy Basis Point of View" By Nicholas Tumbas and Russell Smith

Measurement

Background

- Do we need equally spaced damage measurements?

- Why or why not? When? Where?

- Especially, do we need them out in the field?

Measurement

Background

- ★ - In order to “Make Crush Work” ... NO!!! You do not have to take equally spaced measurements.
- ★ - Refer to the Presentation made at WREX 2016 which is on our web site at: http://www.4n6xprt.com/papers/
- ★ - You are much better off when out in the field to measure to the “inflection points”
- ★ - To put it another way, document the critical points just as you would document any other evidence, If you can draw it, you can take additional measurements when needed

Measurement

Background

- ★ - When needed .... what does that mean??
- ★ - Many of the CRASH 3 programs require that the crush measurements be entered with equal spacing between the measurements.
- ★ - So .... now what???
- ★ - Now you take your measurements made in the field, draw them out to scale, and then lay out where your equally spaced crush measurements will be, then measure the crush

Measurement

Background

- ★ - If you are scanning the damage, and can scan an exemplar vehicle, determining what the crush is, and where to measure from and too, becomes even easier with a program like CLOUD COMPARE (https://www.danielgm.net/cc/)
- ★ - Whether you measure by hand, with a total station, or with a scanner, it will always be easier to measure the critical points in the field (and yes, a scanner will get both c"critical" and non-critical points as part fo its scan), and then get your equally spaced crush measurements in the comfort of your office.

Measurement

Background

- So, to summarize,

1 - Measure to the critical points (the inflection or bend points) with appropriate references to “landmark” points on the vehicle while in the field. This will speed up the physical measurement process tremendously, while also reducing what you have to remember

Measurement

Background

- So, to summarize (cont)

2 - Obtain your equally spaced crush measurements once you are back in the comfort of your office. This is the “When” and the “Where” that these measurements should be obtained, if and when they are needed.

Crush - "No Class"

Another "objection" I have heard through the years regarding not using crush is a lack of formal training

- While formal training is of benefit, it is not required

- This presentation, and others like it, can be considered formal training

- The BEST training is self-training - i.e. - try it and see what works

Crush - "No Class"

Self-Training steps

- First you have to document the crush, since if you have no crush, you cannot calculate the "speed from crush". This might sound like a simple concept, but at times it has been lost on people. (See slide 141)

- Next, apply the various types of calculations (see slides to come) to the crush you have documented.

- Again, no crush = no speed to be calculated ... although, you might be able to say "***The speed was "less than" XX mph***" based on the elastic variable (CRASH 3).

Crush - “No Class”

Self-Training steps

- Then, compare the speed(s) you have calculated from crush to the speeds you have obtained through other methods (i.e. - momentum, CDR, etc)

- Last, set a procedure (protocol) and/or set of calculations for which you feel you can defend what/why/how when you are questioned about it.

Crush - "Don't need it due to CDR"

- First - not every vehicle on the roadway has a CDR/EDR to download
- Second - Even if it has the module, you cant always GET a download

In the event of either or both of these occurring in your collision, you need a backup method to determine speed.

Crush - "Don't need it due to CDR"

- You usually have to go through a process, which takes time, before you can do the download. With the proper tools, you can get an idea of the speeds from crush immediately upon your return to the office, if not out at the scene itself. This can at times help you get an idea of what else about the case you might want to look at.

Crush - Inaccurate

In and of itself speeds arrived at from crush are no more or less accurate than speeds determined through other methods - Momentum, other energy calculations (i.e.- spin, yaw, skidding, braking, etc.), airborne, etc.

Speed from crush may, however, be less PRECISE than other methods to determine speeds

Crush - Inaccurate

Precise vs Accurate

Taken from https://www.honolulu.hawaii.edu/instruct/natsci/science/brill/sci122/SciLab/L5/accprec.html#:~:text=Accurate%20means%20%22capable%20of%20providing,of%20the%20thing%20being%20measured.

The Science of Measurement: Accuracy vs. Precision

The dictionary definitions of these two words do not clearly make the distinction as it is used in the science of measurement.

Accurate means "capable of providing a correct reading or measurement." In physical science it means 'correct'. A measurement is accurate if it correctly reflects the size of the thing being measured.

Crush - Inaccurate

Precise vs Accurate

Taken from
https://www.honolulu.hawaii.edu/instruct/natsci/science/brill/sci122/SciLab/L5/accprec.html#:~:text=Accurate%20means%20%22capable%20of%20providing,of%20the%20thing%20being%20measured.

The Science of Measurement: Accuracy vs. Precision

The dictionary definitions of these two words do not clearly make the distinction as it is used in the science of measurement.

Precise means "exact, as in performance, execution, or amount. "In physical science it means "repeatable, reliable, getting the same measurement each time."

Crush - Inaccurate

Precise vs Accurate

Taken from https://www.honolulu.hawaii.edu/instruct/natsci/science/brill/sci122/SciLab/L5/accprec.html#:~:text=Accurate%20means%20%22capable%20of%20providing,of%20the%20thing%20being%20measured.

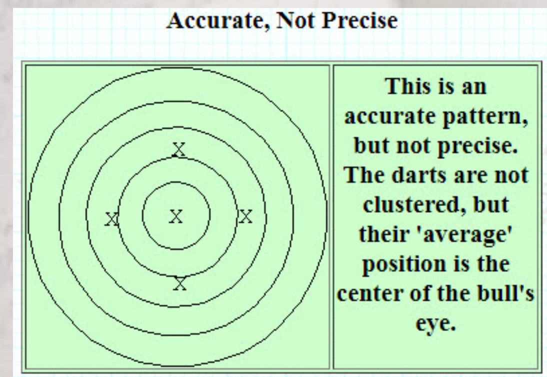
The Science of Measurement: Accuracy vs. Precision

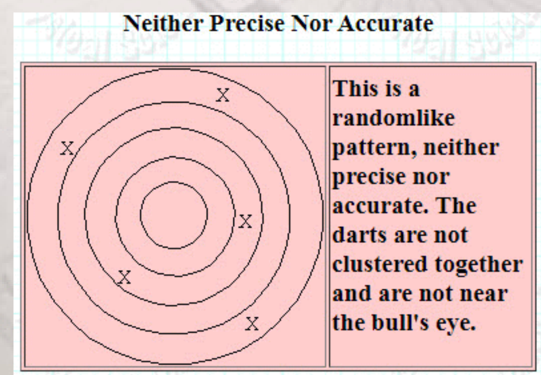
We can never make a perfect measurement. The best we can do is to come as close as possible within the limitations of the measuring instruments.

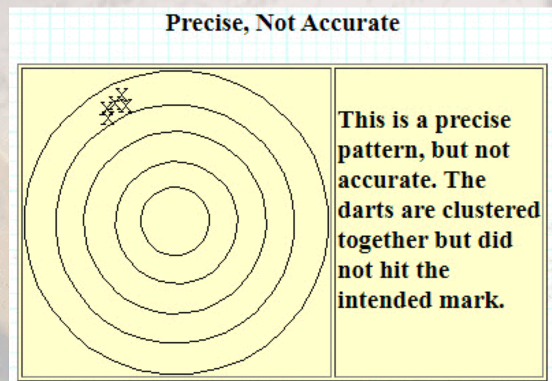
Crush - Inaccurate

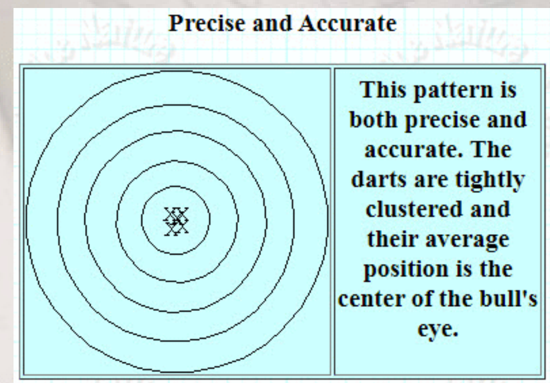
Precise vs Accurate

Taken from
https://www.honolulu.hawaii.edu/instruct/natsci/science/brill/sci122/SciLab/L5/accprec.html#:~:text=Accurate%20means%20%22capable%20of%20providing,of%20the%20thing%20being%20measured.









Crush - Inaccurate

Precise vs Accurate

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The Science of Measurement: Accuracy vs. Precision

Some additional references -

https://manoa.hawaii.edu/exploringourfluidearth/physical/world-ocean/map-distortion/practices-science-precision-vs-accuracy

https://www.thoughtco.com/difference-between-accuracy-and-precision-609328

https://www.quora.com/What-is-the-meaning-of-accuracy-and-precision-in-Science

Crush - Inaccurate

The accuracy of a speed from crush calculation depends upon the crush measurements taken, the data that is used to develop stiffness values, and how well the crash under investigation fits the model that was used to develop the calculation method.

As with any other calculation, if your data sucks, and the model doesn't fit the crash in question, your results should be EXPECTED to be poor.

Crush - Inaccurate

Examples of poor data and/or bad models

Some examples of poor data and/or bad models follow:

- Speed from skid when there are no skidmarks - Statement gets made, the driver didn't brake

- Speed from Yaw, using the "flattest" tire mark when the vehicle was actually in a spin

Crush - Inaccurate

Examples of poor data and/or bad models

Some examples of poor data and/or bad models follow (cont):

*- Calculating the minimum speed at the start of skid for a vehicle to slide 10 feet and then slam into a tree, leaving 2 feet of crush into the front of the vehicle as 15 mph .... SQR(30*10*.75)*

i.e.- ignoring the crush

Crush - Prefer Momentum

As with the CDR preference, sometimes momentum is not an option

- the previous example of a car into a tree (light pole, bridge, house, etc) is one example of this.

- hard to do momentum if there are no measurements for point/area of impact and/or points of rest due to lack of documentation.

Speed from Crush

When should I use it?

You should do one or more crush calculations every chance you get, not just when that is the only thing left

- Like anything else, you need to stay “fluent” in crush, which means practice, if you only use it as a last resort, your gonna make mistakes

Speed from Crush

When should I use it?

- If you use it and compare to other results, then when its all you have you can say "I routinely calculate a speed from crush, and find that it falls within the speed range of other speed calculations. I have no reason to expect it would be any different here if there were other ways to check the speed"
- Your calculations do not have to be "in depth" and you don't have to include them in your report, especially if nothing goes down on paper.

Crush Measurements

Protocol / What do you need to measure Damage? / End Damage / Side Damage

Crush Measurements

Why?

- Document extent
- Document location
- Help determine PDOF and how the vehicle(s) came together
- Help determine Energy expenditure (i.e. speed necessary to cause the crush)
- Help to illustrate the severity of the collision

Crush Measurements

Definition of **PROTOCOL**

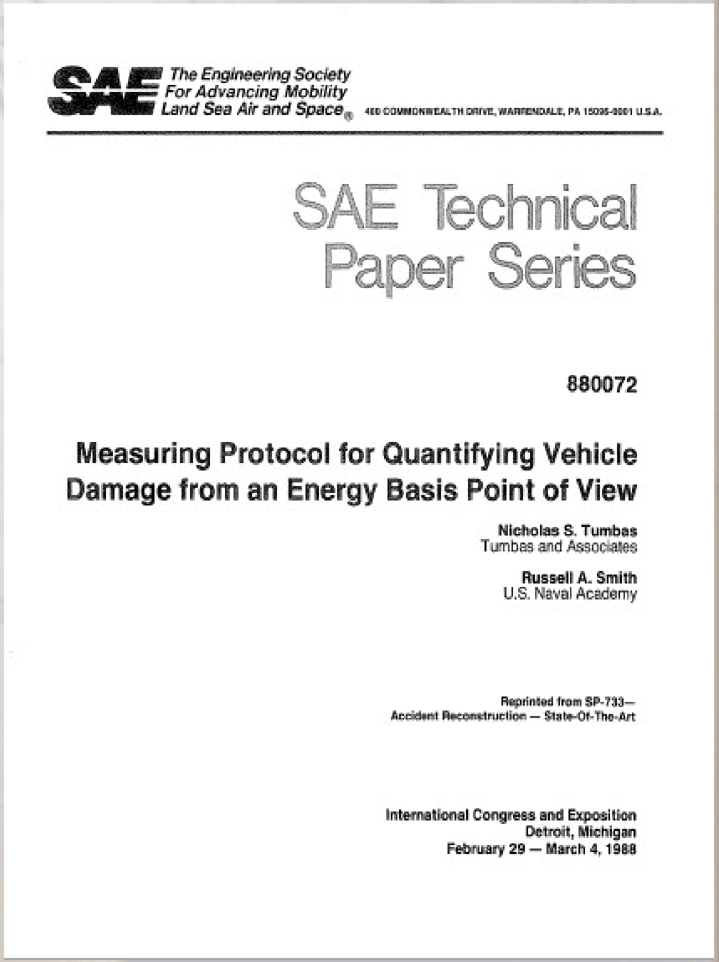
http://www.merriam-webster.com/dictionary/protocol

- PROTOCOL
  - 3(b) : a set of conventions governing the treatment and especially the formatting of data in an electronic communications system <network protocols>
  - 3(c) : convention 3a,b
  - 4 : a detailed plan of a scientific or medical experiment, treatment, or procedure

Crush Measurements

Tumbas "Protocol" Summary

- SAE 880072 Lays it out specifically for part 4 of the previous definition
- Called the "Tumbas Protocol" in honor of one of the authors
- 2, 4, or 6 equally spaced measurements along the FIELD crush Length
- Locate damage midpoint, both direct damage midpoint and induced damage midpoint, and position them relative to vehicle Center of Mass
- Lots of other conditions for handling "Specialty" situations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880072

Measuring Protocol for Quantifying Vehicle Damage from an Energy Basis Point of View

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Russell A. Smith
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Crush Measurements

“Protocol” (cont)

- Do you really need to be worrying about all that at a scene, or even in a tow yard?
- Isnt it better to concentrate on documenting the evidence, something you do regularly, instead of worrying how many measurements, whats the spacing, etc?
- Proper crush documentation - If you think it MIGHT be important, or you MIGHT be asked about it, it should probably be documented.
- More on this at the end

Crush Measurements

What do you need to measure Damage?

What do you need to measure crush?

- ★ Do you need a Scanner?
- ★ A Total Station?
- ★ A Commercial Jig?

While all of these are nice, and have there uses, all you really need is several tape measures.

Crush Measurements

Minimalists guide

- How many measurements do you need to take? As many as are required **to properly document** the damage.
- If using a Total Station this could be as little as 1, the max crush point, if you are already documenting the vehicle as part of the scene.
- It should probably be at least 3 - the two “end points” of the crush as well as the perceived max crush point.

Crush Measurements

Minimalists guide - cont

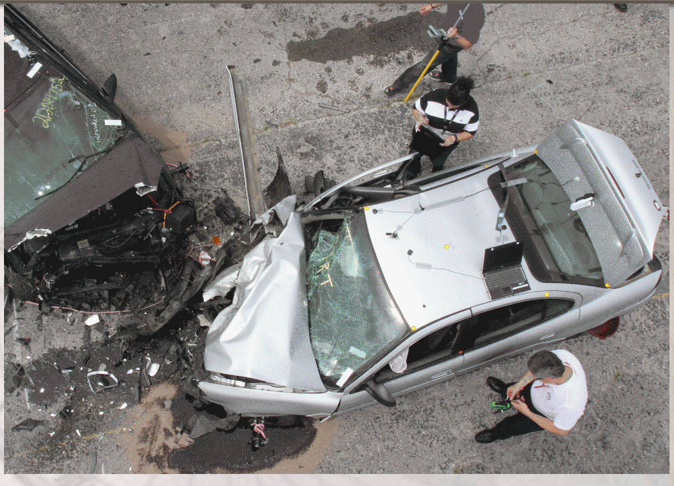
- With a Tape Measure Jig you will need at least 4 tape measures, 2 of which that are 25-35 foot in length. 3 of these are for your jig, one is for measuring "depth". You also need a "plumb bob", for which there are many possible "Field Expedients" including a bottle of water or another tape measure. The purpose of the plumb bob is to insure you are measuring depth and depth measurement position "accurately".

Crush Measurements

End Measurement

- ★ Need to “tie” to an undamaged feature. Typically this will be far “axle” position from the damage. For a Front impact that would be the rear axles, and vice-versa for a rear impact.
- ★ If there is no end shifting, it is easiest to line up both tapes so that they are against the outside of the tires.

Crush Measurements



End Measurement - cont

- ★ If there is end shift, you need to establish how far “off” of undamaged positions on the vehicle the tape is laid.
- ★ Do this on both sides of the vehicle.

Crush Measurements

End Measurement - cont

- Then extend a third tape across the two tapes at the same point on the tapes. If the furthest projection is at say, 123 inches, lay the third tape across at the 130 inch point. For a lot of reasons, it will simplify your life if you can remember to have the "0" point of the tape on the driver side. One of the primary reasons is because then your progression C_1 to C_{final} will be in the same progression as the Protocol measurements. While not essential, it removes a "smoke screen" issue from the other side when being asked about your measurements.

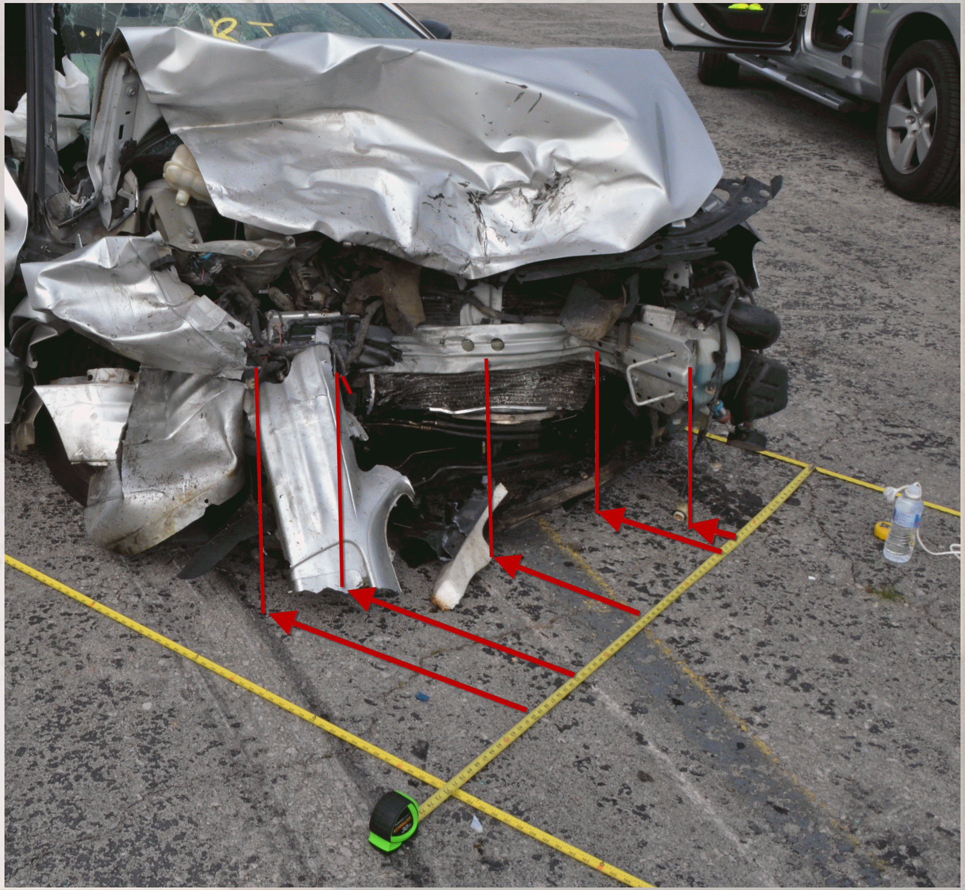
Crush Measurements

End Measurement - cont

Crush Measurements

End Measurement - cont

- From there, document your damage across and in. If it is all at one height, fine, if not, you may want to also document the height of the object above ground as well.



Crush Measurements

End Measurement - cont

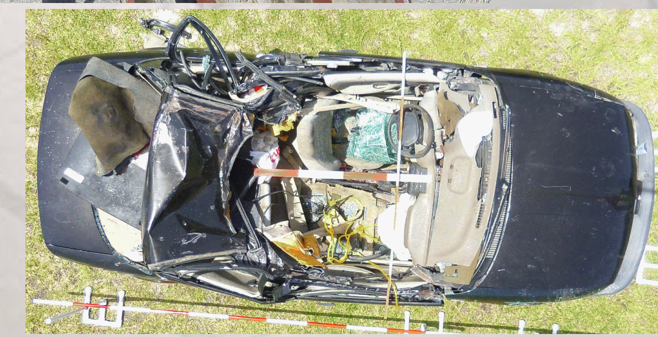
- ★ Usually you will be measuring at bumper height, however
  - ★ If you have a under/over ride situation, your bumper may have been only partially engaged, or not engaged at all.
  - ★ Document the bumper position
  - ★ Document the crush depth, and height
  - ★ Depending upon how much of the vehicle structure is involved, the measurements may not be able to be used in a CRASH 3 calculation, but should still be documented for damage extent and allow for matching of one vehicle to the other. Also, there are other methods of speed determination besides the CRASH 3 approach.

See - A Scientific Approach to Tractor-Trailer Side Underride Analysis -SAE 2003-01-0178

Crush Measurements

End Measurement - cont

A Scientific Approach to Tractor-Trailer Side Underride Analysis -SAE 2003-01-0178



Crush Measurements

End Measurement - cont

- Before picking up your tapes, walk your side measurements and note salient points -other axle position, and any other damage such as back of door relative to "B" pillar.

Crush Measurements

Side Measurement

- As a bit of forshadowing, this is also a valid method for side damage measurements, especially when there is bowing to the vehicle.
- Lay a tape down along the undamaged side.
- Lay a tape along the damaged side a set distance off of the other tape.

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Measurement

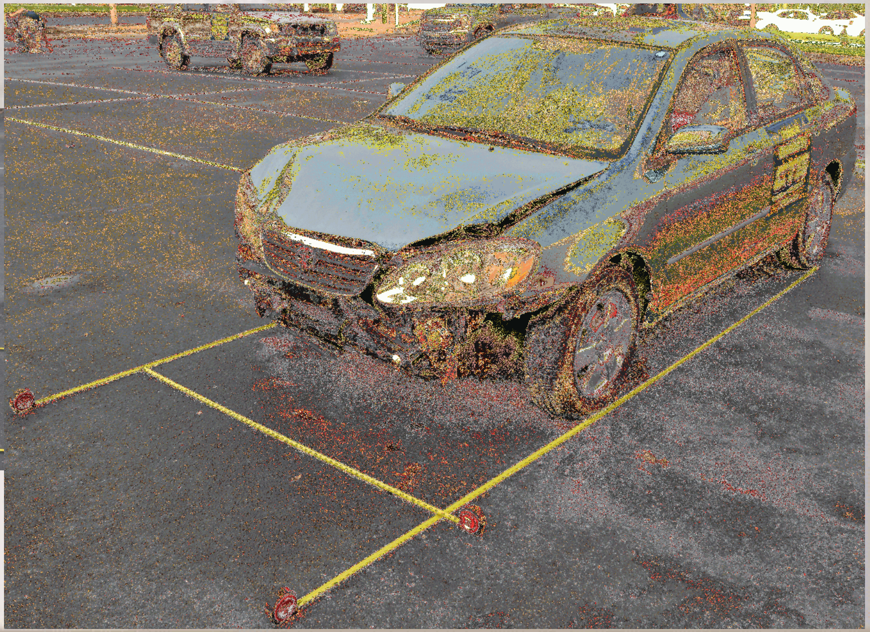
Front and Rear Damage

Find your Damage

Measurement

Front and Rear Damage

Layout Tapes for Left and Right Side, with a cross tape at the same distance on each side



Measurement

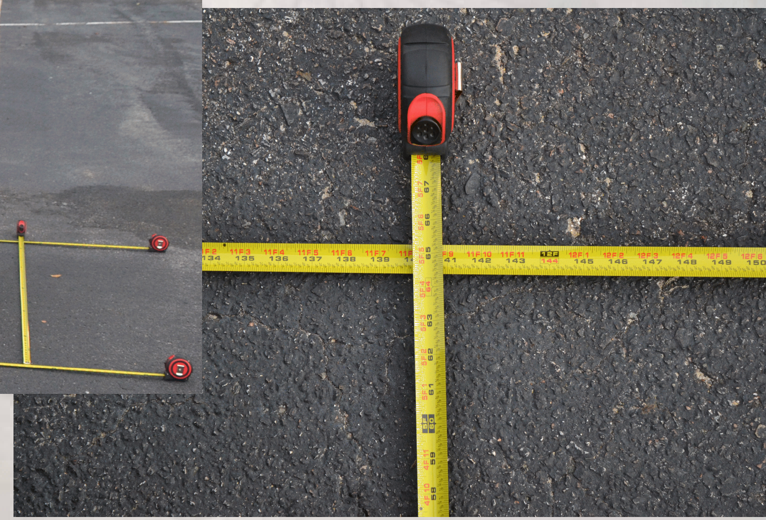
Front and Rear Damage

Document your Reference Points

Measurement

Front and Rear Damage

Document your Reference Points



Measurement

Front and Rear Damage

Take your measurement(s)

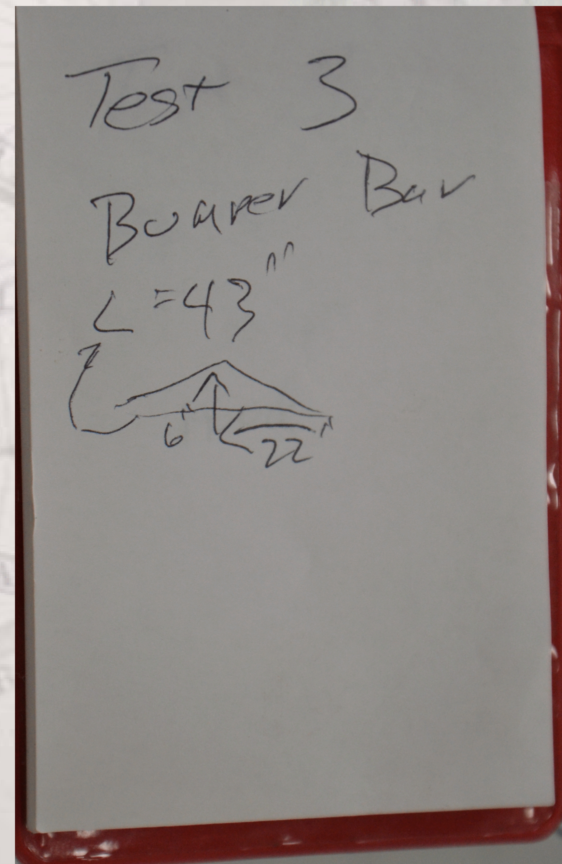
Measurement

Front and Rear Damage

Record your measurement(s):

In this instance I made the field adjustment for "depth" of crease minus depth of two bumper bar corners.

It would be better documentation practice to record the distance "across" and "depth" for each corner as well as the damage "crease" when in the field, and then do the calculations once you are back in the office.



Measurement

Front and Rear Damage

Don't forget the bumper foam/plastic/energy absorber material thickness

Measurement

Front and Rear Damage

At its thickest point the foam and/or plastic energy absorber material is 3-4 inches thick. It generally tapers at the ends to a thickness of 1-2 inches.

When/if measuring your crush depth to the bumper bar, you need to subtract this thickness from your crush depth. If you do not, your crush depth is too deep, which will result in a higher speed calculation.

Measurement

Front and Rear Damage - Practical Application

For the vehicle shown in this example, for a crush depth to the bar of 6 inches, which is at the center of the bar, the resulting crush depth would be 3 inches.

6 inches of crush minus 3 inches of foam =

3 inches of crush damage

Measurement

Side Damage

Crush Measurements

Side Measurement

- Again, best to line up the “0" end of the tape with the rear corner or axle, depending on where the crush (direct or induced, whichever is furthest back) ends.

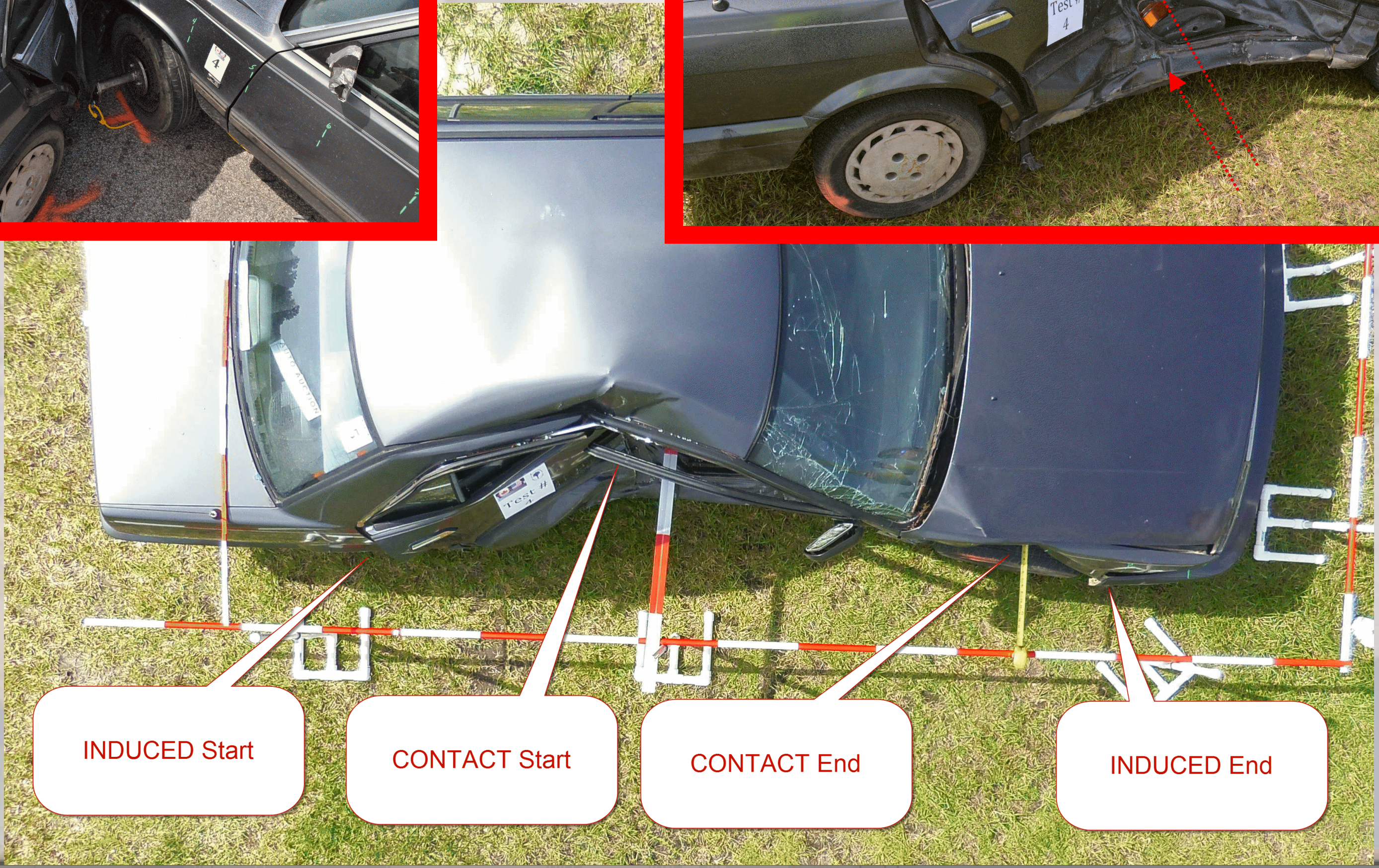
Crush Measurements

Side Measurement

- ★You want to document both ends of induced damage, and both ends of contact damage, along with deepest crush point.

Crush Measurements

Side Measurement



Crush Measurements

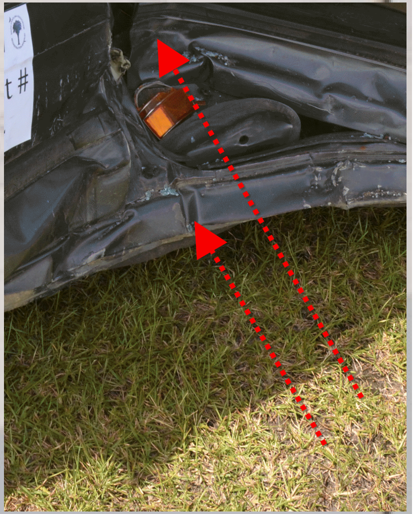
Side Measurement

- Document other "tie in" points as you feel are needed/appropriate - axles, A-B-C pillars, etc.

Crush Measurements

Side Measurement - cont

- Look for signs of "structural failure". One good indicator of this would be the bottom of the door(s) pulled away from the sill. In this case you should document depth to sill as well as deepest point. Deepest point will normally be about bumper level (of the "bullet" vehicle). Also document what failed and where it is.



Crush Measurements

Side Measurement - cont

Crush Measurements

Your "Guiding Light"

- ★ Document the crush the same way you would document any other evidence
- ★ Tie in your base line.
- ★ Note WHERE the depth measurements were taken along with how deep.
- ★ If you feel its necessary for proper documentation to measure up from the ground to the point you were measuring, do so. ESPECIALLY if the point is outside the "normal" height range.

Crush Measurements

Your "Guiding Light"

- ★ Photograph the damage before you lift your baseline tape - while this is not required, it could be helpful.
- ★ Remember, if its not documented, it can't be considered.

Crush Analysis Formulas

History
And
Formulas

Crush Analysis Formulas

History & Formulas

$$v = 1.1C$$

- 1968 -R.I. Emori presented a formula in SAE paper 680016 for calculating vehicle impact speed based on Maximum Permanent crush
- v = 1.1 C
- v = speed in miles per hour, C = maximum permanent crush in inches

Crush Analysis Formulas

History & Formulas

$$v = 1.1C$$

SAMPLE APPLICATION

- ★For instance, you have a 3130 pound vehicle impacting a barrier at 35 mph, which results in an average crush depth of 21.4 inches. However, use of Emori's formula does not require exemplar test crashes. This is included in this Sample Application for continuity with other Sample Applications.
- ★NO calculations are needed from exemplar crashes for an application of Emori's formula. It is what it is, which is part of its appeal, especially for those just beginning to use crush.

Crush Analysis Formulas

History & Formulas

$$v = 1.1C$$

- Now, in the "real" collision you have an average crush depth of 10 inches, and a vehicle weight of 3000 pounds. Applying your constant of 1.1, you get -
  - Speed = (1.1*Crush Dist)
  - Speed = (1.1*10)
  - Speed = 11 mph

Crush Analysis Formulas

History & Formulas

$$V = b_o + b_1 C$$

- 1974 -Kenneth L. Campbell presented a formula in SAE paper 740565 for calculating vehicle impact speed based on residual crush to assist in estimating the severity of automobile collisions.
- V = b(o) + b(1)*C
- V=impact speed in mile per hour, b(o) = “y” intercept in miles per hour, b(1) = crush vs. speed slope in miles per hour per inch, and C = residual crush in inches

Crush Analysis Formulas

History & Formulas

$$F = A + BC \qquad E = (AC + \frac{B * C^2}{2} + G) * w$$

- ~1975 -Raymond R. McHenry followed Campbell's work with the CRASH computer program to estimate impact speed from damage using a force deflection (spring) model.
- F = A + B*C
- E = (A*C + B*C^2/2 + G) * w

Where
- E=Crush Energy in inch*pounds
- C = Crush depth in inches
- A = pounds/inch
- G = A^2/2B in pounds
- F=pounds
- w = the length (width) of the crush
- B = pounds/inch^2

Crush Analysis Formulas

History & Formulas

$$E = (AC + \frac{B * C^2}{2} + G) * w$$

- 1981 -David Segal gave a physical interpretation of the constants in a presentation to Transport Canada
- A is the spring pre-loading value, pounds/inch
- B is the energy absorbed in plastic (permanent) deformation, the spring constant, lb/in^2
- G is the energy absorbed in the elastic (non-permanent) range of the “structure”, (A^2 / 2*B)

Crush Analysis Formulas

$$E = (AC + \frac{B * C^2}{2} + G) * w$$

$$b_0 = NDS_{mph} * \frac{12 * 5280}{3600}$$

$$b_1 = \frac{V_i - b_0}{Cr}$$

- The constants (A, B, & G) are calculated using values that seem to go back to Campbell's work ... with slight modification
- The first step in establishing the constants (A, B, & G) is to calculate the values of $b_{(0)}$ and $b_{(1)}$
- $b_{(0)}$ is again the "y" intercept, or "No Damage Speed" (NDS), only this time in inch/sec instead of miles/hour
- $b_{(1)}$ is again the slope of the crush vs. speed slope, only now it has a few more elements involved in determining its value, $V_{(I)}$ is the "impact" speed in inches/sec, and Cr is the crush value in inches.

Crush Analysis Formulas

$$E = (AC + \frac{B * C^2}{2} + G) * w$$

$$A = \frac{W * b_0 * b_1}{g * L} \qquad B = \frac{W * b_1 * b_1}{g * L} \qquad G = \frac{A * A}{2 * B}$$

- A is calculated using both the $b_{(0)}$ and the $b_{(1)}$ values, along with the vehicle weight (W), gravity in inches/sec^2 (g=386.4 in/sec/sec) and the length (L) of the crush in inches. *{Note: "Crush Length" is also referred to as Crush Width, especially when looking at front and rear end damage.}*
- B is calculated using only the $b_{(1)}$ value in conjunction with the vehicle weight (W), gravity (g),and the length (L) of the crush.
- G is calculated as a ratio of A to B

Crush Analysis Formulas

History & Formulas

- Once you have "stiffness" values, the constants (A, B, & G), you can then calculate the energy absorbed by the vehicle damage, and from there a EBV/EES/EBS/BEV/BES/KEES.

(In the KEES calculation, gamma is comprised of the Yaw Moment of Inertia and the Force Moment Arm, and can be ignored for Full Frontal Barrier tests)

$$E = (AC + \frac{B * C^2}{2} + G) * w$$

$$KEES_{mph} = \frac{3600}{5280} * \sqrt{\frac{\left(\frac{2 * E * \gamma}{12}\right)}{\left(\frac{W}{g}\right)}}$$

Crush Analysis Formulas

History & Formulas

- This equation (the "Campbell" equation) is popular due to its use in the various flavors of CRASH3 programs that are out for use, however, it also has its problems, briefly -
  - It is complex
  - It relies on knowing the stiffness values or having one or more tests to calculate the values from (so what happens when you have no tests to calculate the stiffness values from?? And if you have only one test, how do you know that vehicle/test is representative??)
  - It is complex, as in hard to do by hand, even with no rotation

Crush Analysis Formulas

History & Formulas

- "Campbell" equation cont.-
  - It is complex, as in to use in "real" collisions, the gamma value must taken into account due to vehicle rotation -making the calculations even more difficult to do by hand
  - It is complex, as in hard to answer hypotheticals when on the stand (i.e. -what happens to your speeds if there is only 10 inches of crush instead of the 18 you used?)
  - And, did I mention, It is complex???

Crush Analysis Formulas

History & Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

Is this the “Vomhof” Equation????

Crush Analysis Formulas

History & Formulas

- 1975 -The First Edition of the **Traffic Accident Investigation Manual** by J. Stannard Baker was published. In that manual he published a table of "Typical Values of Acceleration and Deceleration of Motor Vehicles on Level Surfaces". In that table, he gave the following Drag Factor values:
  - Car crash into standing car = -5.00
  - Crash into solid fixed object = -20.00
- These Drag factor values can be used in the well known slide to stop equations:

$$Speed = 5.5\sqrt{d * f}$$

$$Speed = \sqrt{30 * d * f}$$

Crush Analysis Formulas

scale, *d*, at 6.4, the additional travel due to acceleration. The sum of these two, 88 + 6.4 = 94.4, is the total distance travelled.

Deceleration from any velocity. The distance travelled while decelerating from any velocity is calculated in the same way as the distance travelled while accelerating except that the change in distance is subtracted from, rather than added to, the distance the vehicle would have travelled at constant speed. The equation then becomes

$$d = vt - 16.1\, t^2 f \text{ ft.}$$

In the foregoing example, if the vehicle had been decelerating from 44 ft per sec (instead of accelerating), at the end of 2 sec it would have gone a distance of 88 ft at the constant velocity; but from this must be deducted 6.44 ft due to slowing for 2 sec at 0.1*g*. That gives the actual distance travelled in the 2 sec as 88 − 6.44 = 81.6 ft.

Calculations combining distance, time, velocity, and drag factor can be used in numberless combinations to solve problems in connection with accident reconstruction. Only a few examples of more common problems can be given here as illustrations.

Stop-sign problems. A common

Exhibit 9-53

TYPICAL VALUES OF ACCELERATION AND DECELERATION FOR MOTOR VEHICLES ON LEVEL SURFACES *Coeff. of fric.*

ACCELERATION OR DECELERATION	Speed range	ACCELERATION, a: Drag factor $f = a/g \approx \mu$	Meters per sec²	Feet per sec²
Free fall		+ 1.00	+ 9.81	+ 32.2
Passenger cars, normal acceleration	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	+ 0.15 + 0.10 + 0.05	+ 1.47 + 0.98 + 0.48	+ 4.8 + 3.2 + 1.6
Passenger cars, rapid acceleration	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	+ 0.30 + 0.15 + 0.10	+ 2.94 + 1.47 + 0.98	+ 9.7 + 4.8 + 3.2
Medium trucks, normal acceleration	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	+ 0.10 + 0.05 + 0.03	+ 0.98 + 0.48 + 0.29	+ 3.2 + 1.6 + 1.0
Big trucks loaded, normal acceleration	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	+ 0.05 + 0.03 + 0.01	+ 0.48 + 0.29 + 0.10	+ 1.6 + 1.0 + 0.3
Pedestrians, normal acceleration in walking Pedestrians in a hurry		+ 0.05 + 0.10	+ 0.48 + 0.98	+ 1.6 + 3.2
Passenger cars, coasting out of gear	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	− 0.01 − 0.02 − 0.04	− 0.10 − 0.20 − 0.39	− 0.3 − 0.6 − 1.3
Passenger cars, engine braking high gear	Less than 20 mph (30 km per hr) 20 to 40 mph (30 to 60 km per hr) More than 40 mph (60 km per hr)	− 0.04 − 0.05 − 0.08	− 0.39 − 0.48 − 0.78	− 1.3 − 1.6 − 2.6
Gradual slowing, light braking Normal braking, no skidding		− 0.10 − 0.20	− 0.98 − 1.96	− 3.2 − 6.4
Quick stop, skids on ice or snow Hard braking, skids on most surfaces Maximum braking on high-friction surface		− 0.40 − 0.65 − 0.95	− 3.92 − 6.38 − 9.32	− 12.9 − 20.7 − 30.6
Car crash into standing car Crash into solid fixed object		− 5.00 −20.00	−49.01 −196.0	−161.0 −644.0

ACCELERATION, a
Drag factor $f = a/g \approx \mu$ | Meters per sec² | Feet per sec²
Maximum braking on high friction surface − 0.95 − 9.32 − 30.6
Car crash into standing car − 5.00 −49.01 −161.0
Crash into solid fixed object −20.00 −196.0 −644.0

Crush Analysis Formulas

History & Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

Is this the "Vomhof" Equation????

Answer #1 - No, it is the "Speed from Skid" equation.

Answer #2 - No, it is the "Baker (?) Equation".

Answer #3 - If anything is "Vomhof" about the equation, it is the term "Crush Factor" and the modification and refinement of the deceleration value (ie - CF).

Crush Analysis Formulas

History & Formulas

- Our work between 1977-1990 with the values published in the **Traffic Accident Investigation Manual** found that the "Car crash into standing car" value seemed to give speed values which were far too low when compared to other calculations (i.e. -momentum)
- 1990-1991 we did some evaluation of the NHTSA Crash Test data as published in the Accident Reconstruction Journal, from which we were able to refine the Crush Factor value to 21 for frontal crashes.
  - We use the term "Crush Factor" in the formula because, well, we are talking about crush rather than a skid/slide to stop.

Crush Analysis Formulas

History & Formulas

- 1997-present further work with the NHTSA Crash Test data has found that the "generic" value of 21 is still a good first approximation number for determination of the KEES from damage to the Front, Side, and Rear of passenger vehicles.
- See the January-February 2019 issue of the Accident Reconstruction Journal for an article entitled "CRUSH FACTOR: A VALIDITY ANALYSIS – PART I (FRONTAL)" which covers the CF=21 for frontal impacts.
- A reprint of the article can be downloaded from our web site at -http://www.4n6xprt.com/papers/

Crush Analysis Formulas

History & Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

- 1991 - the first sales of Expert AutoStats and Expert Qwic Calcs were made. These programs incorporated the evaluation work completed between 1990-1991. Expert AutoStats contained the published Crush Factor values of:
  - Frontal impact damage, CF=21
  - Side or Rear impact damage, CF=27 *(It has since been determined that the CF=27 value calculates an estimate of Bullet vehicle speed at impact from Target vehicle damage only, no Post-Impact Energy losses should be combined with this speed)*

Crush Analysis Formulas

History & Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

- These values (CF=21 or CF=27) are used in the equation Speed=SQR(30*MID*CF) where:

  - 30 = a constant that converts the input distance of feet into an output of mph
  - MID = Maximum Indentation Depth in Feet
  - CF = Crush Factor

Crush Analysis Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

Who uses it??

Crush Analysis Formulas

Speed = SQR(30*MID*CF) - Who Uses It??

- In conjunction with our Update Order Forms for the Expert AutoStats program in 2004 we conducted a survey on the use of this formula.

- The 2004 survey was a two part survey.
  - First part - Have you used the Expert AutoStats Crush Factor Value for speed calculations?
  - Second part - Have you found the calculated speed to be in good agreement with your other calculations? (i.e. - “Peer Review” prior to Daubert)

Crush Analysis Formulas

Speed = SQR(30*MID*CF) - Who Uses It??

- Out of 417 updates -
  - 235 responded to the survey (55%)
  - 84 indicated they had tried the Equation and Crush Factor values in Expert AutoStats (36% of responses)
- Of the YES responses to part 1
  - 72 said yes, there was reasonably good agreement (85.7% of Pt 1 YES responses)
  - 8 said no,, there was not reasonably good agreement (9.5% of Pt 1 YES responses)
  - 4 indicated they had tried the Equation but did not indicate whether the agreement was good or not (4.8% of Pt 1 YES responses)

Crush Analysis Formulas

Speed = SQR(30*MID*CF) - Who Uses It??

- The 2004 survey comments-
  - It works, what else can I say?
  - It is simple. Simple is good. Juries understand simple.
  - It is too simple
  - Too general in nature
  - I've never seen the formula. Didn't know it was there.

Crush Analysis Formulas

Speed = SQR(30*MID*CF) - Who Uses It??

- Conclusions from the 2004 survey -
- Of the people who have tried/tested the speed from crush calculation using the Crush Factor suggested in Expert AutoStats, the vast majority have found that the results are in reasonably good agreement with other methods of speed calculation (again, pre Daubert, - peer reviewed)

Crush Analysis Formulas

History & Formulas

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

$$CF = \frac{Speed_{mph}^{\ 2}}{30 * MID}$$

How is the Crush Factor (CF) Calculated?

- In the same way that you would derive a drag factor from test skids, you obtain the Crush Factor from test crashes -
- $CF = Speed^2/(30*Crush\ Distance)$
  - Note - the Crush Distance is in feet
  - Note - the "Speed" is only the closing speed when looking at frontal barrier tests
  - In vehicle-vehicle or moving barrier-vehicle tests, additional calculations need to be made to find the appropriate "Speed" to use in the equation.

Crush Analysis Formulas

History & Formulas - Sample Application

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

$$CF = \frac{Speed_{mph}^{\;2}}{30 * MID}$$

SAMPLE APPLICATION

- For instance, you have a 3130 pound vehicle impacting a barrier at 35 mph, which results in an average crush depth of 21.4 inches

  - For the CF value, Weight is not important

  - TEST SPECIFIC CF=35^2/(30*(21.4/12))
  - TEST SPECIFIC CF = 22.897 (i.e. - 23)

Crush Analysis Formulas

History & Formulas - Sample Application

$$Speed_{mph} = \sqrt{30 * MID * CF}$$

$$CF = \frac{Speed_{mph}^{2}}{30 * MID}$$

- Now, in the "real" collision you have an average crush depth of 10 inches, and a vehicle weight of 3000 pounds. Applying your constant from the test crash, you get -
  - Speed = SQR(30*CF*Crush Dist)
  - Speed = SQR(30*23*(10/12))
  - Speed = 23.979 (i.e.-24 mph)
- Using the Generic CF from AutoStats, you get -
  - Speed = SQR(30*21*(10/12))
  - Speed = 22.91 (i.e.-23 mph)

Crush Analysis Formulas

History & Formulas

$$v_{equivalent} = \sqrt{\frac{2*k*c}{m}}$$

- 1994 -The book **Engineering Analysis of Vehicular Accidents** by Randall K. Noon is published.
- In Chapter 10 he proposes the following method for the evaluation of speed from Crush:
  - From test crashes, use the equation $KE=1/2*m*v^2$ to develop a “k” value which has the units lb-ft/in

Crush Analysis Formulas

History & Formulas

$$v_{equivalent} = \sqrt{\frac{2 * k * c}{m}}$$

- 1994 -The book **Engineering Analysis of Vehicular Accidents** by Randall K. Noon is published. (Cont.)

- Using that k value, and the equation V_{eq}=SQR(2*k*c/m), calculate the speed from crush in ft/sec
  - V_{eq}=Velocity equivalent of a impact into a fixed barrier (feet/sec)
  - k=constant with units of pound-feet/inch
  - c=average inches of crush
  - m=vehicle mass, (weight/gravity)

Crush Analysis Formulas

History & Formulas - Sample Application

$$v_{equivalent} = \sqrt{\frac{2 * k * c}{m}}$$

SAMPLE APPLICATION

- Again, you have a 3130 pound vehicle impacting a barrier at 35 mph, which results in an average crush depth of 21.4 inches
  - From this you calculated the Kinetic Energy expended was 128,200 lb-ft ($KE=1/2*m*v^2$)
  - Dividing the Kinetic energy by the crush depth gives you a "k" value of 5990 lb-ft/in

Crush Analysis Formulas

History & Formulas - Sample Application

$$v_{equivalent} = \sqrt{\frac{2 * k * c}{m}}$$

- Now, in the "real" collision you have an average crush depth of 10 inches, and a vehicle weight of 3000 pounds. Applying your constant from the test crash, you get -
  - V_{eq}=SQR(2*5990*10/(3000/32.2))
  - V_{eq}=SQR(119800/93.17)
  - V_{eq}=35.86 ft/sec or 24.4 miles/hour

Crush Analysis Formulas

History & Formulas - Sample Application

- Taking the sample applications one step further -if you have 30 feet of pre-impact skid on a .74 mu surface, how fast was the vehicle going at the start of the skid / “loss of control”???

Skid Energy loss = SQR(30*30*.74)=SQR(666)=~25.81mph

  - Emori crush speed (impact ~11 mph), beginning speed -28.05 mph
  - CF ~ 23 crush speed (impact ~23.98 mph), beginning speed -35.23 mph
  - CF ~ 21 crush speed (impact ~22.91 mph), beginning speed -34.51 mph
  - k ~5990 crush speed (impact ~24.4 mph), beginning speed -35.51 mph
- ∴ Calculated Beginning Speed ~ 35 mph (except for Emori)

Crush Analysis Formulas

History & Formulas - Sample Application

- Taking the sample applications one step further (cont)

- "What If" the "Actual" Crush (impact) speed was 20 mph? 28 mph?
  - If "Actual" impact ~ 20 mph, beginning speed -32.65 mph
  - If "Actual" impact ~ 28 mph, beginning speed -38.08 mph
- ∴ "Actual" Beginning Speed +/- ~ 3 mph from our calculated speed (Except for Emori, which is conservatively low)

Crush Analysis Formulas

History & Formulas

- ★ Several formulas have been presented, including some with a "case sample"
- ★ Note, I haven't even attempted to do a case sample with the "Campbell" approach (Did I mention it's complex??)
- ★ Of the formulas presented, Emori and the "Minimum Speed From Skid" formulas require the least amount of supporting data and are the easiest to use
- ★ Emori's formula is conservative, maybe TOO conservative

Crush Analysis Formulas

History & Formulas

- Several formulas have been presented (cont)

- The "Minimum Speed From Skid" formula with the AutoStats CF values is designed as a "Near Actual" value for the crush speed, as is Noon's approach, rather than a "minimum speed"
- The "Minimum Speed From Skid" formula can be made to be more conservative by reducing the CF value and/or by applying it to AVERAGE crush of the subject vehicle.

Speed Calculations

Crash Test Examples

Speed Calculations

Crash Test Examples

The following three examples are based on crash tests done this year as part of SCARS

The first two were hit over the axles, to illustrate adjustments needed to the ACM/CDR speed values.

The third test was designed so that the PDOF goes nearly through the CG of the Target vehicle.

Speed Calculations

Crash Test Examples - CT1

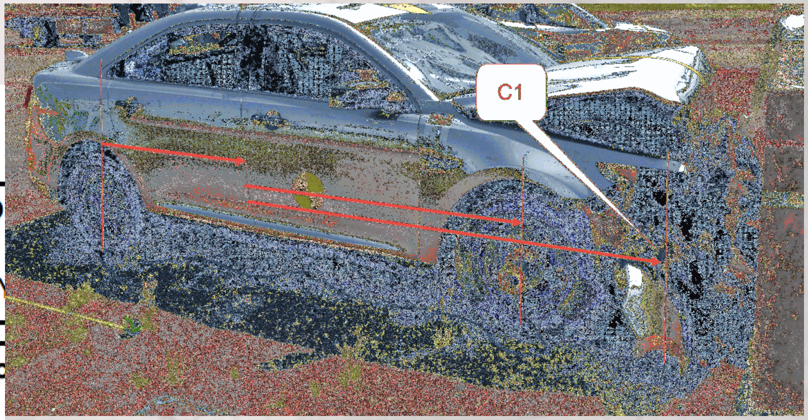
2013 FORD TAURUS AWD - Front Impact

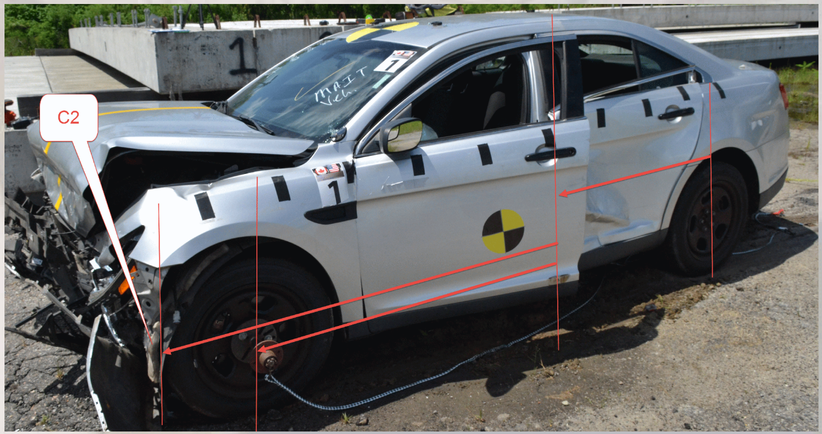
Curb Weight (pounds):	4296
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	4296
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	65.0
Crush Profile Measurements:	2

PDO

"Kno

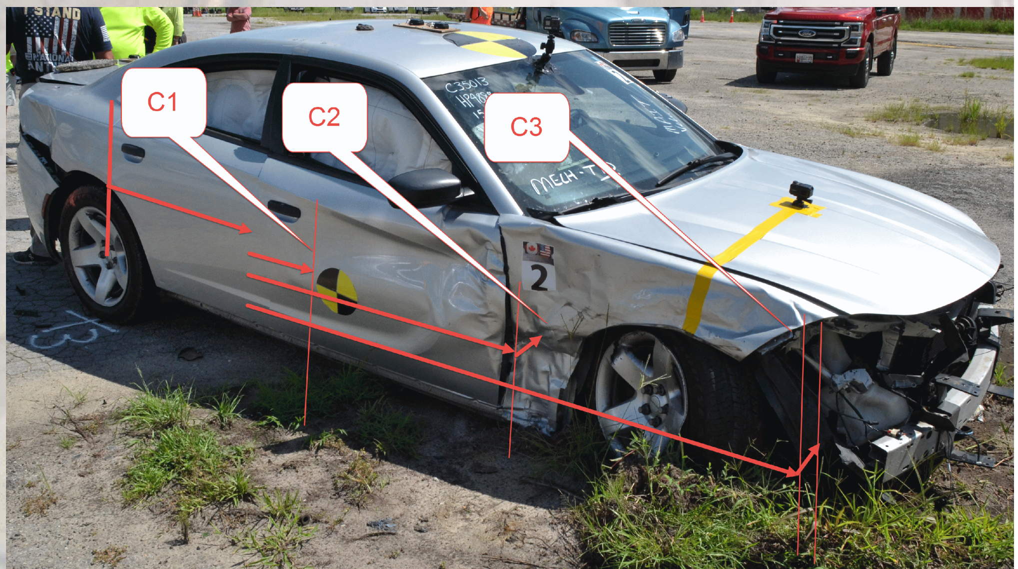
		Equal Spacing (inches)	Zone Area (inches²)	Zo Dep (in
C1 (inches)	7.00	65.00	975.00	
C2 (inches)	23.00			





Speed Calculations

Crash Test Examples - CT1



2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	8.04
Damage Length (inches):	84.0
Crush Profile Measurements:	3

		Unequal Spacing (inches)	Zone Area (inches^2)
C1 (inches)	0.00	47.00	305.50
C2 (inches)	13.00	37.00	370.00
C3 (inches)	7.00		

Speed Calculations

Crash Test Examples - CT1

Speed Calculations

Crash Test Examples - CT1

Emori				
Speed mp	1.1 * c			
c =	Maximum Crush in inches			
Crush Factor				
Speed mp	SQR(30*CF*MID)			
MID =	Maximum Crush in Feet (at primary contact level)			
CF =	Crush Factor (G's)			
Noon				
v in fps =	SQR(2*k*c/m)			
k =	lb-ft/in			
c inches =	avg crush depth - inches			
m =	vehicle mass = wt / 32.2			

Speed Calculations

Crash Test Examples - CT1

CRASH 3	
E =	(A*C + (B*C*C/2) + G) * L (in/lbs)
A =	Spring pre-lading value (lbs/inch)
B =	Energy absorbed in permanent deformation (lb/(in*in))
G =	Energy abosrobed in elastic deformation ((A*A)/(2*B))
C =	Avg Crush (inches)
L =	Damage Length (in)
KEES / BEV / EBS	
KEES =	(360/528)* SQR[((2*E*gamma)/12) / (w/g)] (mph)
E =	Crush Energy (inch/lbs)
gamma =	constant coming from Yaw Moment of Inertia and Moment arm - ignored for these illustrations
w =	weight (lbs)
g =	gravity (ft/s/s)

Speed Calculations

Crash Test Examples - CT1 - Input Variables

							CRASH 3	Noon's		
Weight	Crush Length	Avg Crush	Max Crush	A	B	G	E	k		
4296	65	15	23	348.4	116.2	522.3	1223352.0	2748.59	Bullet	2013 Ford Taurus AWD
3950	84	8.04	13	249.8	355.9	97.1	1143111.0	1469.39	Target	2015 Dodge Charger

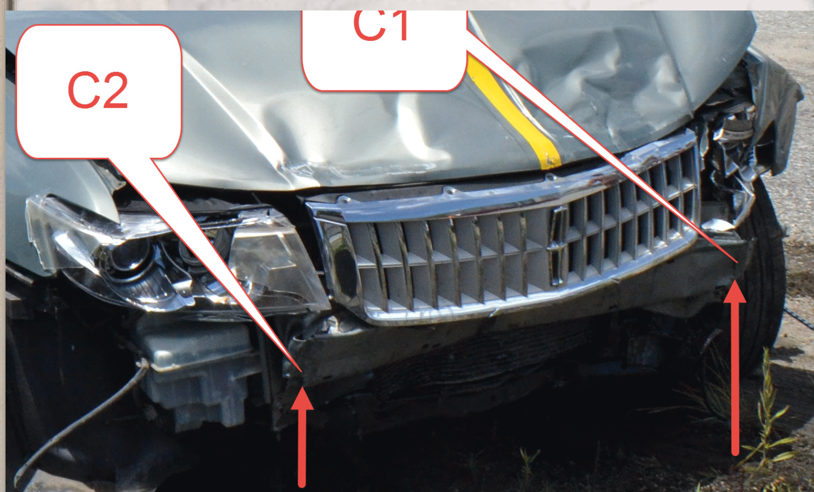
Speed Calculations

Crash Test Examples - CT1 - Output

		Emori		Crush Factor		Noon		CRASH 3	
		Damage Speed		Damage Speed		Damage Speed		Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	2013 Ford Taurus AWD	37.1	**25.3**	51.0	**34.7**	24.9	**17.0**	39.1	**26.7**
Target	2015 Dodge Charger	21.0	**14.3**	38.3	**26.1**	13.9	**9.5**	39.4	**26.9**
Combined Speed			**29.1**		**43.5**		**19.4**		**37.8**
Instrumented Closing Speed			**~47**		**~47**		**~47**		**~47**
Instrumented delta-v Bullet			22-23		22-23		22-23		22-23
Instrumented delta-v Target			~26-27		~26-27		~26-27		~26-27
Combined Crush + Rollout Speed			**45.8**		**56.1**		**40.4**		**51.8**

Speed Calculations

Crash Test Examples - CT2



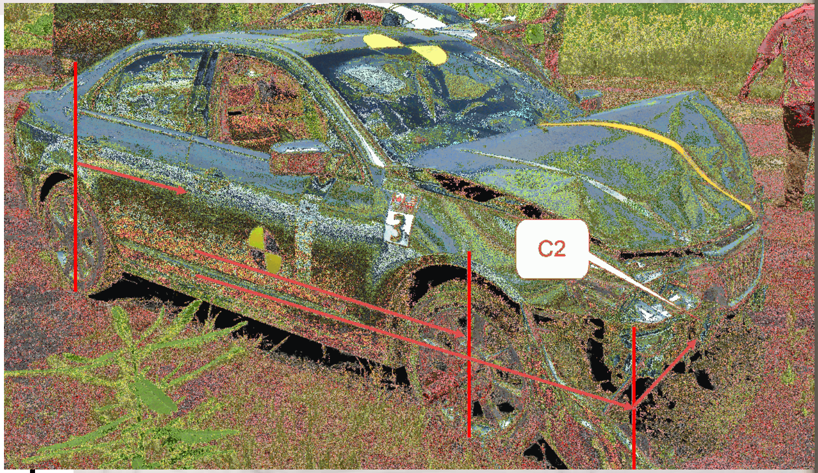
Speed Calculations

Crash Test Examples - CT2

2008 LINCOLN MKZ - Front Impact

Curb Weight (pounds):	3519
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3519
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	62.0
Crush Profile Measurements:	2

		Equal Spacing (inches)	Zone Area (inches^2)
C1 (inches)	18.00	62.00	930.00
C2 (inches)	12.00		



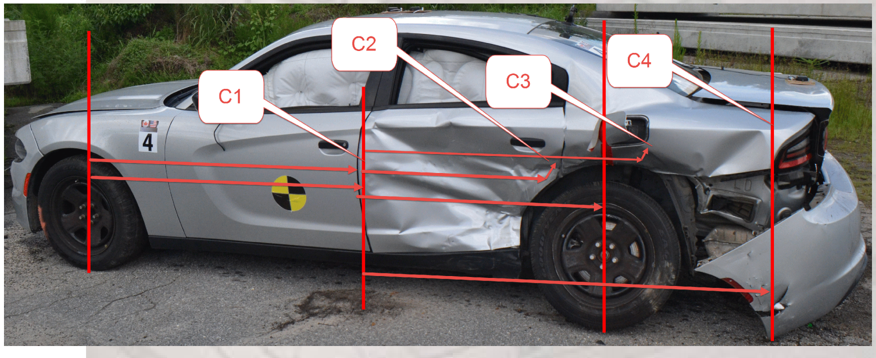
Speed Calculations

Crash Test Examples - CT2

2015 DODGE CHARGER - Side Impact

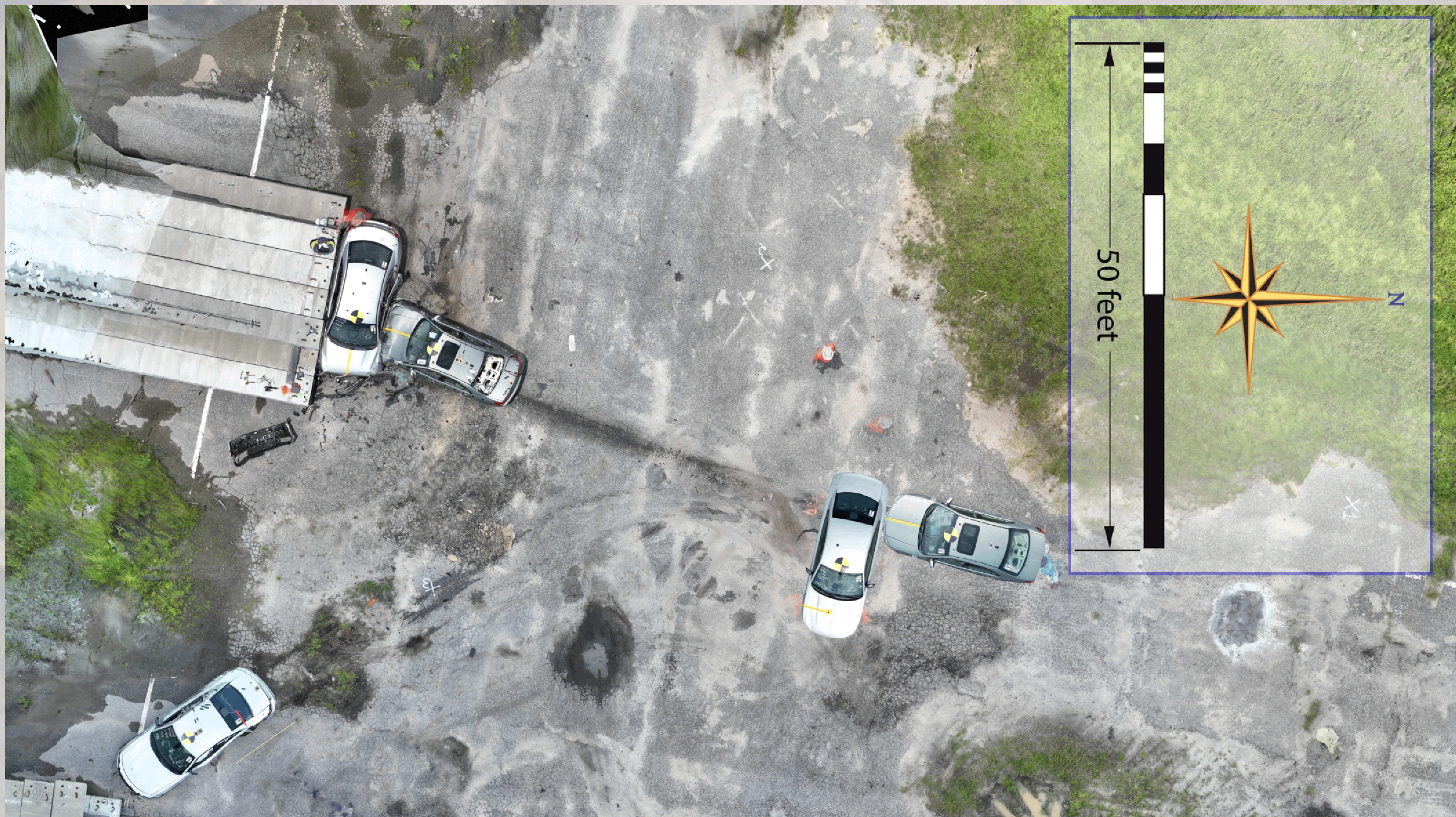
Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4

		Unequal Spacing (inches)	Zone Area (inches²)
C1 (inches)	0.00		
		31.00	108.50
C2 (inches)	7.00		
		19.00	104.50
C3 (inches)	4.00		
		32.00	64.00
C4 (inches)	0.00		



Speed Calculations

Crash Test Examples - CT2



Speed Calculations

Crash Test Examples - CT2

Emori				
Speed mp	1.1 * c			
c =	Maximum Crush in inches			
Crush Factor				
Speed mp	SQR(30*CF*MID)			
MID =	Maximum Crush in Feet (at primary contact level)			
CF =	Crush Factor (G's)			
Noon				
v in fps =	SQR(2*k*c/m)			
k =	lb-ft/in			
c inches =	avg crush depth - inches			
m =	vehicle mass = wt / 32.2			

Speed Calculations

Crash Test Examples - CT2

CRASH 3	
E =	(A*C + (B*C*C/2) + G) * L (in/lbs)
A =	Spring pre-lading value (lbs/inch)
B =	Energy absorbed in permanent deformation (lb/(in*in))
G =	Energy abosrobed in elastic deformation ((A*A)/(2*B))
C =	Avg Crush (inches)
L =	Damage Length (in)
KEES / BEV / EBS	
KEES =	(360/528)* SQR[((2*E*gamma)/12) / (w/g)] (mph)
E =	Crush Energy (inch/lbs)
gamma =	constant coming from Yaw Moment of Inertia and Moment arm - ignored for these illustrations
w =	weight (lbs)
g =	gravity (ft/s/s)

Speed Calculations

Crash Test Examples - CT2 - Input

							CRASH 3	Noon's		
Weight	Crush Length	Avg Crush	Max Crush	A	B	G	E	k		
3519	62	15	18	356.7	121.7	522.7	1212998.4	1875.48	Bullet	2008 Lincoln MKz
3950	82	3.38	7	249.8	355.9	97.1	243900.5	1469.39	Target	2015 Dodge Charger

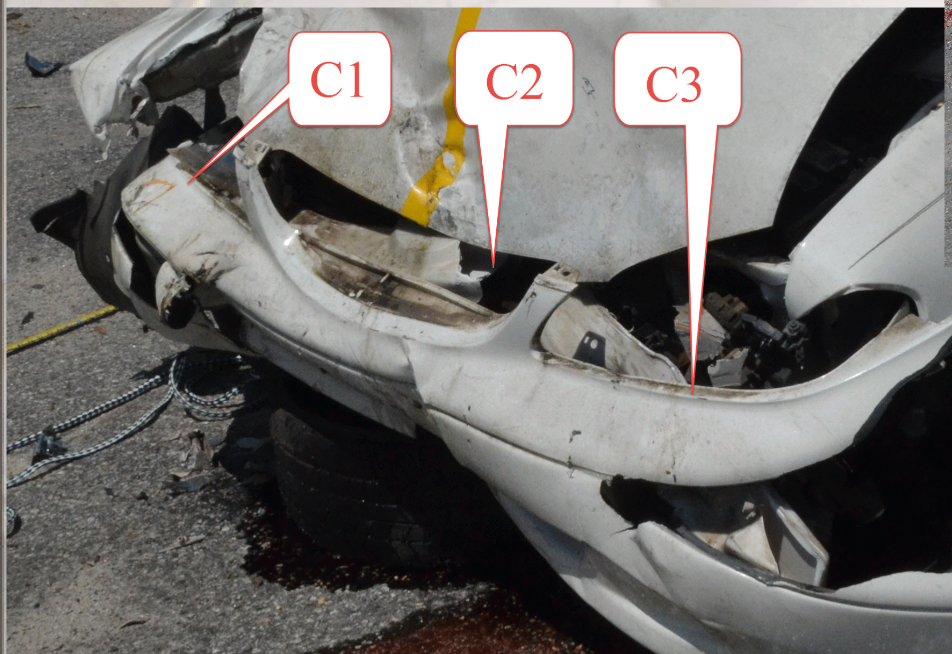
Speed Calculations

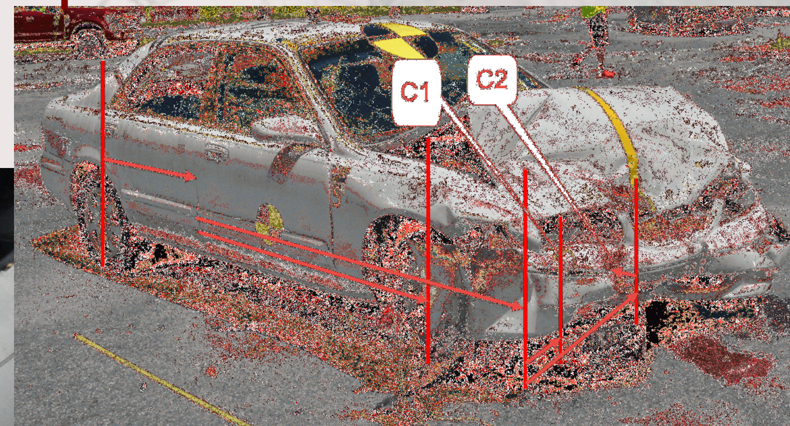
Crash Test Examples - CT2 - Output

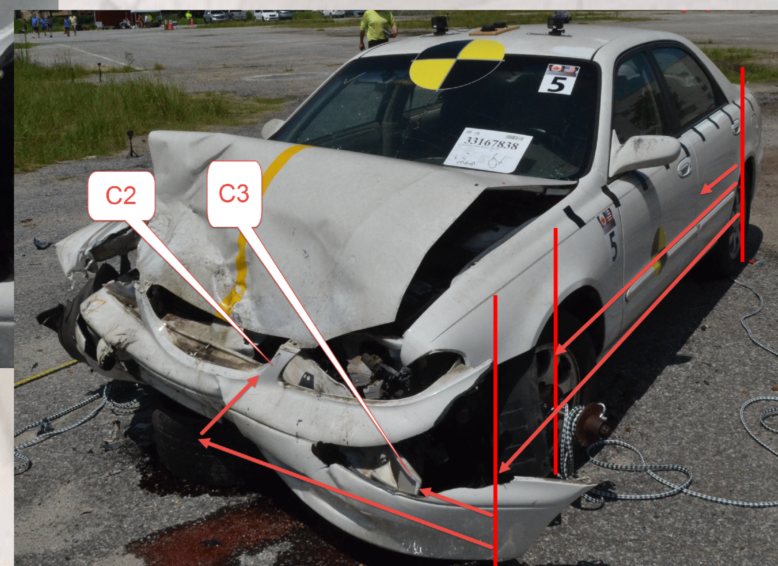
		Emori Damage Speed		Crush Factor Damage Speed		Noon Damage Speed		CRASH 3 Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	2008 Lincoln MKz	29.0	**19.8**	45.1	**30.7**	22.7	**15.5**	43.0	**29.3**
Target	2015 Dodge Charger	11.3	**7.7**	28.1	**19.2**	9.0	**6.1**	18.2	**12.4**
Combined Speed			**21.2**		**36.2**		**16.6**		**31.8**
Instrumented Closing Speed			**~48**		**~48**		**~48**		**~48**
Instrumented delta-v Bullet			22-23		22-23		22-23		22-23
Instrumented delta-v Target			~26-31		~26-31		~26-31		~26-31
Combined Crush + Rollout Speed			**44.2**		**53.1**		**42.2**		**50.2**

Speed Calculations

Crash Test Examples - CT3







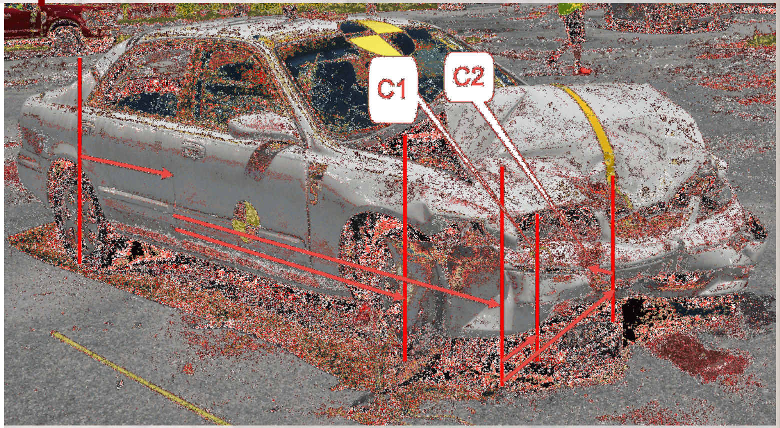
Speed Calculations

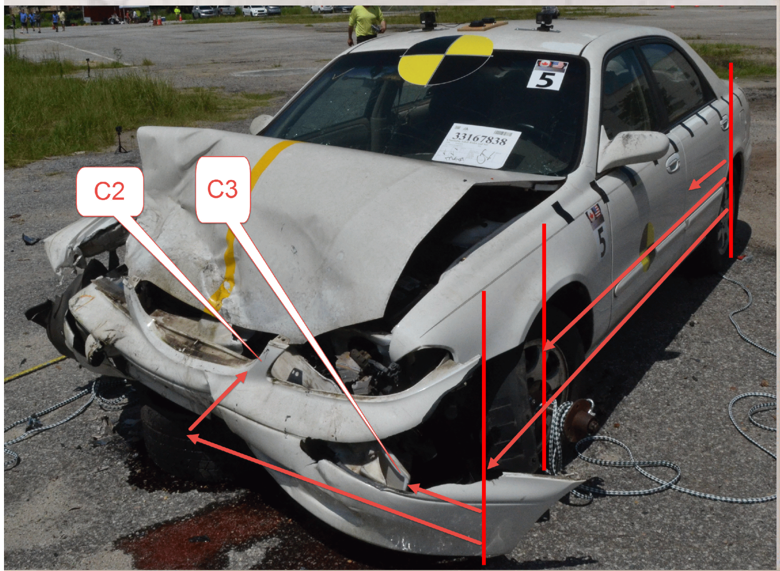
Crash Test Examples - CT3

1996 MAZDA 626 - Front Impact

Curb Weight (pounds):	2626
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	2626
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	18.40
Damage Length (inches):	59.0
Crush Profile Measurements:	3

		Unequal Spacing (inches)	Zone Area (inches^2)
C1 (inches)	18.00	33.00	643.50
C2 (inches)	21.00	26.00	442.00
C3 (inches)	13.00		





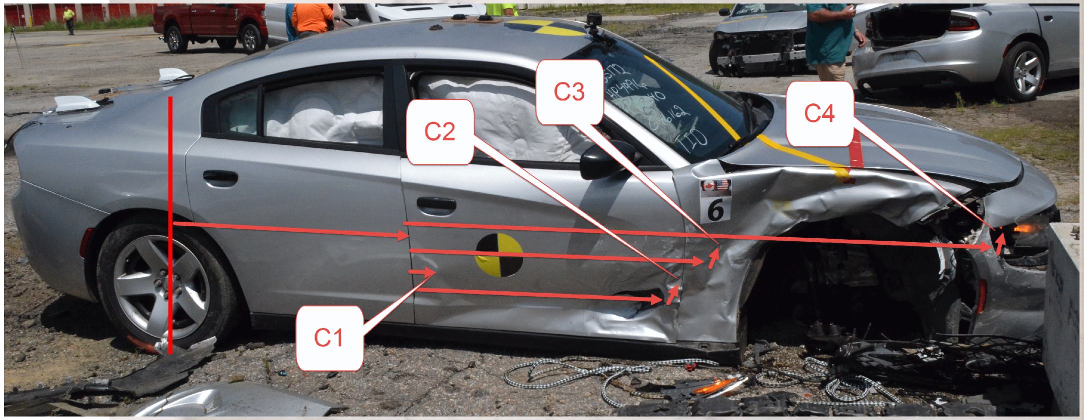
Speed Calculations

Crash Test Examples - CT3

2016 DODGE CHARGER

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	2.72
Damage Length (inches):	92.0
Crush Profile Measurements:	4

		Unequal Spacing (inches)	Zone Area (inches^2)
C1 (inches)	0.00	44.00	44.00
C2 (inches)	2.00	5.00	12.50
C3 (inches)	3.00	43.00	193.50
C4 (inches)	6.00		



Speed Calculations

Crash Test Examples - CT3

Speed Calculations

Crash Test Examples - CT3

Emori				
Speed mp	1.1 * c			
c =	Maximum Crush in inches			
Crush Factor				
Speed mp	SQR(30*CF*MID)			
MID =	Maximum Crush in Feet (at primary contact level)			
CF =	Crush Factor (G's)			
Noon				
v in fps =	SQR(2*k*c/m)			
k =	lb-ft/in			
c inches =	avg crush depth - inches			
m =	vehicle mass = wt / 32.2			

Speed Calculations

Crash Test Examples - CT3

CRASH 3	
E =	(A*C + (B*C*C/2) + G) * L (in/lbs)
A =	Spring pre-lading value (lbs/inch)
B =	Energy absorbed in permanent deformation (lb/(in*in))
G =	Energy abosrobed in elastic deformation ((A*A)/(2*B))
C =	Avg Crush (inches)
L =	Damage Length (in)
KEES / BEV / EBS	
KEES =	(360/528)* SQR[((2*E*gamma)/12) / (w/g)] (mph)
E =	Crush Energy (inch/lbs)
gamma =	constant coming from Yaw Moment of Inertia and Moment arm - ignored for these illustrations
w =	weight (lbs)
g =	gravity (ft/s/s)

Speed Calculations

Crash Test Examples - CT3 - Input

							CRASH 3	Noon's		
Weight	Crush Length	Avg Crush	Max Crush	A	B	G	E	k		
2626	59	18.4	21	287.1	89.3	461.5	1230790.6	1577.77	Bullet	1996 Mazda 626
3950	92	2.72	6	249.8	355.9	97.1	192565.3	1469.39	Target	2016 Dodge Charger

Speed Calculations

Crash Test Examples - CT3 - Output

		Emori Damage Speed		Crush Factor Damage Speed		Noon Damage Speed		CRASH 3 Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	1996 Mazda 626	33.9	**23.1**	48.7	**33.2**	26.7	**18.2**	50.2	**34.2**
Target	2016 Dodge Charger	9.7	**6.6**	26.0	**17.7**	8.1	**5.5**	16.2	**11.0**
Combined Crush Speed			**24.0**		**37.6**		**19.0**		**35.9**
Instrumented Closing Speed			**~50-51**		**~50-51**		**~50-51**		**~50-51**
Instrumented delta-v Bullet			~37-38		~37-38		~37-38		~37-38
Instrumented delta-v Target			~22-23		~22-23		~22-23		~22-23
Combined Crush + Rollout Speed			**35.2**		**45.6**		**31.9**		**44.2**

Speed Calculations

Force Balance

Speed Calculations

Force Balance

The Force Balance model is an extension of the CRASH 3 model.

The original purpose of this model was to “get” stiffness values for one vehicle when none were otherwise obtainable, and is based on Newton’s Third Law of “Equal but Opposite Force”.

Speed Calculations

Force Balance

In many instances you have collisions with "non-standard" alignment. The most common instances of this are:

- Under/Over ride
- One vehicle lacks a bumper (dump truck, box truck, semi trailer, etc.)

Additionally or alternatively, you may have a vehicle which has no crash tests:

- Rear impact after 1998
- Lamborghini, Maserati, Porsche, etc.

Speed Calculations

Force Balance

One way to develop A-B-G stiffness values is through a process called Force Balance.

In this method/model you calculate the Force on the vehicle that you "know" the stiffness values for (or at least have the most confidence in that vehicles values).

Then applying the Law of "Equal but Opposite" Forces, you calculate the Stiffness values for the "Unknown" vehicle.

Speed Calculations

Force Balance

Extending this model a bit further, in addition to calculating Stiffness values for the unknown vehicle, you can calculate

- KEES/BEV for the damage to both vehicles
- delta-v for both vehicles
- Closing Speed between the vehicles.

Speed Calculations

Force Balance

In order for this model to work, you must have

- Stiffness values for one vehicle
- Damage to both vehicles

Speed Calculations

Force Balance - CT1

Results

BULLET	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Avg - 1 Std. Deviations	269.5	62.6	39276.25	66802.92	21.6	15.1	46.8
Average	348.4	116.2	67970.50	108659.78	27.5	19.4	60.1
Avg + 1 Std. Deviations	427.3	169.8	96664.75	150912.93	32.5	22.9	71.0

Results

TARGET	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Avg - 1 Std. Deviations	123.4	101.0	39276.25	34646.23	16.2	16.4	28.8
Average	165.2	180.7	67970.50	58466.06	21.1	21.1	38.5
Avg + 1 Std. Deviations	198.7	261.5	96664.75	82098.64	25.0	24.9	46.3

Instrumented Closing Speed		~47
Instrumented delta-v Bullet		22-23
Instrumented delta-v Target		~26-27

Speed Calculations

Force Balance - CT2

Results

BULLET

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Avg - 1 Std. Deviations	288.7	77.5	44987.20	70800.01	24.6	20.1	38.0
Average	356.7	121.7	67648.20	102026.37	29.5	24.2	45.8
Avg + 1 Std. Deviations	424.7	165.9	90309.20	133438.01	33.7	27.7	52.4

Results

TARGET

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Avg - 1 Std. Deviations	202.3	264.8	44987.20	19176.12	12.1	17.9	46.1
Average	252.8	413.4	67648.20	28184.58	14.6	21.6	57.6
Avg + 1 Std. Deviations	295.4	564.3	90309.20	37133.87	16.8	24.7	67.2

Instrumented Closing Speed		~48
Instrumented delta-v Bullet		22-23
Instrumented delta-v Target		~26-31

Speed Calculations

Force Balance - CT3

Results

BULLET	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Avg - 1 Std. Deviations	181.6	27.5	20284.20	42554.21	22.0	18.6	31.0
Average	287.1	89.3	56941.49	103505.36	34.4	29.2	48.5
Avg + 1 Std. Deviations	392.6	151.1	93598.78	165374.08	43.5	36.9	61.4

Results

TARGET	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Avg - 1 Std. Deviations	126.3	115.7	20284.20	7954.56	7.8	12.4	32.3
Average	226.4	371.9	56941.49	20655.05	12.5	19.4	57.8
Avg + 1 Std. Deviations	296.8	639.0	93598.78	33188.31	15.9	24.5	75.8

Instrumented Closing Speed		**~50-51**
Instrumented delta-v Bullet		~37-38
Instrumented delta-v Target		~22-23

Speed Calculations

Special Considerations
Narrow Objects

Speed Calculations

Special Considerations - Narrow Objects

- **Crush Factor**
  - The general value, when nothing else is known, is 21
  - This is an average value, rounded to the nearest whole number, of all NHTSA Crash tests 1979-1992
  - This value is still observed to hold true when reviewing 4N6XPRT StifCalcs® reports
- Narrow Object (Pole) Impacts
- **KEES = SQR (30*MID*CF*0.60)**

Speed Calculations

Special Considerations - Narrow Objects

- ★ Narrow Object (Pole) Impacts
- ★ **KEES = SQR (30*MID*CF*0.60)**
  - ★ Due to the Narrow Object concentrating the force, the crush depth will be greater
  - ★ The concentration of force is compensated for by reducing the Crush Factor. This is why the 60% (0.60) multiplier is present in the formula.
  - ★ It was thought that the multiplier would be easier to remember than a "new/different" Crush Factor value.
- ★ But what is a "Narrow Object"?

Speed Calculations

Special Considerations - Narrow Objects

- ★But what is a “Narrow Object”?
- ★A Narrow Object is, generally, something that has a “diameter” of ~ 2 foot or less
- ★A pole, a tree, but also it can be a corner of a building, or bridge support column

Speed Calculations

Special Considerations - Narrow Objects

- When is the 60% modifier applied?
- In general, if you can see an indentation to the crush profile as opposed to a “flat” line, start thinking about a possible modifier.
- If the crush indentation is 6-10 inches in from the sides or less, you usually want to use the full Crush Factor

Speed Calculations

Special Considerations - Narrow Objects

- When is the 60% modifier applied? (Cont)
- If the crush indentation is 12-18 inches in from the sides or more, you usually want to use the 60% modifier.
- In the area of 6-18 inches .... you need to look at the rest of the evidence and THINK!

"No brain at all, some of them [people], only grey fluff that's blown into their heads by mistake, and they don't THINK."

Speed Calculations

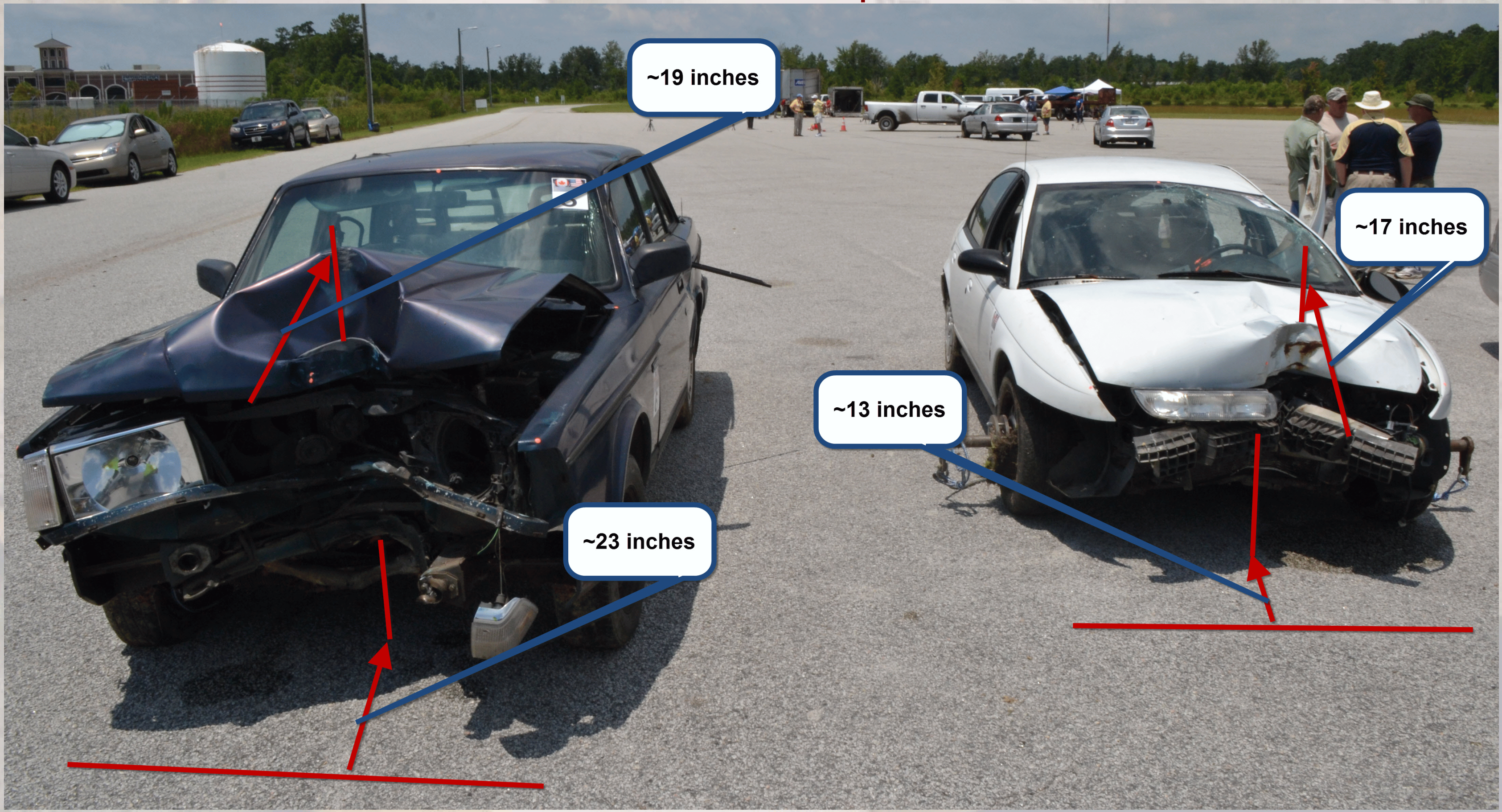
Special Considerations - Narrow Objects

- When is the 60% modifier applied? (Cont)
- Do you have a concentration of Force which results in greater crush depth penetration than you would expect?
  - Yes - Apply modifier
  - No - Use full value

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2013 Pole Impact Tests



Speed Calculations

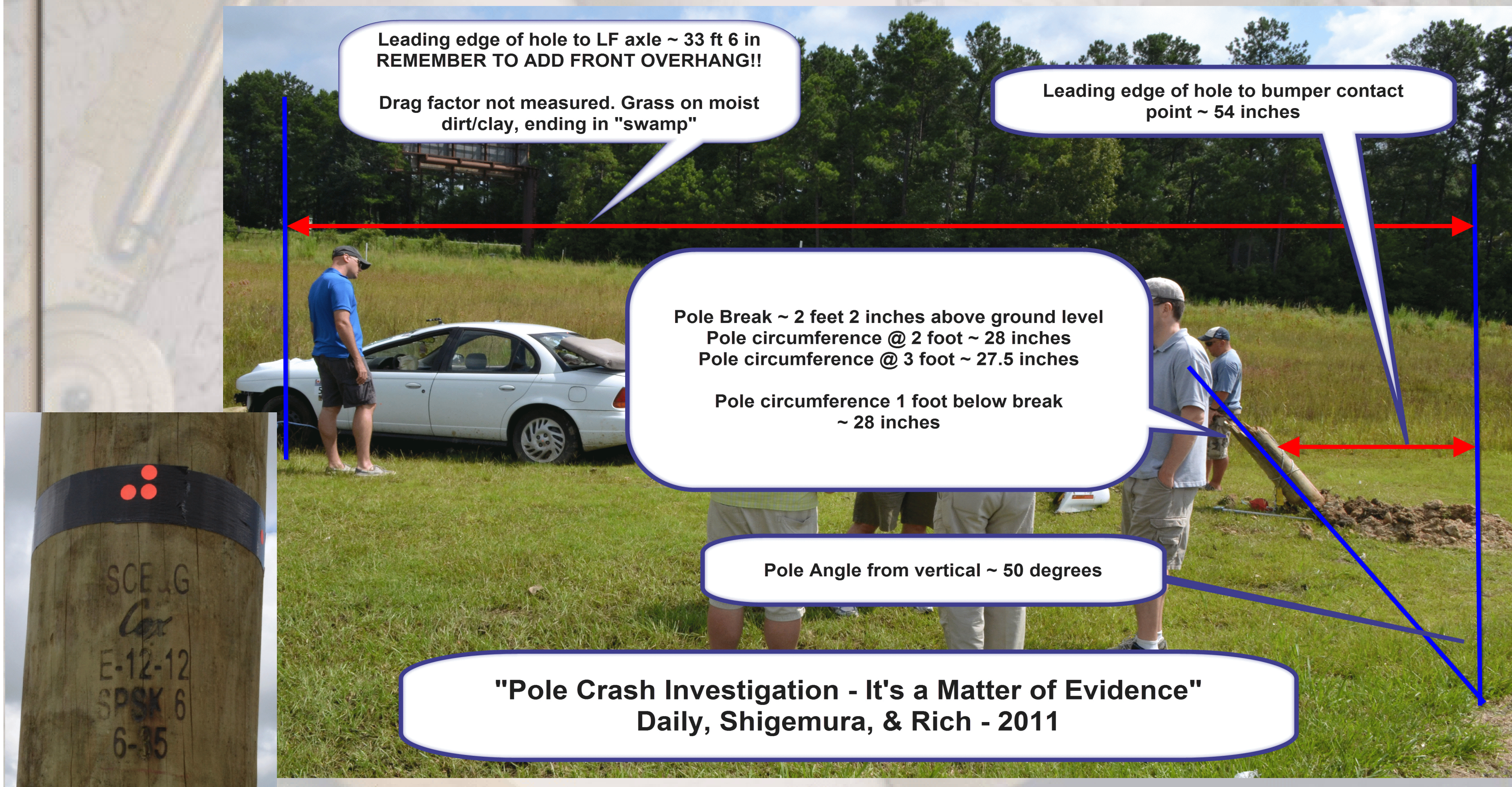
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1998 Saturn SL2 - KEES Speed

- Max Crush at Bumper Level ~ 13 inches
  - KEES = SQR(30*(13/12)*21*0.6)
  - KEES ~ 20 mph

- Max Crush at Hood ~ 17 inches
  - KEES = SQR(30*(17/12)*21*0.6)
  - KEES ~ 23 mph

Speed Calculations

Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests (1998 Saturn SL2)
Field Evidence



Speed Calculations

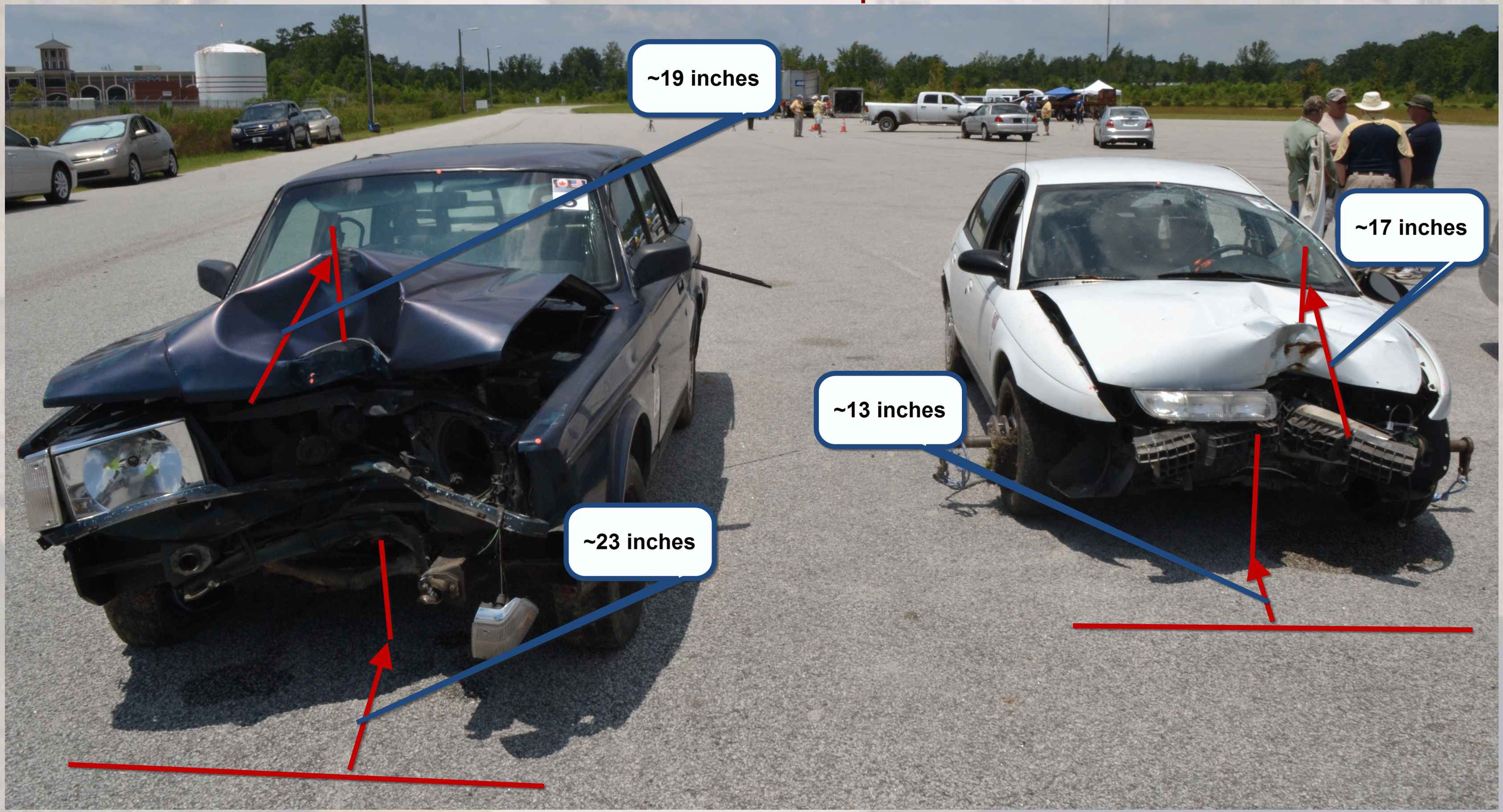
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1998 Saturn SL2 - Impact Speed

- Drag factor estimated 0.4-0.6
- Max Crush at Bumper Level ~ 13 inches
  - Impact Speed = SQR(KEES^2 + 30*33.5*0.4)
  - Impact Speed ~ 28-29 mph
- Max Crush at Hood ~ 17 inches
  - Impact Speed = SQR(KEES^2 + 30*33.5*0.6)
  - KEES ~ 33-34 mph
- **Instrumented Impact Speed = 41-42 mph**

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2013 Pole Impact Tests



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Speed Calculations

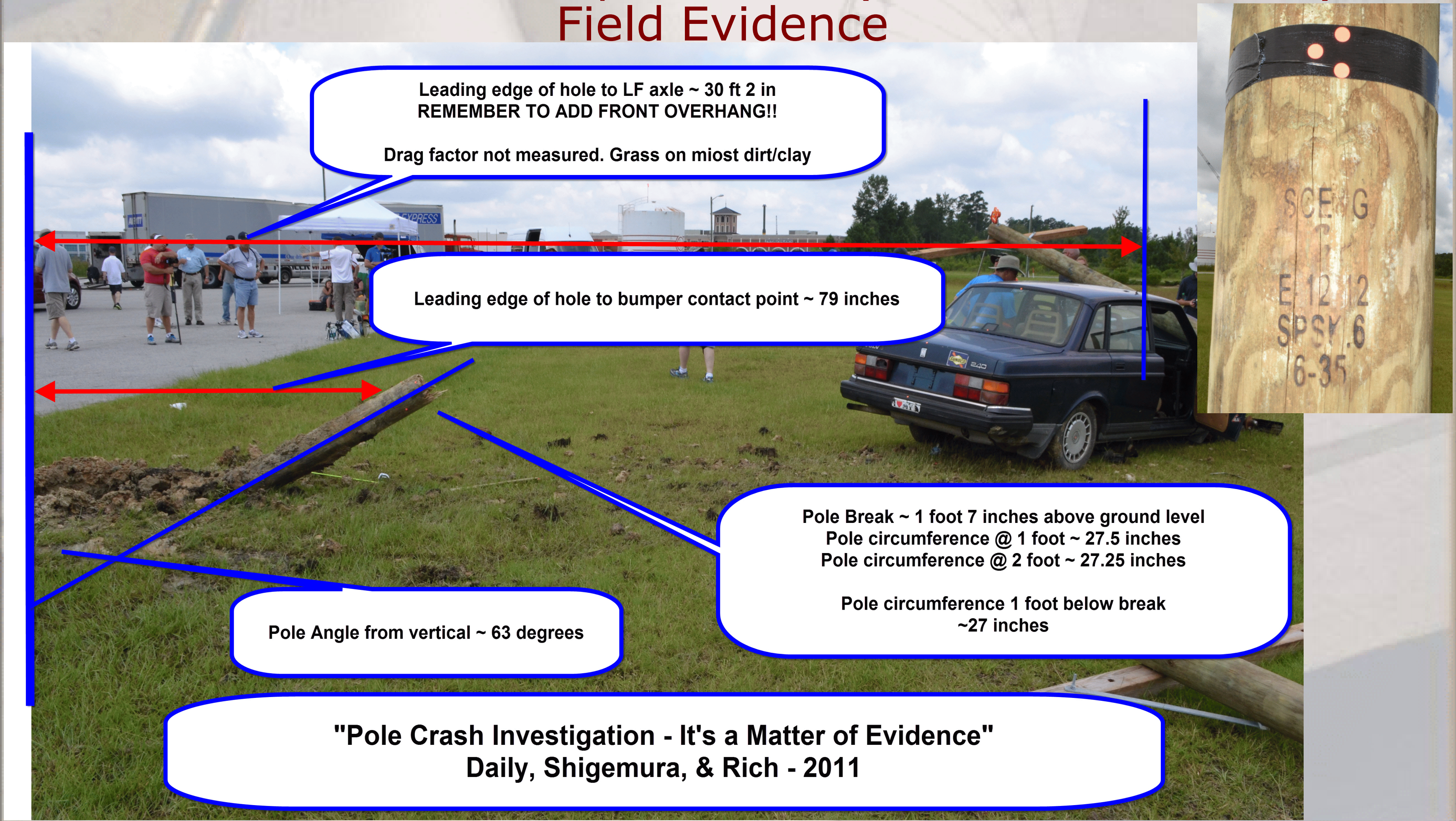
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1992 Volvo 240 DL- KEES Speed

- Max Crush at Bumper Level ~ 23 inches
  - KEES = SQR(30*(23/12)*21*0.6)
  - KEES ~ 27 mph

- Max Crush at Hood ~ 19 inches
  - KEES = SQR(30*(19/12)*21*0.6)
  - KEES ~ 24-25 mph

Speed Calculations

Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests (1992 Volvo 240 DL)
Field Evidence



Speed Calculations

Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1992 Volvo 240 DL - Impact Speed

- Drag factor estimated 0.4-0.6
- Max Crush at Bumper Level ~ 23 inches
  - Impact Speed = SQR(KEES^2 + 30*33.2*0.4)
  - Impact Speed = ~ 33-34 mph
- Max Crush at Hood ~ 19 inches
  - Impact Speed = SQR(KEES^2 + 30*33.2*0.6)
  - Impact Speed = ~ 34-35 mph
- **Instrumented Impact Speed = 42 mph**

Speed Calculations

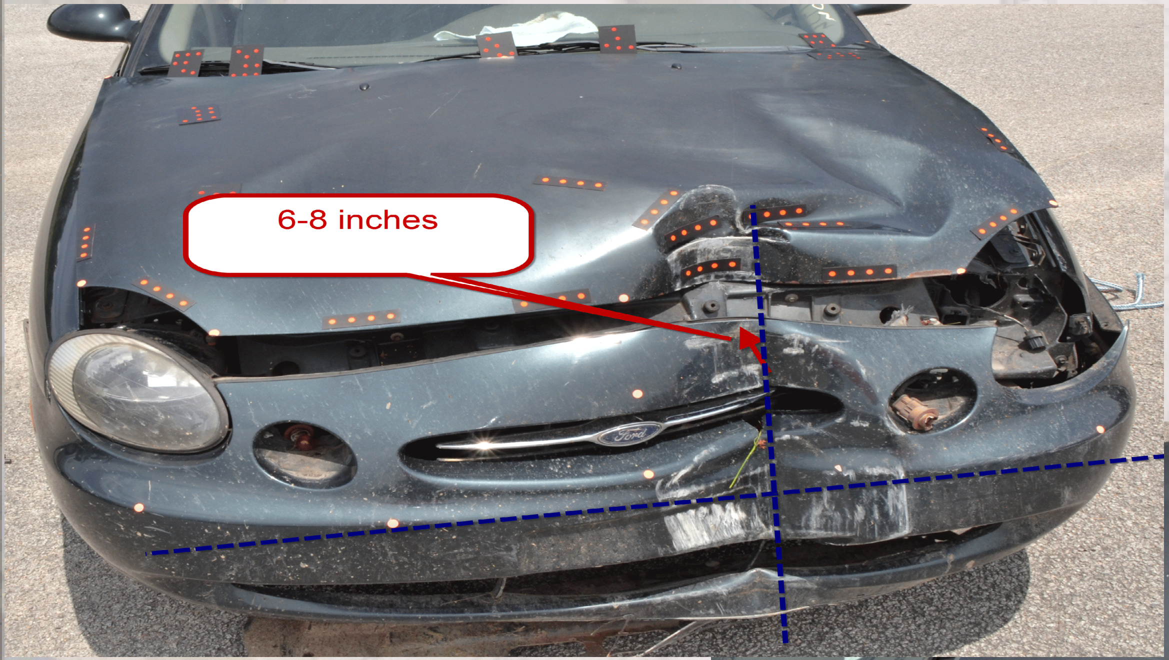
Special Considerations - Narrow Objects

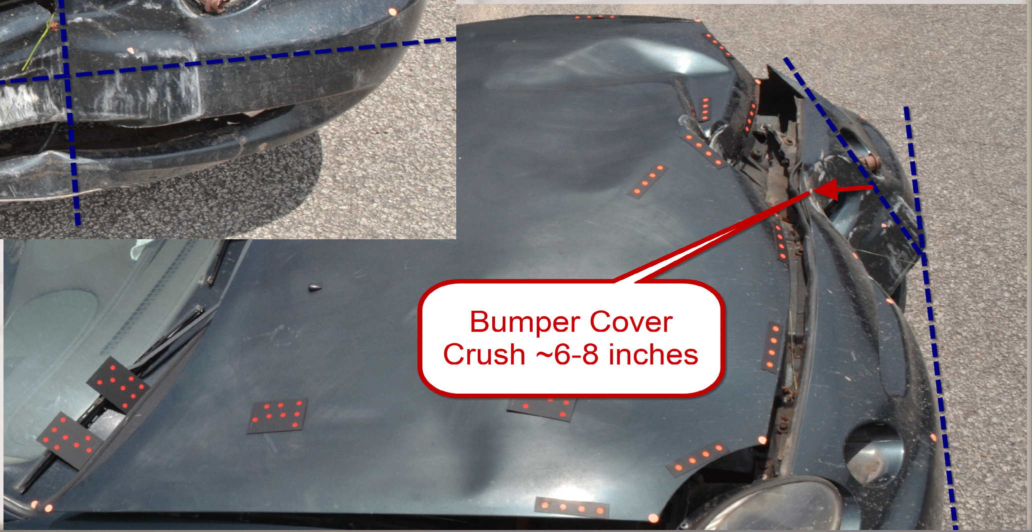
SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus





Speed Calculations

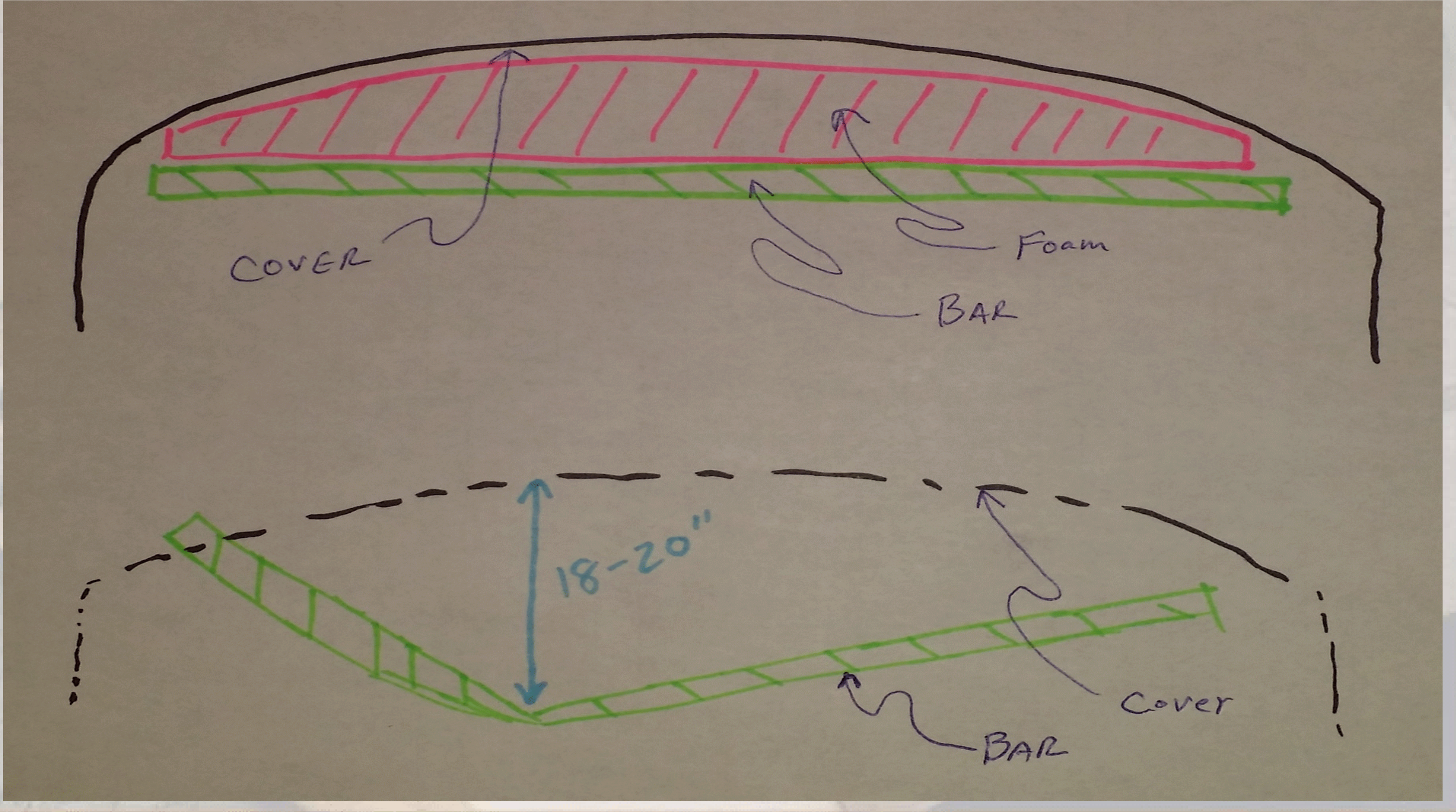
Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Speed Calculations

Special Considerations - Narrow Objects

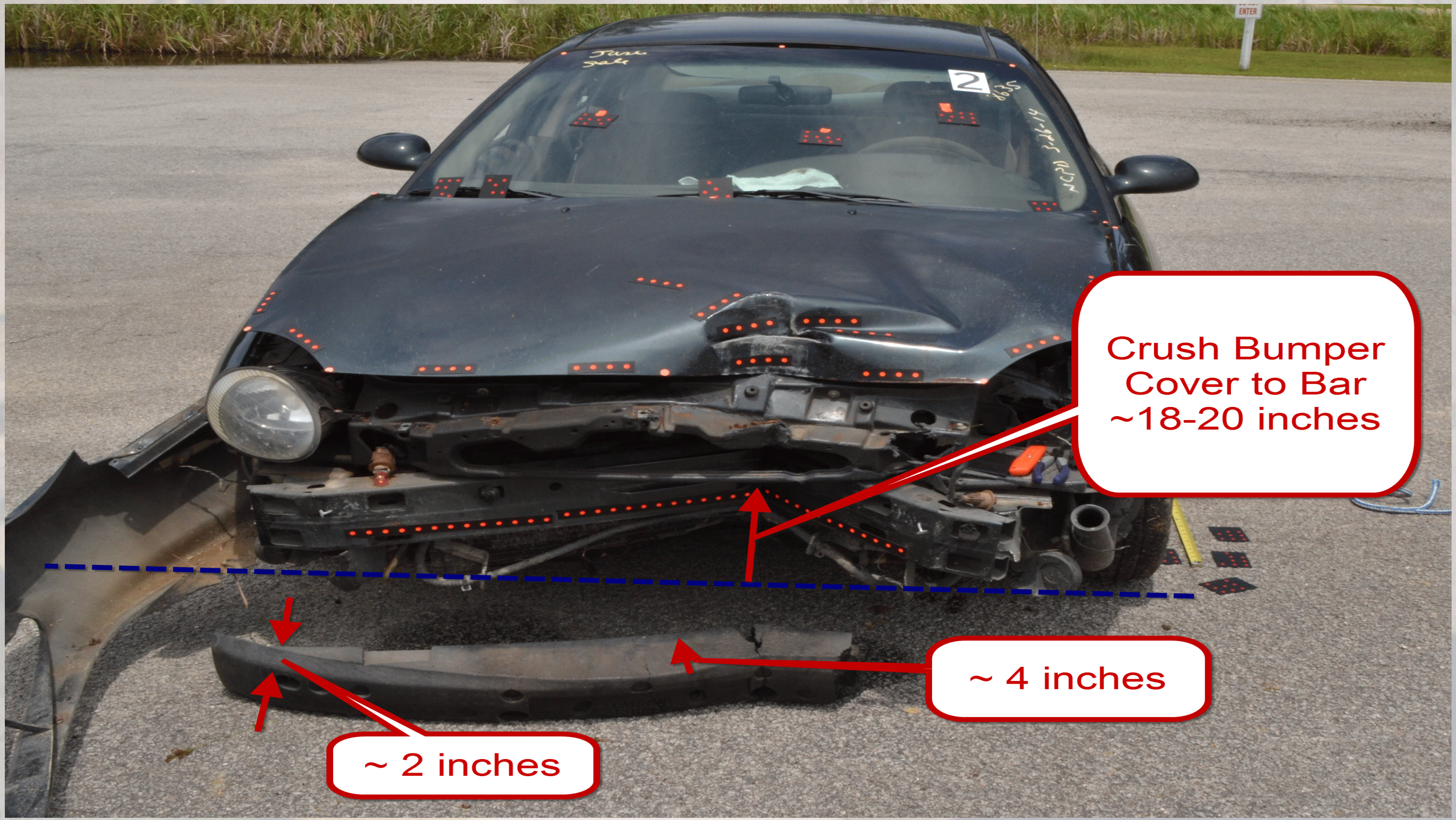
SCARS 2014 Pole Impact Tests - 1999 Ford Taurus



Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus



Speed Calculations

Special Considerations - Narrow Objects
SCARS 2014 Pole Impact Tests
1999 Ford Taurus - KEES Speed

- Max Crush measured from ~ bumper cover to bumper bar ≈19 inches
- Energy absorbing Plastic thickness ≈ 4 inches
- Therefore, Max Crush at Bumper Level ≈ **15 inches** (not 19)
  - KEES = SQR**(**30*(15/12)*21*0.6**)**
  - KEES ~ 21.7 mph

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

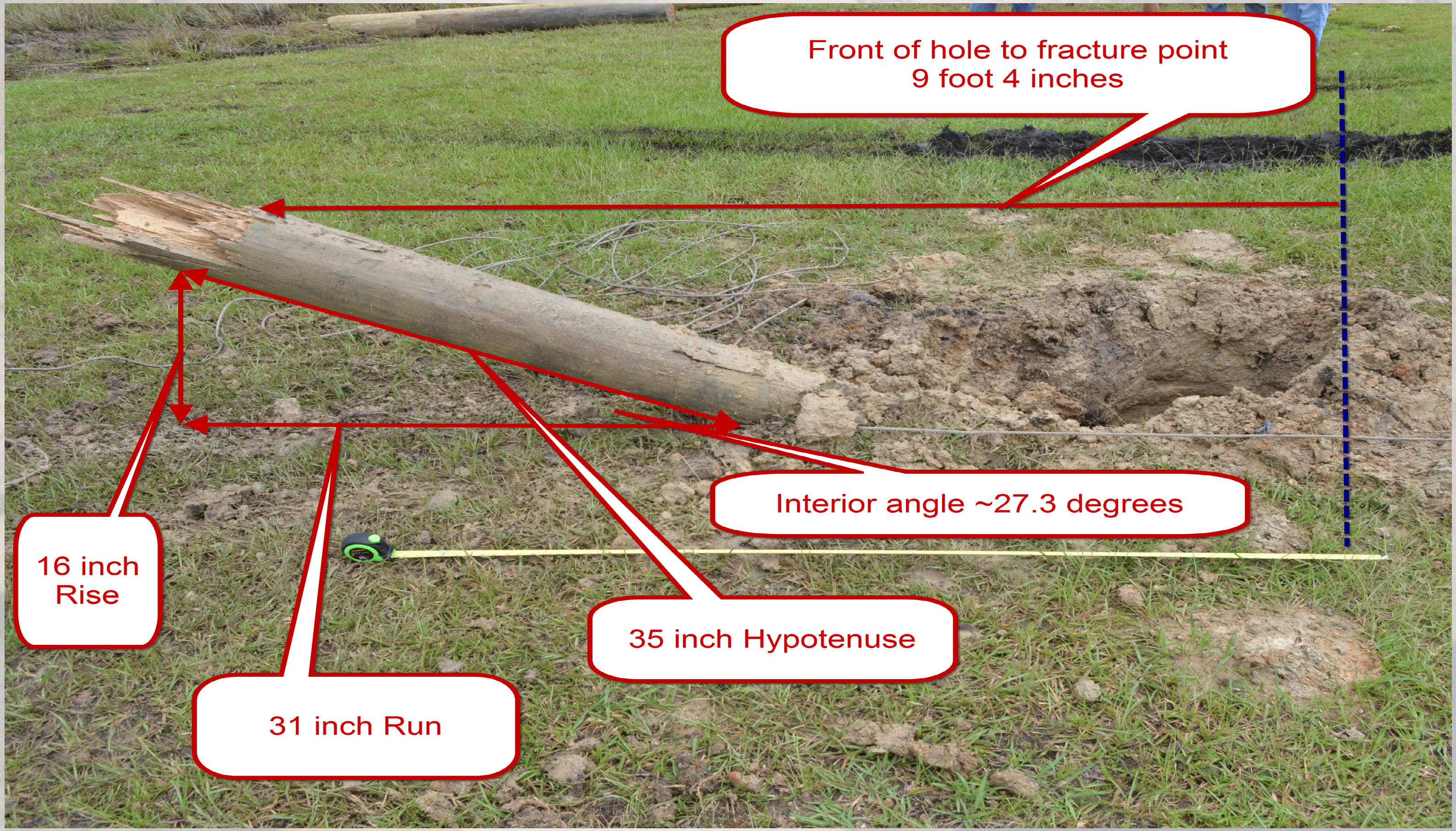
Field Evidence

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Field Evidence



Speed Calculations

Special Considerations - Narrow Objects

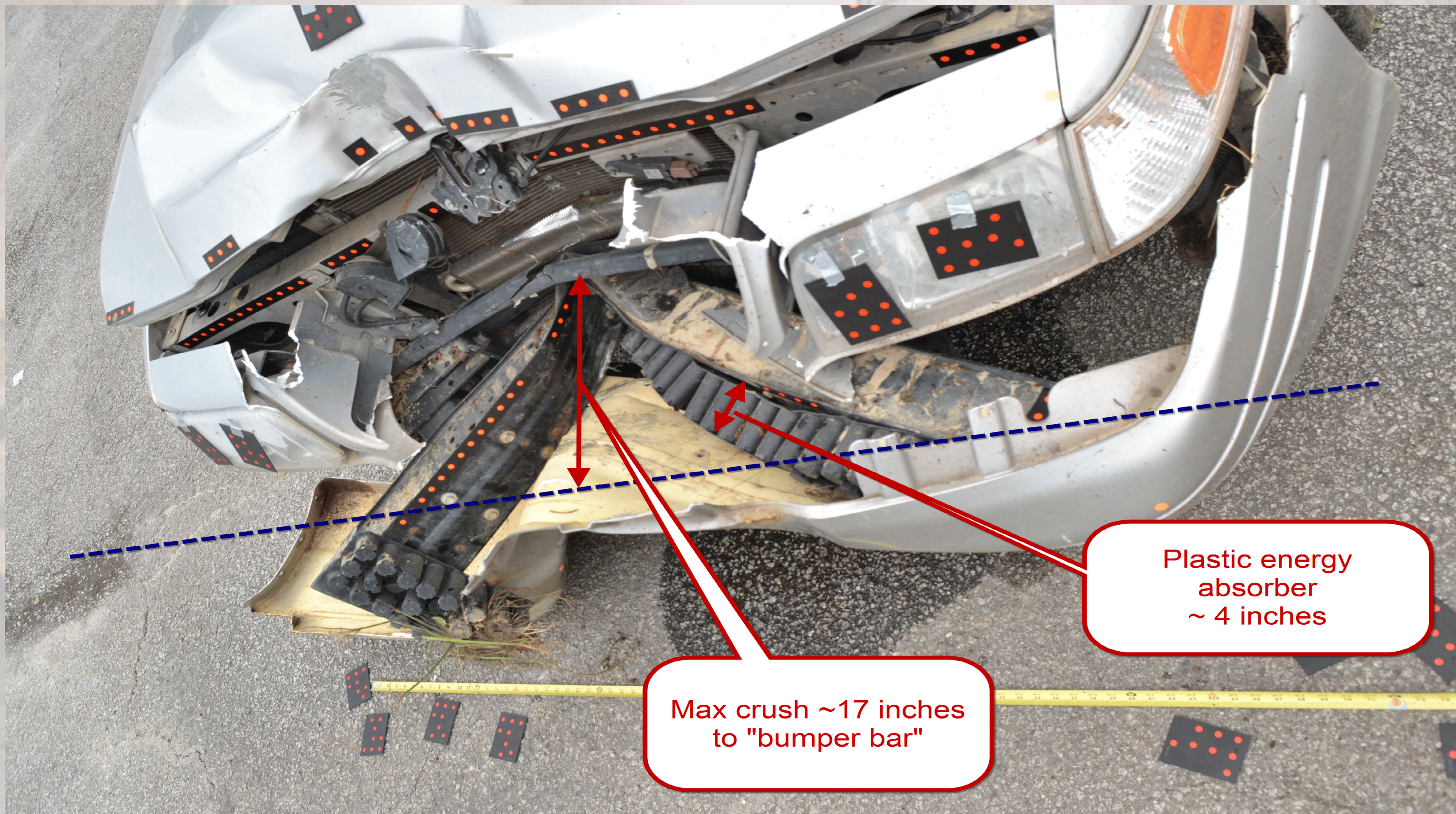
SCARS 2014 Pole Impact Tests - 1999 Ford Taurus
Impact Speed

- Drag factor estimated 0.2-0.4
- Instrumented Drag Factor - Rolling - WITH Brakes - 0.4
- Max Crush at Bumper Level ~ 15 inches
  - Impact Speed = SQR(KEES^2 + 30*180*0.4)
  - Impact Speed ~ 51 mph
- **Instrumented Impact Speed = 50 mph**

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 2008 Ford Crown Victoria



Speed Calculations

Special Considerations - Narrow Objects
SCARS 2014 Pole Impact Tests
2008 Ford Crown Victoria - KEES Speed

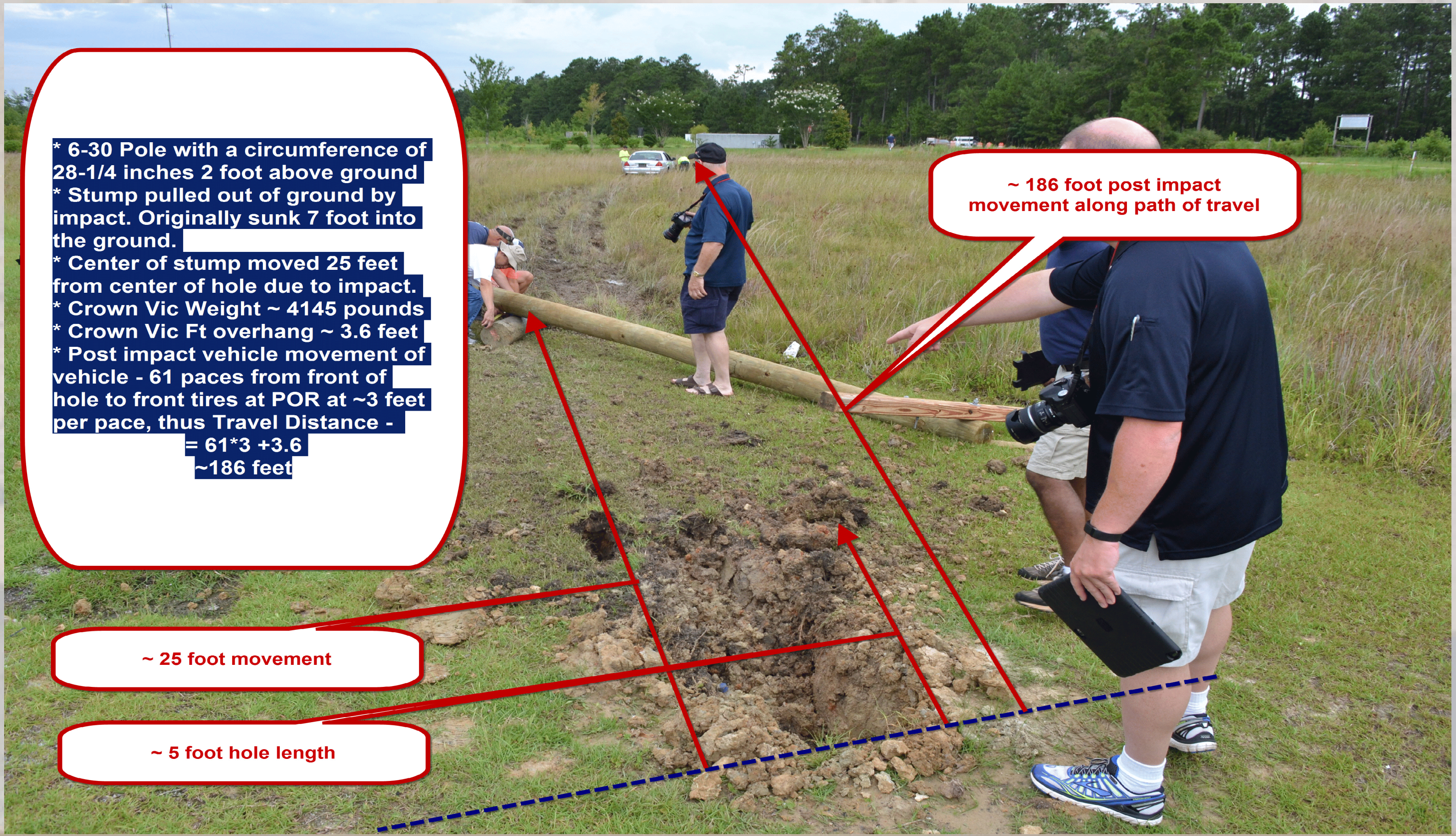
- ★Max Crush measured from ~ bumper cover to bumper bar ≈17 inches
- ★Energy absorbing Plastic thickness ≈ 4 inches
- ★Therefore, Max Crush at Bumper Level ≈ 13 inches
  - ★KEES = SQR**(**30*(13/12)*21*0.6**)**
  - ★KEES ~ 20 mph

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 2008 Ford Crown Victoria

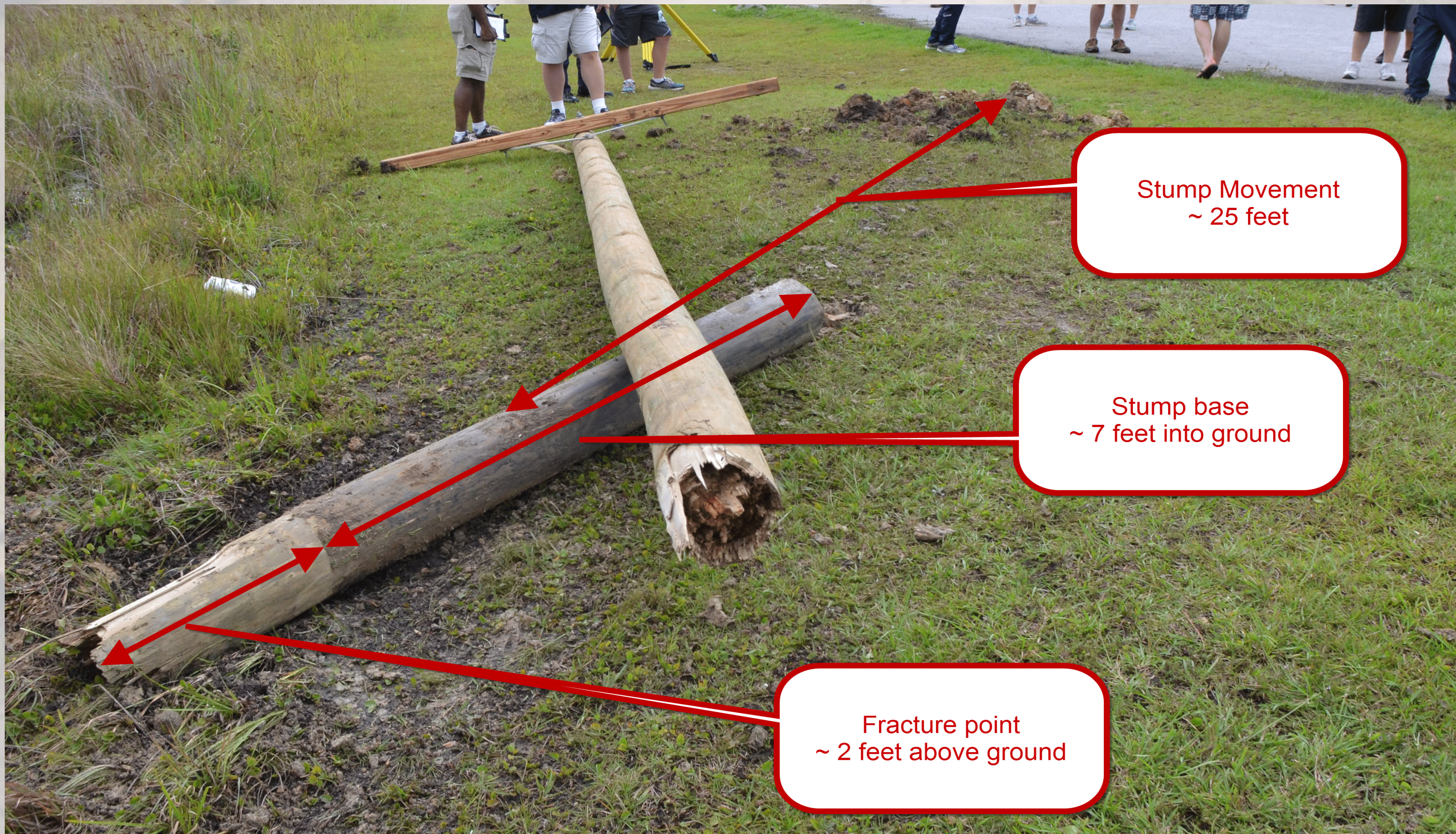
Field Evidence



Speed Calculations

Special Considerations - Narrow Objects

Field Evidence



Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 2008 Ford Crown Victoria

Impact Speed

- Drag factor estimated 0.2-0.4
- Instrumented Drag Factor - Rolling -No Brakes - 0.2
- Max Crush at Bumper Level ~ 13 inches
  - Impact Speed = SQR(KEES^2 + 30*186*0.2)
  - Impact Speed ~ 39 mph
- **Instrumented Impact Speed = 47-49 mph**

Speed Calculations

Special Considerations - Narrow Objects
SCARS Pole Impact Tests
Summary

- What have we left out?
  - Break Energy for the Pole
  - Energy to move the post in the earth

- Look to "Pole Crash Investigation - It's a Matter of Evidence" by Daily, Shigemura, and Rich -2011 for the addition of the above energies, and calculation of damage energy through the use of the CRASH III approach.

Speed Calculations

Special Considerations - Narrow Objects
SCARS Pole Impact Tests
Summary

- Again, look to "Pole Crash Investigation - It's a Matter of Evidence" by Daily, Shigemura, and Rich -2011 for the calculation of damage energy through the use of the CRASH III approach and how to calculate the Pole Fracture Energy and the energy required to move the pole in the earth.
- When those energy losses are included, and combined with the speed/energy calculated with the Crush Factor approach (as opposed to CRASH III approach) -
  - Taurus Impact Speed ~ 59 mph (Inst=50 mph)**
  - Crown Vic Impact Speed ~46 mph (Inst=47 mph)

*****It is suspected that part of this descrepancy in speed is due to trying to "pace" the roll out distance in essentially "swamp" while watching for water moccasins, leading to unequal strides.***

Speed Calculations

Special Considerations - Narrow Objects
Calculation Summary

- 2013
  - Saturn - Max Crush 13-17 inches
  - Saturn - Post Impact Roll Out ~37 feet

  - Volvo - Max Crush 13-17 inches
  - Volvo - Post Impact Roll Out ~33.2 feet
- 2014
  - Crown Vic - Max Crush ~13 inches
  - Crown Vic - Post Impact Roll Out ~186 feet

  - Taurus - Max Crush ~15 inches
  - Taurus - Post Impact Roll Out ~180 feet

Speed Calculations

Special Considerations - Narrow Objects
Calculation Summary

- 2013
  - Saturn - Calculated Impact Speed - 33-34 mph
  - Saturn - Instrumented Impact Speed -41-42 mph

  - Volvo - Calculated Impact Speed - 33-34 mph
  - Volvo - Instrumented Impact Speed - 42 mph
- 2014
  - Crown Vic - Calculated Impact Speed ~ 39 mph
  - Crown Vic - Instrumented Impact Speed = 47 mph

  - Taurus - Calculated Impact Speed ~ 51 mph
  - Taurus - Instrumented Impact Speed = 50 mph

Speed Calculations

Crush - Your “Guiding Light”

★

Remember …..

if its not documented,

it can’t be considered!

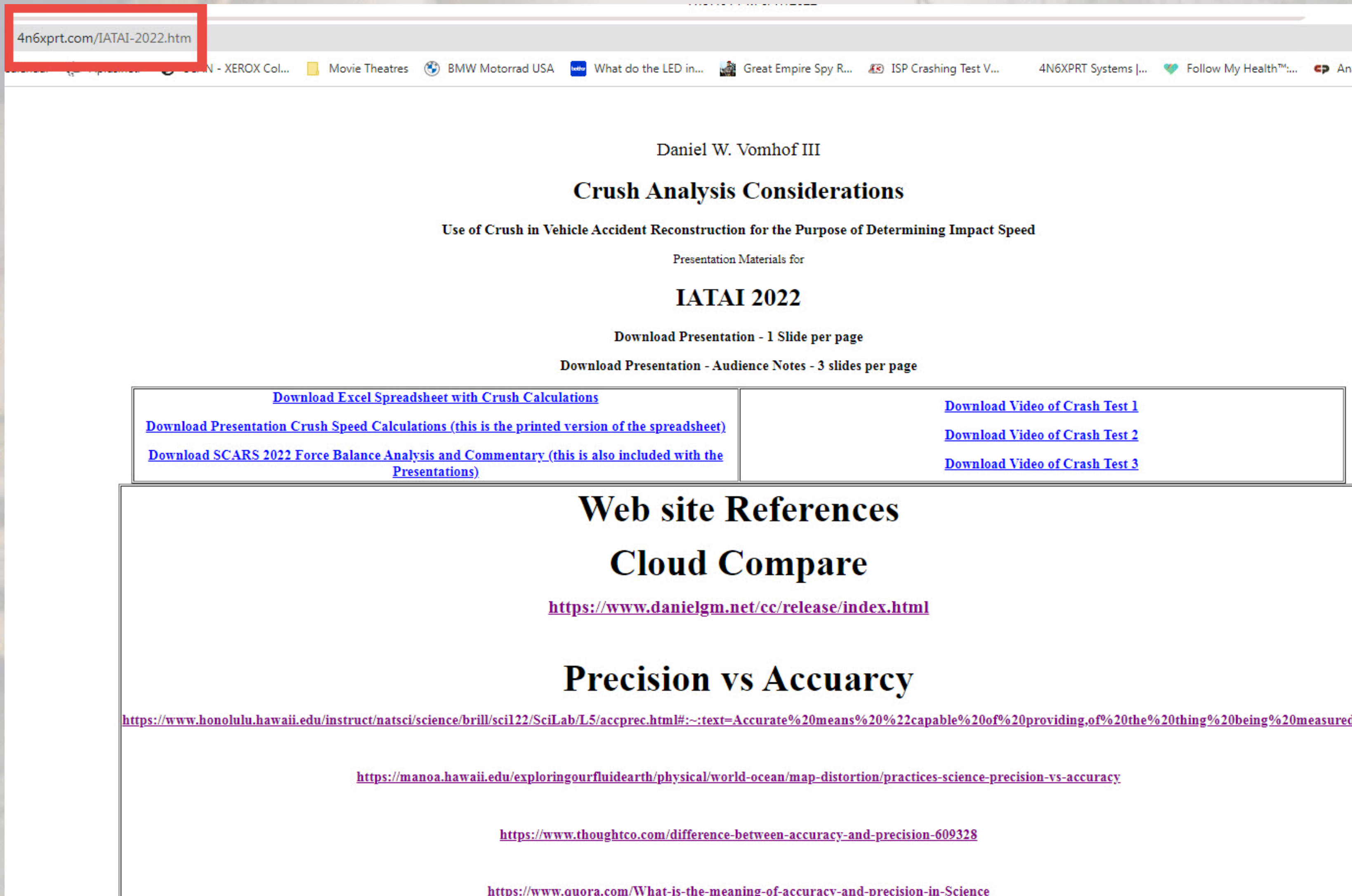
Crush Analysis Considerations

This presentation has been and still is a continuing "Work in Progress". As such, it is will possibly be updated between when it is submitted to IATAI and when it is being presented. Any updates will be provided to IATAI AS WELL AS uploaded to my website and can be downloaded from my web site at the following page -

http://www.4n6xprt.com/IATAI-2022.htm

Some additional "extras" will also be made available on that page.

Crush Analysis Considerations
www.4n6xprt.com/IATAI-2022.htm



Crush Analysis Considerations

Using CRUSH -

Summary

Crush Analysis Considerations

Summary

- Crush/Energy solution is a valid tool which should not be ignored
- Even when a momentum solution can be performed, an energy solution SHOULD ALSO be performed as a double check. Results should generally compare within +/- 5 mph or less
- Crush calculations can be made to be MUCH more complex than they need to be
- While a class in Crush is useful, in a number of ways, it IS NOT a pre-requisite to a person conducting basic speed from crush calculations

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ACCIDENT SPECIFIC EDUCATION (3,196+ Hrs)

PROFESSIONAL CERTIFICATION:

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- Accredited Traffic Accident Reconstructionist, The Accreditation Commission for Traffic Accident Reconstruction, Registration #484, 1993
- Certified Accident Reconstruction Specialist - Institute of Police Traffic Management, 1983

EXPERIENCE:

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(1992-present) - Accident Reconstructionist.
(1984-1992) - Accident Reconstruction Assoc.
(1981-1984) - Accident Reconstructionist.
(1976-1981) - Technician.

Primary responsibilities include:

- Evaluation of traffic signal timing related to vehicle, pedestrian, and motorcycle accidents
- Reconstruction of vehicle, pedestrian, and motorcycle accidents
- Evaluation of Pedestrian/Facility/Walking Surface interactions
- Measurement and evaluation of lighting as it affects perception of hazards
- Measurement and evaluation of sound levels
- Documentation of vehicle evidence and scene conditions through photography and measurements
- Preparation of scale scene diagrams and other exhibits for use in depositions, arbitration hearings, and trial.

4N6XPRT Systems

(1992-present) - General Manager/Technical Support/Programmer

Primary responsibilities include:

- Maintain data and Software Programs available for sale
- Provide Technical Support to program owners
- Provide data to Accident Investigators throughout North America when requested via email, phone, or fax

City of La Mesa - Traffic Engineering
(1988-1992) - Engineering Technician I.

Primary responsibilities in the field included preparation, review, and inspection of traffic control plans; preparation of striping, signing, and traffic signal plans and layouts for the field crews; traffic signal system coordination; field changes to traffic signal timing plans; and determination of proper sign type and placement to remedy existing traffic problems.

Primary responsibilities in the office included monthly review of accident reports for possible conditions contributing to the accidents which would be correctable by engineering projects; preparation of individual and system traffic signal timing plans; preparation of staff reports and exhibits for public hearings; and presentation of staff reports at public hearings.

Acted as Primary Interface between Traffic Engineering and Police Department in issues of Traffic Signal timing and downloads

<u>SWORN TESTIMONY:</u>

Qualified in San Diego and San Bernardino Superior Court on:
- Traffic Signal timing sequence and "who had the green" issues

Qualified in San Diego, El Cajon, Vista, San Bernardino, Pasadena, Solano, and Wisconsin Superior Courts on one or more of these issues:
*Time-Speed-Distance-Force calculations
*Speed survey design, conduction, & data analysis
*Preparation of scale diagrams of roadways
*Lighting considerations
*Vehicle and pedestrian paths of travel
*"Normal" vehicle speeds for an area
*Human factors - Perception, Reaction, Line-of-Sight
*Vehicle and Occupant movements
*Speed from Damage

<u>Computer Software Programs Developed and Maintained:</u>

D.W. Vomhof III, D. W. Vomhof, and S. Young, 4N6XPRT StifCalcs, 4N6XPRT SYSTEMS, La Mesa, CA (2007-2021)
D.W. Vomhof III and D. W. Vomhof, Expert AutoStats, 4N6XPRT SYSTEMS, La Mesa, CA (1993-2022)
D.W. Vomhof, D. W. Vomhof III, and S. Young, Expert VIN DeCoder, 4N6XPRT SYSTEMS, La Mesa, CA (2007-2021)
D.W. Vomhof III, D. W. Vomhof, and B. Cunningham, 4N6XPRT StifCalcs, 4N6XPRT SYSTEMS, La Mesa, CA (2003-2006)
D.W. Vomhof and D. W. Vomhof III, 4N6XPRT Ped & Bike Calcs, 4N6XPRT SYSTEMS, La Mesa, CA (1996)

<u>Publications:</u>

A-B-G Stiffness Values ... How to Research .... and Calculate .... Step-by-Step, Published by IPTM Press, Copyright 2014

Emori
Speed mph 1.1 * c
c = Maximum Crush in inches

Crush Factor
Speed mph SQR(30*CF*MID)
MID = Maximum Crush in Feet (at primary contact level)
CF = Crush Factor (G's)

Noon
v in fps = SQR(2*k*c/m)
k = lb-ft/in
c inches = avg crush depth - inches
m = vehicle mass = wt / 32.2

CRASH 3
E = (A*C + (B*C*C/2) + G) * L (in/lbs)
A = Spring pre-lading value (lbs/inch)
B = Energy absorbed in permanent deformation (lb/(in*in))
G = Energy abosrobed in elastic deformation ((A*A)/(2*B))
C = Avg Crush (inches)
L = Damage Length (in)

KEES / BEV / EBS
KEES = (360/528)* SQR[((2*E*gamma)/12) / (w/g)] (mph)
E = Crush Energy (inch/lbs)
gamma = constant coming from Yaw Moment of Inertia and Moment arm - ignored for these illustrations
w = weight (lbs)
g = gravity (ft/s/s)

Side Impact Test Summary
Report Filter Settings
Year Range: 2015 - 2021
Make: DODGE
Model: CHARGER

Test Number	Year	Make	Model	Body Style	No Damage Speed (mph)	Average Crush (inch)	KEES	A	B	G	Kv	Crush Factor	b_sub_1	Crush Length	Vehicle Weight (pounds)	Noon-KE	Noon - k
9502	2016	DODGE	CHARGER	FOUR DOOR SEDAN	2	5.5	20	375.5	615.2	114.6	759.3	29.2	57.7	58.5	4179.1	25957.14	1297.86
9504	2016	DODGE	CHARGER	FOUR DOOR SEDAN	2	14.3	24.3	124.1	96.7	79.6	114.8	16.5	27.4	87.6	4348.8	39874.58	1640.93
							Average (AVG)	249.8	355.9	97.1	437	22.8				65831.72	1469.39
							Minimum (MIN)	124.1	96.7	79.6	114.8	16.5					
							Maximum (MAX)	375.5	615.2	114.6	759.3	29.2					
							Standard Deviation (STDev-sample	177.8	366.6	24.8	455.7	8.9					
						Number of Tests (n)	2										

Front Impact Test Summary
Report Filter Settings
Year Range: 2013 - 2019
Make: FORD
Model: TAURUS

Test Number	Year	Make	Model	Body Style	No Damage Speed (mph)	Average Crush (inch)	KEES	A	B	G	Kv	Crush Factor	b_sub_1	Crush Length	Vehicle Weight (pounds)	Noon-KE	Noon - k
7872	2013	FORD	TAURUS	FOUR DOOR SEDAN	5	15.4	34.8	474.2	183.1	614	249.8	31.4	34	75.8	4646.4	87375.41	2510.79
9125	2013	FORD	TAURUS	FOUR DOOR SEDAN	5	8.9	41.1	1001.2	815.9	614.3	1057.4	76.3	71.7	76.3	4679.4	122740.52	2986.39
							Average (AVG)	737.7	499.5	614.1	653.6	53.8				210115.92	2748.59
							Minimum (MIN)	474.2	183.1	614	249.8	31.4					
							Maximum (MAX)	1001.2	815.9	614.3	1057.4	76.3					
							Standard Deviation (STDev-sample	372.6	447.4	0.2	571.1	31.8					
						Number of Tests (n)	2										

Front Impact Test Summary
Report Filter Settings
Year Range: 2007 - 2012
Make: LINCOLN
Model: MKZ

Test Number	Year	Make	Model	Body Style	No Damage Speed (mph)	Average Crush (inch)	KEES	A	B	G	Kv	Crush Factor	b_sub_1	Crush Length	Vehicle Weight (pounds)	Noon-KE	Noon - k
6225	2008	FORD	FUSION	FOUR DOOR SEDAN	5	23.4	35	268.9	68.9	524.3	93.8	20.9	22.6	71.7	3749.3	71318.21	2037.66
6755	2010	FORD	FUSION	FOUR DOOR SEDAN	5	21.9	35	278.5	76.1	509.5	103.7	22.3	24.1	71.6	3639.1	69222.01	1977.77
5546	2006	FORD	FUSION	FOUR DOOR SEDAN	5	22	35.1	300.2	82.1	549	111.6	22.4	24.1	71.7	3925.6	75099.04	2139.57
5804	2006	FORD	FUSION	FOUR DOOR SEDAN	5	12.5	25.1	344.7	111	535.3	173.2	20.2	28.3	72.2	3859.5	37756.58	1504.25
7339	2011	FORD	FUSION HYBRID	FOUR DOOR SEDAN	5	19.6	35.1	354.2	108.7	577.4	147.7	25.1	27	71.5	4121.8	78852.47	2246.51
7132	2011	FORD	FUSION	FOUR DOOR SEDAN	5	7.9	20	368.9	139.9	486.4	248.6	20.2	33.4	71.6	3476	21590.06	1079.50
7139	2011	FORD	FUSION	FOUR DOOR SEDAN	5	17.7	35.2	401.1	136.9	587.3	186	28	30	71.4	4185.7	80531.83	2287.84
5821	2006	FORD	FUSION	FOUR DOOR SEDAN	5	9.2	24.7	420.8	179.9	492.2	282.6	26.5	37.6	71.3	3502.4	33179.80	1343.31
6728	2010	FORD	FUSION HYBRID	FOUR DOOR SEDAN	5	14.8	35	473.1	192.2	582.3	261.6	33.2	35.8	71.7	4163.7	79200.82	2262.88
							Average (AVG)	356.7	121.7	538.2	178.7	24.3				60750.09	1875.48
							Minimum (MIN)	268.9	68.9	486.4	93.8	20.2					
							Maximum (MAX)	473.1	192.2	587.3	282.6	33.2					
							Standard Deviation (STDev-sample	68	44.2	38.5	71.5	4.3					
						Number of Tests (n)	9										

Front Impact Test Summary
Report Filter Settings
Year Range: 1965 - 2021
Make: NA
Model: 626

Test Number	Year	Make	Model	Body Style	No Damage Speed (mph)	Average Crush (inch)	KEES	A	B	G	Kv	Crush Factor	b_sub_1	Crush Length	Vehicle Weight (pounds)	Noon-KE	Noon - k
599	1983	MAZDA	626	FOUR DOOR SEDAN	5	24.4	35.3	216.8	53.8	436.8	73	20.4	21.8	66.5	2898.5	56083.72	1588.77
1055	1987	MAZDA	626	FOUR DOOR SEDAN	5	20.3	29.5	217.2	52.4	450.5	75.9	17.1	21.2	66.2	2975.6	40209.87	1363.05
118	1980	MAZDA	626	TWO DOOR COUPE	5	22.5	35.2	253	67.7	472.7	92	21.9	23.5	65	3066	58989.08	1675.83
1015	1987	MAZDA	626	FOUR DOOR SEDAN	5	24	35	262.6	65.6	525.9	89.3	20.4	22	57.9	3039.5	57816.58	1651.90
1742	1993	MAZDA	626	FOUR DOOR SEDAN	5	20	35	276.5	82.9	461.2	112.8	24.5	26.4	69	3176.2	60416.85	1726.20
2866	1998	MAZDA	626	FOUR DOOR SEDAN	5	11.4	29.6	496.7	213.5	577.8	309.2	30.6	37.8	55.1	3178.4	43242.03	1460.88
							Average (AVG)	287.1	89.3	487.5	125.4	22.5				52793.02	1577.77
							Minimum (MIN)	216.8	52.4	436.8	73	17.1					
							Maximum (MAX)	496.7	213.5	577.8	309.2	30.6					
							Standard Deviation (STDev-sample	105.5	61.8	53.8	91.2	4.6					
						Number of Tests (n)	6										

SCARS
Crash Test #1

		Weight	Crush Length	Avg Crush	Max Crush	A	B	G	CRASH 3 E	Noon's k
Bullet	2013 Ford Taurus AWD	4296	65	15	23	348.4	116.2	522.3	1223352.0	2748.59
Target	2015 Dodge Charger	3950	84	8.04	13	249.8	355.9	97.1	1143111.0	1469.39

		Emori Damage Speed		Crush Factor Damage Speed		Noon Damage Speed		CRASH 3 Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	2013 Ford Taurus AWD	37.1	**25.3**	51.0	**34.7**	24.9	**17.0**	39.1	**26.7**
Target	2015 Dodge Charger	21.0	**14.3**	38.3	**26.1**	13.9	**9.5**	39.4	**26.9**
Combined Speed			**29.1**		**43.5**		**19.4**		**37.8**
Instrumented Closing Speed			**~47**		**~47**		**~47**		**~47**
Instrumented delta-v Bullet			22-23		22-23		22-23		22-23
Instrumented delta-v Target			~26-27		~26-27		~26-27		~26-27
Combined Crush + Rollout Speed			**45.8**		**56.1**		**40.4**		**51.8**

SCARS
Crash Test #2

		Weight	Crush Length	Avg Crush	Max Crush	A	B	G	CRASH 3 E	Noon's k
Bullet	2008 Lincoln MKz	3519	62	15	18	356.7	121.7	522.7	1212998.4	1875.48
Target	2015 Dodge Charger	3950	82	3.38	7	249.8	355.9	97.1	243900.5	1469.39

		Emori Damage Speed		Crush Factor Damage Speed		Noon Damage Speed		CRASH 3 Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	2008 Lincoln MKz	29.0	**19.8**	45.1	**30.7**	22.7	**15.5**	43.0	**29.3**
Target	2015 Dodge Charger	11.3	**7.7**	28.1	**19.2**	9.0	**6.1**	18.2	**12.4**
Combined Speed			**21.2**		**36.2**		**16.6**		**31.8**
Instrumented Closing Speed			**~48**		**~48**		**~48**		**~48**
Instrumented delta-v Bullet			22-23		22-23		22-23		22-23
Instrumented delta-v Target			~26-31		~26-31		~26-31		~26-31
Combined Crush + Rollout Speed			**44.2**		**53.1**		**42.2**		**50.2**

SCARS
Crash Test #3

		Weight	Crush Length	Avg Crush	Max Crush	A	B	G	CRASH 3 E	Noon's k
Bullet	1996 Mazda 626	2626	59	18.4	21	287.1	89.3	461.5	1230790.6	1577.77
Target	2016 Dodge Charger	3950	92	2.72	6	249.8	355.9	97.1	192565.3	1469.39

		Emori Damage Speed		Crush Factor Damage Speed		Noon Damage Speed		CRASH 3 Damage Speed	
		v = fps	v = mph	v = fps	v = mph	v = fps	v = mph	v = fps	v = mph
Bullet	1996 Mazda 626	33.9	**23.1**	48.7	**33.2**	26.7	**18.2**	50.2	**34.2**
Target	2016 Dodge Charger	9.7	**6.6**	26.0	**17.7**	8.1	**5.5**	16.2	**11.0**
Combined Crush Speed			**24.0**		**37.6**		**19.0**		**35.9**
Instrumented Closing Speed			**~50-51**		**~50-51**		**~50-51**		**~50-51**
Instrumented delta-v Bullet			~37-38		~37-38		~37-38		~37-38
Instrumented delta-v Target			~22-23		~22-23		~22-23		~22-23
Combined Crush + Rollout Speed			**35.2**		**45.6**		**31.9**		**44.2**

Force Balance Commentary
2022 Crash Test Force Balance Results

For 2022 SCARS had 3 crash tests. In Crash Tests 1 & 2 the bullet vehicle experienced 2 impacts (with resulting crush) as part of the test. There were also secondary impacts by the target vehicle into the side of the bullet vehicle in both tests due to the spin induced in the target by the offset hit. These secondary impacts have not been analyzed.

In Crash Test 1 the bullet vehicle impacted the target, and then continued on to hit the concrete rails stacked behind the impact point.

In Crash Test 2 the bullet vehicle impacted the target, and then continued on to hit the side of the bullet vehicle from test 1 driving it on to hit the concrete rails stacked beyond the impact point.

In Crash Test 3 neither the bullet vehicle nor the target vehicle had any secondary impacts.

Obviously, Crash Test 3 is ideal for a Speed from Crush analysis since there is no crushing of the vehicles other than in the crash itself.

Crash Tests 1 & 2 are less ideal since they had crush energy losses at two points within the test, with no way to separate how much crush was done in the first impact between the bullet and target, and how much crush was due to the secondary impact between the concrete (in test 1) or the buffer vehicle (in test 2).

Due to a limited number of Crash Tests in the NHTSA database for the Similar Vehicle year range for the Ford Police Interceptor (Taurus) and the Mazda 626, “CLASS” vehicles based on the Make and Model were developed to establish the A-B Stiffness MIN-AVG-MAX and Standard Deviation used within the Force Balance model.

CRASH TEST 1

The setup for Test 1 is that the Charger began to pull out into the intersection and then stopped. The driver of the Police Interceptor stated that he was doing “around 50 mph”. After the collision occurred, the Police Interceptor continued on and impacted a concrete wall on the opposite side of the “T” intersection.

In Crash Test 1 a 2 point profile was used for the crush damage to the front of the crush damage to the Ford Police Interceptor bullet vehicle, and a 3 point profile was used for the damage to the side of the Dodge Charger around the front wheel well.

For the first run through I like to set the Lever Arm on both vehicles to 0 and set the Angle to the Collision Surface to 0 for both vehicles. The result of this on the speed calculations is that the closing speeds calculated will be at a minimum for each set of A-B stiffness values.

Using this setup, the closing (in this case, impact) speed of the Police Interceptor based on average stiffness values for the Police Interceptor (Taurus) is 49.3 mph. The likely range of the closing speed is within +/- one Standard Deviation of the average which is 38.4-58.2 mph.

Since the impact was over the front axle of the Charger, the effect of the lever arm of ~56 inches was also analyzed. When the lever arm was added, the closing speed of the Police Interceptor based on the average stiffness values increases to 60.1 mph with a likely range of 46.8-71.0 mph. It can be seen that adding the lever arm increases the calculated closing speed in this test by about 11 mph for the average stiffness values.

Recall that the bullet vehicle had two significant impacts to its front end in this test, the result of this is that there is more crush to the Police Interceptor than can be attributed to the impact between the Police Interceptor and the Charger. This will result in a higher than actual speed calculated for the Police Interceptor for the impact between the Police Interceptor and the Charger.

The Force Balance model results for this test printed “two up” follow this explanation. The CLASS Stiffness Test Summary and 2 pages for each of the Force Balance results printed one per page follow at the end of these explanations.

Available Test Results
Front Impact Test Summary
Report Filter Settings

Year Range: 2000 - 2021
Make: FORD
Model: TAURUS

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
5143	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	20.9	34.7	297.6	84.6	523.1	115.5	23.1
4150	2001 FORD TAURUS FOUR DOOR SEDAN	5.0	19.3	34.7	326.1	100.5	529.3	137.2	25.0
4174	2001 FORD TAURUS FOUR DOOR SEDAN	5.0	15.1	29.5	341.7	110.4	529.0	160.1	22.9
4134	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	14.9	29.7	352.2	116.5	532.3	168.5	23.6
4135	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	14.9	29.6	352.3	116.8	531.4	169.0	23.6
3248	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	17.8	35.2	363.8	123.2	537.1	167.4	27.8
4776	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	17.8	35.1	364.4	123.1	539.6	167.3	27.6
3225	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.0	27.3	375.3	140.2	502.5	209.9	25.0
4987	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	10.6	24.7	379.3	141.6	508.0	222.4	23.1
6808	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	19.4	35.1	381.8	118.7	614.1	161.4	25.5
7302	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	24.7	384.5	125.4	589.5	197.0	20.2
7271	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	11.9	24.7	392.5	130.5	590.3	205.0	20.6
6964	2011 FORD TAURUS FOUR DOOR SEDAN	5.0	17.9	35.1	408.3	137.1	608.0	186.4	27.5
3224	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	30.0	412.6	170.2	500.2	245.0	29.7
3150	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	29.9	428.2	175.7	521.7	253.4	29.5
6967	2011 FORD TAURUS FOUR DOOR SEDAN	5.0	7.5	19.9	443.5	176.9	556.1	315.7	21.2
7872	2013 FORD TAURUS FOUR DOOR SEDAN	5.0	15.4	34.8	474.2	183.1	614.0	249.8	31.4

		A	B	G	Kv	Crush Factor
Average (AVG)		**381.1**	**133.8**	**548.6**	**195.9**	**25.1**
Minimum (MIN)		**297.6**	**84.6**	**500.2**	**115.5**	**20.2**
Maximum (MAX)		**474.2**	**183.1**	**614.1**	**315.7**	**31.4**
Standard Deviation (STDev-sample)		**43.7**	**28.2**	**39.2**	**49.7**	**3.3**
Number of Tests (n)	**17**					

Crash Test 1 - No Lever Arm

2013 FORD TAURUS AWD - Front Impact

Curb Weight (pounds):	4296
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	4296
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	65.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	3218.88

"Known" Stiffness Values

	A	B
Average	348.4	116.2
Minimum	181.2	29.5
Maximum	593.3	286.6
Std. Devation	78.9	53.6

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	7.00						
		65.00	975.00	8.21	8005.83	38.28	37320.83
C2 (inches)	23.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	181.2	29.5	20270.25	37417.88	16.2	13.7	28.6
Avg - 2 Std. Deviations	190.6	9.0	10582.00	32422.77	15.0	11.9	24.9
Avg - 1 Std. Deviations	269.5	62.6	39276.25	66802.92	21.6	18.4	38.4
Average	348.4	116.2	67970.50	108659.78	27.5	23.6	49.3
Avg + 1 Std. Deviations	427.3	169.8	96664.75	150912.93	32.5	27.9	58.2
Avg + 2 Std. Deviations	506.2	223.4	125359.00	193277.12	36.7	31.6	65.9
Maximum	593.3	286.6	158999.75	242738.01	41.2	35.4	73.9

Damage Centroid Depth (x) (inches)	8.21
Damage Centroid Depth (y) (inches)	38.28
Area of Damage (inches^2):	975.00
k^2	3474.23
Eff. Mass Ratio (gamma)	1.00

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	8.04
Damage Length (inches):	84.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00						
		47.00	305.50	4.33	1323.83	31.33	9572.33
C2 (inches)	13.00						
		37.00	370.00	5.15	1905.50	53.65	19850.50
C3 (inches)	7.00						
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 8.04

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	86.3	49.3	20270.25	18647.28	11.9	14.9	20.1
Avg - 2 Std. Deviations	60.0	23.9	10582.00	10329.33	8.9	13.0	14.0
Avg - 1 Std. Deviations	123.4	101.0	39276.25	34639.16	16.2	20.0	28.8
Average	165.2	180.7	67970.50	58454.05	21.1	25.7	38.5
Avg + 1 Std. Deviations	198.7	261.5	96664.75	82081.74	25.0	30.3	46.3
Avg + 2 Std. Deviations	227.5	342.9	125359.00	105602.27	28.3	34.4	53.1
Maximum	257.4	438.8	158999.75	133087.59	31.8	38.5	60.0

Damage Centroid Depth (x) (inches)	4.78
Damage Centroid Depth (y) (inches)	43.56
Area of Damage (inches^2):	675.36
k^2	3360.21
Eff. Mass Ratio (gamma)	1.00

Crash Test 1 - with Lever Arm

4N6XPRT StifCalcs® Force Balance - Page 1 of 2

2013 FORD TAURUS AWD - Front Impact

Curb Weight (pounds):	4296
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	4296
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	65.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	3218.88

"Known" Stiffness Values

	A	B
Average	348.4	116.2
Minimum	181.2	29.5
Maximum	593.3	286.6
Std. Devation	78.9	53.6

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	7.00	65.00	975.00	8.21	8005.83	38.28	37320.83
C2 (inches)	23.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	181.2	29.5	20270.25	37417.88	16.2	11.2	34.8
Avg - 2 Std. Deviations	190.6	9.0	10582.00	32422.77	15.0	9.8	30.4
Avg - 1 Std. Deviations	269.5	62.6	39276.25	66802.92	21.6	15.1	46.8
Average	348.4	116.2	67970.50	108659.78	27.5	19.4	60.1
Avg + 1 Std. Deviations	427.3	169.8	96664.75	150912.93	32.5	22.9	71.0
Avg + 2 Std. Deviations	506.2	223.4	125359.00	193277.12	36.7	25.9	80.4
Maximum	593.3	286.6	158999.75	242738.01	41.2	29.1	90.1

Damage Centroid Depth (x) (inches)	8.21
Damage Centroid Depth (y) (inches)	38.28
Area of Damage (inches^2):	975.00
k^2	3474.23
Eff. Mass Ratio (gamma)	1.00

4N6XPRT StifCalcs® Force Balance - Page 2 of 2

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	8.04
Damage Length (inches):	84.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	56.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00	47.00	305.50	4.33	1323.83	31.33	9572.33
C2 (inches)	13.00	37.00	370.00	5.15	1905.50	53.65	19850.50
C3 (inches)	7.00						
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 8.04

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	86.3	49.3	20270.25	18651.04	11.9	12.2	20.1
Avg - 2 Std. Deviations	60.0	23.9	10582.00	10331.36	8.9	10.7	14.0
Avg - 1 Std. Deviations	123.4	101.0	39276.25	34646.23	16.2	16.4	28.8
Average	165.2	180.7	67970.50	58466.06	21.1	21.1	38.5
Avg + 1 Std. Deviations	198.7	261.5	96664.75	82098.64	25.0	24.9	46.3
Avg + 2 Std. Deviations	227.5	342.9	125359.00	105624.05	28.3	28.2	53.1
Maximum	257.4	438.8	158999.75	133115.07	31.8	31.6	60.0

Damage Centroid Depth (x) (inches)	4.78
Damage Centroid Depth (y) (inches)	43.56
Area of Damage (inches^2):	675.50
k^2	3360.21
Eff. Mass Ratio (gamma)	0.52

CRASH TEST 2

The setup for Test 2 is that the Charger began to pull out into the intersection and then stopped part way through due to traffic in front of them.. The driver of the Lincoln MKZ stated that he was doing “around 50 mph”. After the collision occurred, the Lincoln MKZ continued on and impacted a vehicle moving through the intersection in the opposite direction.

In Crash Test 2 a 2 point profile was used for the crush damage to the front of the crush damage to the Lincoln MKZ bullet vehicle, and a 4 point profile was used for the damage to the side of the Dodge Charger around the rear wheel well.

For the first run through I like to set the Lever Arm on both vehicles to 0 and set the Angle to the Collision Surface to 0 for both vehicles. The result of this on the speed calculations is that the closing speeds calculated will be at a minimum for each set of A-B stiffness values.

Using this setup, the closing (in this case, impact) speed of the Lincoln MKZ based on average stiffness values for the Lincoln MKZ (Similar Vehicle tests for the Ford Fusion is the basis for the stiffness values) is 45.8 mph. The likely range of the closing speed is within +/- one Standard Deviation of the average which is 38.0-52.4 mph.

Since the impact was over the rear axle of the Charger, the effect of the lever arm of ~64 inches was also analyzed. When the lever arm was added, the closing speed of the Lincoln MKZ based on the average stiffness values increases to 57.4 mph with a likely range of 47.7-65.7 mph. It can be seen that adding the lever arm increases the calculated closing speed in this test by about 12 mph for the average stiffness values.

Recall that the bullet vehicle had two significant impacts to its front end in this test, the result of this is that there is more crush to the Lincoln MKZ than can be attributed to the impact between the Lincoln MKZ and the Charger. This will result in a higher than actual speed calculated for the Lincoln MKZ for the impact between the Lincoln MKZ and the Charger.

The Force Balance model results for this test printed “two up” follow this explanation. The Stiffness Test Summary and 2 pages for each of the Force Balance results printed one per page follow at the end of these explanations.

Available Test Results
Front Impact Test Summary

Report Filter Settings

Year Range: 2007 - 2012
Make: LINCOLN
Model: MKZ

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
6225	2008 FORD FUSION FOUR DOOR SEDAN	5.0	23.4	35.0	268.9	68.9	524.3	93.8	20.9
6755	2010 FORD FUSION FOUR DOOR SEDAN	5.0	21.9	35.0	278.5	76.1	509.5	103.7	22.3
5546	2006 FORD FUSION FOUR DOOR SEDAN	5.0	22.0	35.1	300.2	82.1	549.0	111.6	22.4
5804	2006 FORD FUSION FOUR DOOR SEDAN	5.0	12.5	25.1	344.7	111.0	535.3	173.2	20.2
7339	2011 FORD FUSION HYBRID FOUR DOOR SEDAN	5.0	19.6	35.1	354.2	108.7	577.4	147.7	25.1
7132	2011 FORD FUSION FOUR DOOR SEDAN	5.0	7.9	20.0	368.9	139.9	486.4	248.6	20.2
7139	2011 FORD FUSION FOUR DOOR SEDAN	5.0	17.7	35.2	401.1	136.9	587.3	186.0	28.0
5821	2006 FORD FUSION FOUR DOOR SEDAN	5.0	9.2	24.7	420.8	179.9	492.2	282.6	26.5
6728	2010 FORD FUSION HYBRID FOUR DOOR SEDAN	5.0	14.8	35.0	473.1	192.2	582.3	261.6	33.2

		A	B	G	Kv	Crush Factor
Average (AVG)		**356.7**	**121.7**	**538.2**	**178.7**	**24.3**
Minimum (MIN)		**268.9**	**68.9**	**486.4**	**93.8**	**20.2**
Maximum (MAX)		**473.1**	**192.2**	**587.3**	**282.6**	**33.2**
Standard Deviation (STDev-sample)		**68.0**	**44.2**	**38.5**	**71.5**	**4.3**
Number of Tests (n)	**9**					

Crash Test 2 - No Lever Arm

2008 LINCOLN MKZ - Front Impact

Curb Weight (pounds):	3519
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3519
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	62.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2418.57

"Known" Stiffness Values

	A	B
Average	356.7	121.7
Minimum	268.9	68.9
Maximum	473.1	192.2
Std. Devation	68.0	44.2

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	18.00						
		62.00	930.00	7.60	7068.00	28.93	26908.00
C2 (inches)	12.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	268.9	68.9	40374.40	64132.93	23.4	19.1	36.2
Avg - 2 Std. Deviations	220.7	33.3	22326.20	40496.64	18.6	15.1	28.5
Avg - 1 Std. Deviations	288.7	77.5	44987.20	70800.01	24.6	20.1	38.0
Average	356.7	121.7	67648.20	102026.37	29.5	24.2	45.8
Avg + 1 Std. Deviations	424.7	165.9	90309.20	133438.01	33.7	27.7	52.4
Avg + 2 Std. Deviations	492.7	210.1	112970.20	164917.98	37.5	30.8	58.3
Maximum	473.1	192.2	104039.10	152879.43	36.1	29.7	56.1

Damage Centroid Depth (x) (inches)	7.60	k^2	3186.82
Damage Centroid Depth (y) (inches)	28.93	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	930.00		

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00						
		31.00	108.50	2.33	253.17	20.67	2242.33
C2 (inches)	7.00						
		19.00	104.50	2.82	294.50	27.64	2888.00
C3 (inches)	4.00						
		32.00	64.00	1.33	85.33	74.67	4778.67
C4 (inches)	0.00						
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 3.38

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	190.6	235.0	40374.40	17331.49	11.5	17.1	43.4
Avg - 2 Std. Deviations	136.6	120.7	22326.20	10053.59	8.7	13.4	31.1
Avg - 1 Std. Deviations	202.3	264.8	44987.20	19176.12	12.1	17.9	46.1
Average	252.8	413.4	67648.20	28184.58	14.6	21.6	57.6
Avg + 1 Std. Deviations	295.4	564.3	90309.20	37133.87	16.8	24.7	67.2
Avg + 2 Std. Deviations	332.9	716.7	112970.20	46045.32	18.7	27.4	75.8
Maximum	318.6	656.5	104039.10	42536.84	18.0	26.4	72.5

Damage Centroid Depth (x) (inches)	2.29	k^2	3360.21
Damage Centroid Depth (y) (inches)	35.77	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	277.16		

Crash Test 2 - with Lever Arm

2008 LINCOLN MKZ - Front Impact

Curb Weight (pounds):	3519
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3519
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	62.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2418.57

"Known" Stiffness Values

	A	B
Average	356.7	121.7
Minimum	268.9	68.9
Maximum	473.1	192.2
Std. Devation	68.0	44.2

C1 (inches)	18.00
C2 (inches)	12.00
C3 (inches)	
C4 (inches)	
C5 (inches)	
C6 (inches)	
C7 (inches)	
C8 (inches)	
C9 (inches)	
C10 (inches)	

Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
62.00	930.00	7.60	7068.00	28.93	26908.00

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	268.9	68.9	40374.40	64132.93	23.4	15.3	45.4
Avg - 2 Std. Deviations	220.7	33.3	22326.20	40496.64	18.6	12.0	35.8
Avg - 1 Std. Deviations	288.7	77.5	44987.20	70800.01	24.6	16.0	47.7
Average	356.7	121.7	67648.20	102026.37	29.5	19.3	57.4
Avg + 1 Std. Deviations	424.7	165.9	90309.20	133438.01	33.7	22.1	65.7
Avg + 2 Std. Deviations	492.7	210.1	112970.20	164917.98	37.5	24.6	73.1
Maximum	473.1	192.2	104039.10	152879.43	36.1	23.6	70.3

Damage Centroid Depth (x) (inches)	7.60
Damage Centroid Depth (y) (inches)	28.93
Area of Damage (inches^2):	930.00
k^2	3186.82
Eff. Mass Ratio (gamma)	1.00

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	64.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

C1 (inches)	0.00
C2 (inches)	7.00
C3 (inches)	4.00
C4 (inches)	0.00
C5 (inches)	
C6 (inches)	
C7 (inches)	
C8 (inches)	
C9 (inches)	
C10 (inches)	

Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
31.00	108.50	2.33	253.17	20.67	2242.33
19.00	104.50	2.82	294.50	27.64	2888.00
32.00	64.00	1.33	85.33	74.67	4778.67

Average Crush (inches): 3.38

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	190.6	235.0	40374.40	17331.49	11.5	13.6	43.4
Avg - 2 Std. Deviations	136.6	120.7	22326.20	10053.59	8.7	10.7	31.1
Avg - 1 Std. Deviations	202.3	264.8	44987.20	19176.12	12.1	14.3	46.1
Average	252.8	413.4	67648.20	28184.58	14.6	17.2	57.6
Avg + 1 Std. Deviations	295.4	564.3	90309.20	37133.87	16.8	19.7	67.2
Avg + 2 Std. Deviations	332.9	716.7	112970.20	46045.32	18.7	21.9	75.8
Maximum	318.6	656.5	104039.10	42536.84	18.0	21.1	72.5

Damage Centroid Depth (x) (inches)	2.29
Damage Centroid Depth (y) (inches)	35.77
Area of Damage (inches^2):	277.16
k^2	3360.21
Eff. Mass Ratio (gamma)	0.45

CRASH TEST 3

The setup for Test 3 is that the Charger began to pull out into the intersection to make a left turn and then stopped. The driver of the Mazda 626 stated that he was doing “around 50 mph”. Both the Mazda 626 and the Charger had no additional impacts.

In Crash Test 3 a 3 point profile was used for the crush damage to the front of the crush damage to the Mazda 626 bullet vehicle, and a 4 point profile was used for the damage to the side of the Dodge Charger around the front wheel well.

For the first run through I like to set the Lever Arm on both vehicles to 0 and set the Angle to the Collision Surface to 0 for both vehicles. The result of this on the speed calculations is that the closing speeds calculated will be at a minimum for each set of A-B stiffness values.

Using this setup, the closing (in this case, impact) speed of the Mazda 626 based on average stiffness values for the Mazda 626 is 48.5 mph. The likely range of the closing speed is within +/- one Standard Deviation of the average which is 31.0-61.4 mph.

Although there is a “Angle to the Collision Face” (Side) of the Charger, impact was over the right front corner, with no angle. For that reason, no angle is input.

The Force Balance model results for this test printed “two up” follow this explanation. The CLASS Stiffness Test Summary and 2 pages for the Force Balance results printed one per page follow at the end of these explanations.

Available Test Results
Front Impact Test Summary
Report Filter Settings

Year Range: 1965 - 2021
Model: 626

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
599	1983 MAZDA 626 FOUR DOOR SEDAN	5.0	24.4	35.3	216.8	53.8	436.8	73.0	20.4
1055	1987 MAZDA 626 FOUR DOOR SEDAN	5.0	20.3	29.5	217.2	52.4	450.5	75.9	17.1
118	1980 MAZDA 626 TWO DOOR COUPE	5.0	22.5	35.2	253.0	67.7	472.7	92.0	21.9
1015	1987 MAZDA 626 FOUR DOOR SEDAN	5.0	24.0	35.0	262.6	65.6	525.9	89.3	20.4
1742	1993 MAZDA 626 FOUR DOOR SEDAN	5.0	20.0	35.0	276.5	82.9	461.2	112.8	24.5
2866	1998 MAZDA 626 FOUR DOOR SEDAN	5.0	11.4	29.6	496.7	213.5	577.8	309.2	30.6

Statistic		A	B	G	Kv	Crush Factor
Average (AVG)		**287.1**	**89.3**	**487.5**	**125.4**	**22.5**
Minimum (MIN)		**216.8**	**52.4**	**436.8**	**73.0**	**17.1**
Maximum (MAX)		**496.7**	**213.5**	**577.8**	**309.2**	**30.6**
Standard Deviation (STDev-sample)		**105.5**	**61.8**	**53.8**	**91.2**	**4.6**
Number of Tests (n)	**6**					

Crash Test 3 - no Lever Arm
PDOF goes through CG's

1996 MAZDA 626 - Front Impact

Curb Weight (pounds):	2626
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	2626
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	18.40
Damage Length (inches):	59.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	1498.78

"Known" Stiffness Values

	A	B
Average	287.1	89.3
Minimum	216.8	52.4
Maximum	496.7	213.5
Std. Devation	105.5	61.8

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	18.00	33.00	643.50	9.77	6286.50	16.92	10890.00
C2 (inches)	21.00	26.00	442.00	8.66	3826.33	37.98	16787.33
C3 (inches)	13.00						
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 18.40

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	216.8	52.4	34838.32	65981.71	27.5	23.3	38.7
Avg - 2 Std. Deviations	76.1	-34.3	N/A	N/A	N/A	N/A	N/A
Avg - 1 Std. Deviations	181.6	27.5	20284.20	42554.21	22.0	18.6	31.0
Average	287.1	89.3	56941.49	103505.36	34.4	29.2	48.5
Avg + 1 Std. Deviations	392.6	151.1	93598.78	165374.08	43.5	36.9	61.4
Avg + 2 Std. Deviations	498.1	212.9	130256.07	227361.32	51.0	43.2	72.0
Maximum	496.7	213.5	130540.45	227716.27	51.0	43.3	72.0

Damage Centroid Depth (x) (inches)	9.32	k^2	2646.44
Damage Centroid Depth (y) (inches)	25.50	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	1085.60		

2016 DODGE CHARGER

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	2.72
Damage Length (inches):	92.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00	44.00	44.00	0.67	29.33	29.33	1290.67
C2 (inches)	2.00	5.00	12.50	1.27	15.83	7.67	95.83
C3 (inches)	3.00	43.00	193.50	2.33	451.50	109.89	21263.50
C4 (inches)	6.00						
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 2.72

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	172.2	215.1	34838.32	13031.75	9.9	15.5	44.0
Avg - 2 Std. Deviations	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Avg - 1 Std. Deviations	126.3	115.7	20284.20	7954.56	7.8	12.4	32.3
Average	226.4	371.9	56941.49	20655.05	12.5	19.4	57.8
Avg + 1 Std. Deviations	296.8	639.0	93598.78	33188.31	15.9	24.5	75.8
Avg + 2 Std. Deviations	354.3	910.8	130256.07	45649.46	18.6	28.7	90.5
Maximum	354.7	912.9	130540.45	45745.94	18.6	28.8	90.6

Damage Centroid Depth (x) (inches)	1.99	k^2	3360.21
Damage Centroid Depth (y) (inches)	90.60	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	250.24		

Crash Test 1

Stiffness Test Summary
Force Balance no Lever Arm
Force Balance with Lever Arm

Available Test Results
Front Impact Test Summary
Report Filter Settings

Year Range: 2000 - 2021
Make: FORD
Model: TAURUS

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
5143	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	20.9	34.7	297.6	84.6	523.1	115.5	23.1
4150	2001 FORD TAURUS FOUR DOOR SEDAN	5.0	19.3	34.7	326.1	100.5	529.3	137.2	25.0
4174	2001 FORD TAURUS FOUR DOOR SEDAN	5.0	15.1	29.5	341.7	110.4	529.0	160.1	22.9
4134	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	14.9	29.7	352.2	116.5	532.3	168.5	23.6
4135	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	14.9	29.6	352.3	116.8	531.4	169.0	23.6
3248	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	17.8	35.2	363.8	123.2	537.1	167.4	27.8
4776	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	17.8	35.1	364.4	123.1	539.6	167.3	27.6
3225	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.0	27.3	375.3	140.2	502.5	209.9	25.0
4987	2004 FORD TAURUS FOUR DOOR SEDAN	5.0	10.6	24.7	379.3	141.6	508.0	222.4	23.1
6808	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	19.4	35.1	381.8	118.7	614.1	161.4	25.5
7302	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	24.7	384.5	125.4	589.5	197.0	20.2
7271	2010 FORD TAURUS FOUR DOOR SEDAN	5.0	11.9	24.7	392.5	130.5	590.3	205.0	20.6
6964	2011 FORD TAURUS FOUR DOOR SEDAN	5.0	17.9	35.1	408.3	137.1	608.0	186.4	27.5
3224	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	30.0	412.6	170.2	500.2	245.0	29.7
3150	2000 FORD TAURUS FOUR DOOR SEDAN	5.0	12.1	29.9	428.2	175.7	521.7	253.4	29.5
6967	2011 FORD TAURUS FOUR DOOR SEDAN	5.0	7.5	19.9	443.5	176.9	556.1	315.7	21.2
7872	2013 FORD TAURUS FOUR DOOR SEDAN	5.0	15.4	34.8	474.2	183.1	614.0	249.8	31.4

		A	B	G	Kv	Crush Factor
Average (AVG)		**381.1**	**133.8**	**548.6**	**195.9**	**25.1**
Minimum (MIN)		**297.6**	**84.6**	**500.2**	**115.5**	**20.2**
Maximum (MAX)		**474.2**	**183.1**	**614.1**	**315.7**	**31.4**
Standard Deviation (STDev-sample)		**43.7**	**28.2**	**39.2**	**49.7**	**3.3**
Number of Tests (n)	**17**					

2013 FORD TAURUS AWD - Front Impact

Curb Weight (pounds):	4296
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	4296
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	65.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	3218.88

"Known" Stiffness Values

	A	B
Average	348.4	116.2
Minimum	181.2	29.5
Maximum	593.3	286.6
Std. Devation	78.9	53.6

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	7.00	65.00	975.00	8.21	8005.83	38.28	37320.83
C2 (inches)	23.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	181.2	29.5	20270.25	37417.88	16.2	13.7	28.6
Avg - 2 Std. Deviations	190.6	9.0	10582.00	32422.77	15.0	11.9	24.9
Avg - 1 Std. Deviations	269.5	62.6	39276.25	66802.92	21.6	18.4	38.4
Average	348.4	116.2	67970.50	108659.78	27.5	23.6	49.3
Avg + 1 Std. Deviations	427.3	169.8	96664.75	150912.93	32.5	27.9	58.2
Avg + 2 Std. Deviations	506.2	223.4	125359.00	193277.12	36.7	31.6	65.9
Maximum	593.3	286.6	158999.75	242738.01	41.2	35.4	73.9

Damage Centroid Depth (x) (inches)	8.21
Damage Centroid Depth (y) (inches)	38.28
Area of Damage (inches^2):	975.00
k^2	3474.23
Eff. Mass Ratio (gamma)	1.00

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	8.04
Damage Length (inches):	84.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00	47.00	305.50	4.33	1323.83	31.33	9572.33
C2 (inches)	13.00	37.00	370.00	5.15	1905.50	53.65	19850.50
C3 (inches)	7.00						
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 8.04

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	86.3	49.3	20270.25	18647.28	11.9	14.9	20.1
Avg - 2 Std. Deviations	60.0	23.9	10582.00	10329.33	8.9	13.0	14.0
Avg - 1 Std. Deviations	123.4	101.0	39276.25	34639.16	16.2	20.0	28.8
Average	165.2	180.7	67970.50	58454.05	21.1	25.7	38.5
Avg + 1 Std. Deviations	198.7	261.5	96664.75	82081.74	25.0	30.3	46.3
Avg + 2 Std. Deviations	227.5	342.9	125359.00	105602.27	28.3	34.4	53.1
Maximum	257.4	438.8	158999.75	133087.59	31.8	38.5	60.0

Damage Centroid Depth (x) (inches)	4.78	k^2	3360.21
Damage Centroid Depth (y) (inches)	43.56	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	675.36		

2013 FORD TAURUS AWD - Front Impact

Curb Weight (pounds):	4296
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	4296
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	65.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	3218.88

"Known" Stiffness Values

	A	B
Average	348.4	116.2
Minimum	181.2	29.5
Maximum	593.3	286.6
Std. Devation	78.9	53.6

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	7.00						
C2 (inches)	23.00	65.00	975.00	8.21	8005.83	38.28	37320.83
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	181.2	29.5	20270.25	37417.88	16.2	11.2	34.8
Avg - 2 Std. Deviations	190.6	9.0	10582.00	32422.77	15.0	9.8	30.4
Avg - 1 Std. Deviations	269.5	62.6	39276.25	66802.92	21.6	15.1	46.8
Average	348.4	116.2	67970.50	108659.78	27.5	19.4	60.1
Avg + 1 Std. Deviations	427.3	169.8	96664.75	150912.93	32.5	22.9	71.0
Avg + 2 Std. Deviations	506.2	223.4	125359.00	193277.12	36.7	25.9	80.4
Maximum	593.3	286.6	158999.75	242738.01	41.2	29.1	90.1

Damage Centroid Depth (x) (inches)	8.21	k^2	3474.23
Damage Centroid Depth (y) (inches)	38.28	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	975.00		

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	8.04
Damage Length (inches):	84.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	56.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00						
C2 (inches)	13.00	47.00	305.50	4.33	1323.83	31.33	9572.33
C3 (inches)	7.00	37.00	370.00	5.15	1905.50	53.65	19850.50
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 8.04

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	86.3	49.3	20270.25	18651.04	11.9	12.2	20.1
Avg - 2 Std. Deviations	60.0	23.9	10582.00	10331.36	8.9	10.7	14.0
Avg - 1 Std. Deviations	123.4	101.0	39276.25	34646.23	16.2	16.4	28.8
Average	165.2	180.7	67970.50	58466.06	21.1	21.1	38.5
Avg + 1 Std. Deviations	198.7	261.5	96664.75	82098.64	25.0	24.9	46.3
Avg + 2 Std. Deviations	227.5	342.9	125359.00	105624.05	28.3	28.2	53.1
Maximum	257.4	438.8	158999.75	133115.07	31.8	31.6	60.0

Damage Centroid Depth (x) (inches)	4.78
Damage Centroid Depth (y) (inches)	43.56
Area of Damage (inches^2):	675.50
k^2	3360.21
Eff. Mass Ratio (gamma)	0.52

Crash Test 2

Stiffness Test Summary
Force Balance no Lever Arm
Force Balance with Lever Arm

4N6XPRT StifCalcs®

Available Test Results

Front Impact Test Summary

Report Filter Settings

Year Range: 2007 - 2012
Make: LINCOLN
Model: MKZ

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
6225	2008 FORD FUSION FOUR DOOR SEDAN	5.0	23.4	35.0	268.9	68.9	524.3	93.8	20.9
6755	2010 FORD FUSION FOUR DOOR SEDAN	5.0	21.9	35.0	278.5	76.1	509.5	103.7	22.3
5546	2006 FORD FUSION FOUR DOOR SEDAN	5.0	22.0	35.1	300.2	82.1	549.0	111.6	22.4
5804	2006 FORD FUSION FOUR DOOR SEDAN	5.0	12.5	25.1	344.7	111.0	535.3	173.2	20.2
7339	2011 FORD FUSION HYBRID FOUR DOOR SEDAN	5.0	19.6	35.1	354.2	108.7	577.4	147.7	25.1
7132	2011 FORD FUSION FOUR DOOR SEDAN	5.0	7.9	20.0	368.9	139.9	486.4	248.6	20.2
7139	2011 FORD FUSION FOUR DOOR SEDAN	5.0	17.7	35.2	401.1	136.9	587.3	186.0	28.0
5821	2006 FORD FUSION FOUR DOOR SEDAN	5.0	9.2	24.7	420.8	179.9	492.2	282.6	26.5
6728	2010 FORD FUSION HYBRID FOUR DOOR SEDAN	5.0	14.8	35.0	473.1	192.2	582.3	261.6	33.2

		A	B	G	Kv	Crush Factor
Average (AVG)		**356.7**	**121.7**	**538.2**	**178.7**	**24.3**
Minimum (MIN)		**268.9**	**68.9**	**486.4**	**93.8**	**20.2**
Maximum (MAX)		**473.1**	**192.2**	**587.3**	**282.6**	**33.2**
Standard Deviation (STDev-sample)		**68.0**	**44.2**	**38.5**	**71.5**	**4.3**
Number of Tests (n)	**9**					

2008 LINCOLN MKZ - Front Impact

Curb Weight (pounds):	3519
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3519
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	62.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2418.57

"Known" Stiffness Values

	A	B
Average	356.7	121.7
Minimum	268.9	68.9
Maximum	473.1	192.2
Std. Devation	68.0	44.2

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	18.00	62.00	930.00	7.60	7068.00	28.93	26908.00
C2 (inches)	12.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	268.9	68.9	40374.40	64132.93	23.4	19.1	36.2
Avg - 2 Std. Deviations	220.7	33.3	22326.20	40496.64	18.6	15.1	28.5
Avg - 1 Std. Deviations	288.7	77.5	44987.20	70800.01	24.6	20.1	38.0
Average	356.7	121.7	67648.20	102026.37	29.5	24.2	45.8
Avg + 1 Std. Deviations	424.7	165.9	90309.20	133438.01	33.7	27.7	52.4
Avg + 2 Std. Deviations	492.7	210.1	112970.20	164917.98	37.5	30.8	58.3
Maximum	473.1	192.2	104039.10	152879.43	36.1	29.7	56.1

Damage Centroid Depth (x) (inches)	7.60	k^2	3186.82
Damage Centroid Depth (y) (inches)	28.93	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	930.00		

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00	31.00	108.50	2.33	253.17	20.67	2242.33
C2 (inches)	7.00	19.00	104.50	2.82	294.50	27.64	2888.00
C3 (inches)	4.00	32.00	64.00	1.33	85.33	74.67	4778.67
C4 (inches)	0.00						
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 3.38

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	190.6	235.0	40374.40	17331.49	11.5	17.1	43.4
Avg - 2 Std. Deviations	136.6	120.7	22326.20	10053.59	8.7	13.4	31.1
Avg - 1 Std. Deviations	202.3	264.8	44987.20	19176.12	12.1	17.9	46.1
Average	252.8	413.4	67648.20	28184.58	14.6	21.6	57.6
Avg + 1 Std. Deviations	295.4	564.3	90309.20	37133.87	16.8	24.7	67.2
Avg + 2 Std. Deviations	332.9	716.7	112970.20	46045.32	18.7	27.4	75.8
Maximum	318.6	656.5	104039.10	42536.84	18.0	26.4	72.5

Damage Centroid Depth (x) (inches)	2.29	k^2	3360.21
Damage Centroid Depth (y) (inches)	35.77	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches^2):	277.16		

2008 LINCOLN MKZ - Front Impact

Curb Weight (pounds):	3519
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3519
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	15.00
Damage Length (inches):	62.0
Crush Profile Measurements:	2

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	2418.57

"Known" Stiffness Values

	A	B
Average	356.7	121.7
Minimum	268.9	68.9
Maximum	473.1	192.2
Std. Devation	68.0	44.2

		Equal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	18.00	62.00	930.00	7.60	7068.00	28.93	26908.00
C2 (inches)	12.00						
C3 (inches)							
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 15.00

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	268.9	68.9	40374.40	64132.93	23.4	15.3	45.4
Avg - 2 Std. Deviations	220.7	33.3	22326.20	40496.64	18.6	12.0	35.8
Avg - 1 Std. Deviations	288.7	77.5	44987.20	70800.01	24.6	16.0	47.7
Average	356.7	121.7	67648.20	102026.37	29.5	19.3	57.4
Avg + 1 Std. Deviations	424.7	165.9	90309.20	133438.01	33.7	22.1	65.7
Avg + 2 Std. Deviations	492.7	210.1	112970.20	164917.98	37.5	24.6	73.1
Maximum	473.1	192.2	104039.10	152879.43	36.1	23.6	70.3

Damage Centroid Depth (x) (inches)	7.60
Damage Centroid Depth (y) (inches)	28.93
Area of Damage (inches^2):	930.00
k^2	3186.82
Eff. Mass Ratio (gamma)	1.00

2015 DODGE CHARGER - Side Impact

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	64.00
Yaw Moment of Inertia (lb-ft-sec^2)	2862.50

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	0.00						
		31.00	108.50	2.33	253.17	20.67	2242.33
C2 (inches)	7.00						
		19.00	104.50	2.82	294.50	27.64	2888.00
C3 (inches)	4.00						
		32.00	64.00	1.33	85.33	74.67	4778.67
C4 (inches)	0.00						
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 3.38

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	190.6	235.0	40374.40	17331.49	11.5	13.6	43.4
Avg - 2 Std. Deviations	136.6	120.7	22326.20	10053.59	8.7	10.7	31.1
Avg - 1 Std. Deviations	202.3	264.8	44987.20	19176.12	12.1	14.3	46.1
Average	252.8	413.4	67648.20	28184.58	14.6	17.2	57.6
Avg + 1 Std. Deviations	295.4	564.3	90309.20	37133.87	16.8	19.7	67.2
Avg + 2 Std. Deviations	332.9	716.7	112970.20	46045.32	18.7	21.9	75.8
Maximum	318.6	656.5	104039.10	42536.84	18.0	21.1	72.5

Damage Centroid Depth (x) (inches)	2.29
Damage Centroid Depth (y) (inches)	35.77
Area of Damage (inches^2):	277.16
k^2	3360.21
Eff. Mass Ratio (gamma)	0.45

Crash Test 3

Stiffness Test Summary
Force Balance no Lever Arm

Available Test Results
Front Impact Test Summary
Report Filter Settings

Year Range: 1965 - 2021
Model: 626

Test Number	Vehicle Info	No Damage Speed (mph)	Average Crush (inch)	KEES (mph)	Vehicle Width Stiffness Values A	B	G	Kv	Crush Factor
599	1983 MAZDA 626 FOUR DOOR SEDAN	5.0	24.4	35.3	216.8	53.8	436.8	73.0	20.4
1055	1987 MAZDA 626 FOUR DOOR SEDAN	5.0	20.3	29.5	217.2	52.4	450.5	75.9	17.1
118	1980 MAZDA 626 TWO DOOR COUPE	5.0	22.5	35.2	253.0	67.7	472.7	92.0	21.9
1015	1987 MAZDA 626 FOUR DOOR SEDAN	5.0	24.0	35.0	262.6	65.6	525.9	89.3	20.4
1742	1993 MAZDA 626 FOUR DOOR SEDAN	5.0	20.0	35.0	276.5	82.9	461.2	112.8	24.5
2866	1998 MAZDA 626 FOUR DOOR SEDAN	5.0	11.4	29.6	496.7	213.5	577.8	309.2	30.6

		A	B	G	Kv	Crush Factor
Average (AVG)		**287.1**	**89.3**	**487.5**	**125.4**	**22.5**
Minimum (MIN)		**216.8**	**52.4**	**436.8**	**73.0**	**17.1**
Maximum (MAX)		**496.7**	**213.5**	**577.8**	**309.2**	**30.6**
Standard Deviation (STDev-sample)		**105.5**	**61.8**	**53.8**	**91.2**	**4.6**
Number of Tests (n)	**6**					

1996 MAZDA 626 - Front Impact

Curb Weight (pounds):	2626
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	2626
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	18.40
Damage Length (inches):	59.0
Crush Profile Measurements:	3

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec^2)	1498.78

"Known" Stiffness Values

	A	B
Average	287.1	89.3
Minimum	216.8	52.4
Maximum	496.7	213.5
Std. Devation	105.5	61.8

		Unequal Spacing (inches)	Zone Area (inches^2)	Zone Depth(x) (inches)	Area Depth(x) (inches^3)	Zone Depth(y) (inches)	Area Depth(y) (inches^3)
C1 (inches)	18.00	33.00	643.50	9.77	6286.50	16.92	10890.00
C2 (inches)	21.00	26.00	442.00	8.66	3826.33	37.98	16787.33
C3 (inches)	13.00						
C4 (inches)							
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 18.40

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	216.8	52.4	34838.32	65981.71	27.5	23.3	38.7
Avg - 2 Std. Deviations	76.1	-34.3	N/A	N/A	N/A	N/A	N/A
Avg - 1 Std. Deviations	181.6	27.5	20284.20	42554.21	22.0	18.6	31.0
Average	287.1	89.3	56941.49	103505.36	34.4	29.2	48.5
Avg + 1 Std. Deviations	392.6	151.1	93598.78	165374.08	43.5	36.9	61.4
Avg + 2 Std. Deviations	498.1	212.9	130256.07	227361.32	51.0	43.2	72.0
Maximum	496.7	213.5	130540.45	227716.27	51.0	43.3	72.0

Damage Centroid Depth (x) (inches)	9.32
Damage Centroid Depth (y) (inches)	25.50
Area of Damage (inches^2):	1085.60
k^2	2646.44
Eff. Mass Ratio (gamma)	1.00

2016 DODGE CHARGER

Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	2.72
Damage Length (inches):	92.0
Crush Profile Measurements:	4

PDOF

Lever Arm Distance (inches):	0.00
Yaw Moment of Inertia (lb-ft-sec²):	2862.50

		Unequal Spacing (inches)	Zone Area (inches²)	Zone Depth(x) (inches)	Area Depth(x) (inches³)	Zone Depth(y) (inches)	Area Depth(y) (inches³)
C1 (inches)	0.00	44.00	44.00	0.67	29.33	29.33	1290.67
C2 (inches)	2.00	5.00	12.50	1.27	15.83	7.67	95.83
C3 (inches)	3.00	43.00	193.50	2.33	451.50	109.89	21263.50
C4 (inches)	6.00						
C5 (inches)							
C6 (inches)							
C7 (inches)							
C8 (inches)							
C9 (inches)							
C10 (inches)							

Average Crush (inches): 2.72

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	172.2	215.1	34838.32	13031.75	9.9	15.5	44.0
Avg - 2 Std. Deviations	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Avg - 1 Std. Deviations	126.3	115.7	20284.20	7954.56	7.8	12.4	32.3
Average	226.4	371.9	56941.49	20655.05	12.5	19.4	57.8
Avg + 1 Std. Deviations	296.8	639.0	93598.78	33188.31	15.9	24.5	75.8
Avg + 2 Std. Deviations	354.3	910.8	130256.07	45649.46	18.6	28.7	90.5
Maximum	354.7	912.9	130540.45	45745.94	18.6	28.8	90.6

Damage Centroid Depth (x) (inches)	1.99	k^2	3360.21
Damage Centroid Depth (y) (inches)	90.60	Eff. Mass Ratio (gamma)	1.00
Area of Damage (inches²):	250.24		