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
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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.

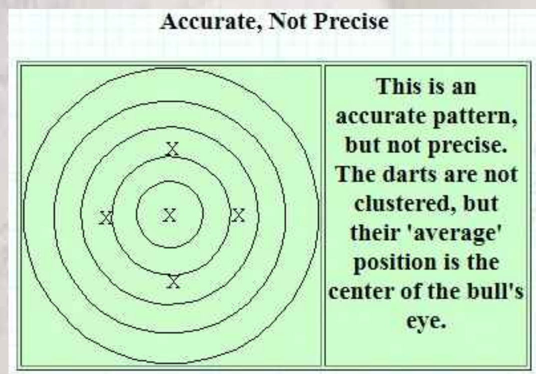
The Science of Measurement: Accuracy vs. Precision

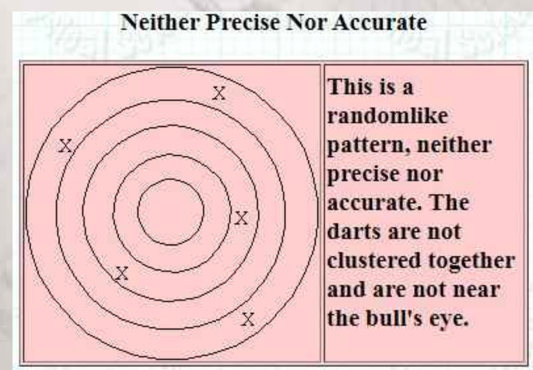
We can never make a perfect measurement. The best we can do is to come as close as possible within the limitations of the measuring instruments.

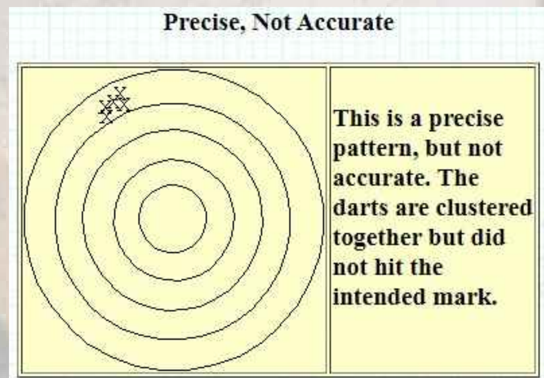
Crush - Inaccurate

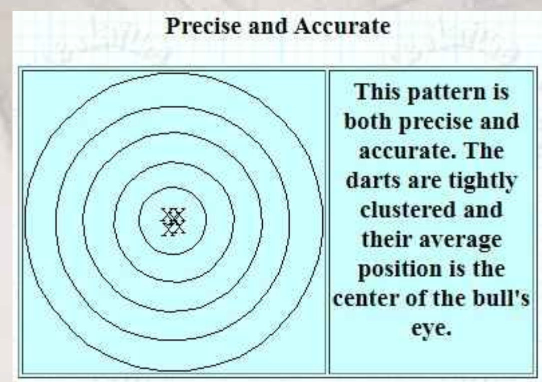
Precise vs Accurate

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

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space
400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096-0001 U.S.A.

SAE Technical Paper Series

880072

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

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Reprinted from SP-733—
Accident Reconstruction — State-Of-The-Art

International Congress and Exposition
Detroit, Michigan
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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

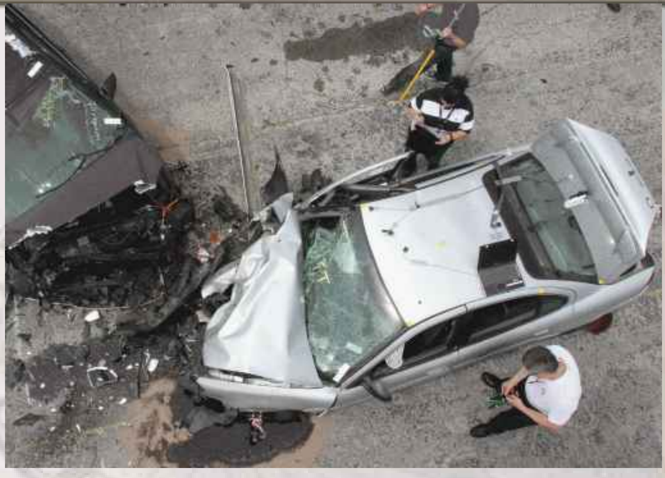
- With a Tape Measure Jig you will need at least 4 tape measures, 2 of which that are 25-35 foot in length. 3 of these are for your jig, one is for measuring “depth”. You also need a “plumb bob”, for which there are many possible “Field Expedients” including a bottle of water or another tape measure.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

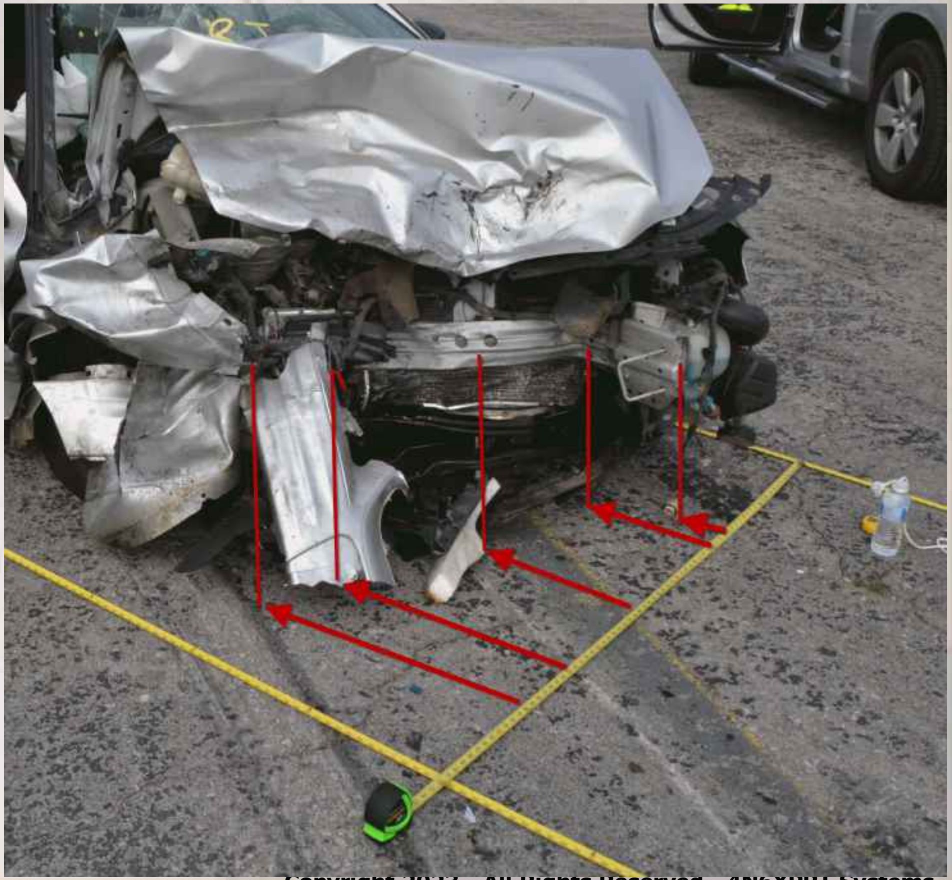
Crush Measurements

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.

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)

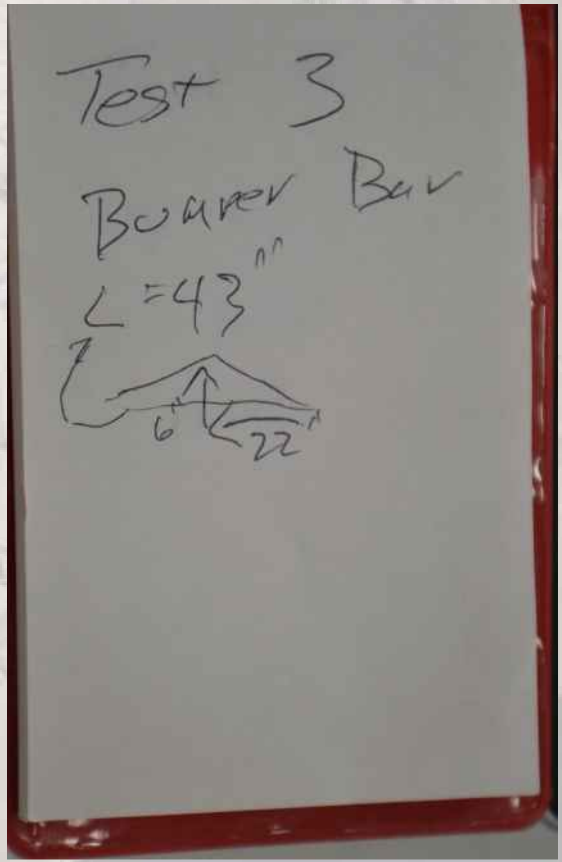
Measurement

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

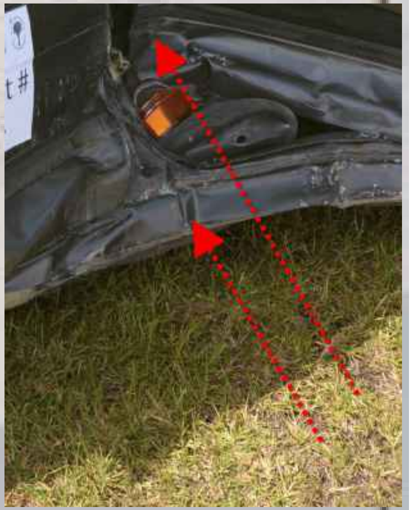
Side Measurement

- ★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

$$F = A + BC$$

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

- ~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

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

$$A = \frac{W * b_0 * b_1}{g * L}$$

$$B = \frac{W * b_1 * b_1}{g * L}$$

$$G = \frac{A * A}{2 * B}$$

- 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

Time and Position 245

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 frict.

ACCELERATION OR DECELERATION	Speed range	ACCELERATION, a: Drag factor $f = a/g$ = μ	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)	+ 0.15	+ 1.47	+ 4.8
	20 to 40 mph (30 to 60 km per hr)	+ 0.10	+ 0.98	+ 3.2
	More than 40 mph (60 km per hr)	+ 0.05	+ 0.48	+ 1.6
Passenger cars, rapid acceleration	Less than 20 mph (30 km per hr)	+ 0.30	+ 2.94	+ 9.7
	20 to 40 mph (30 to 60 km per hr)	+ 0.15	+ 1.47	+ 4.8
	More than 40 mph (60 km per hr)	+ 0.10	+ 0.98	+ 3.2
Medium trucks, normal acceleration	Less than 20 mph (30 km per hr)	+ 0.10	+ 0.98	+ 3.2
	20 to 40 mph (30 to 60 km per hr)	+ 0.05	+ 0.48	+ 1.6
	More than 40 mph (60 km per hr)	+ 0.03	+ 0.29	+ 1.0
Big trucks loaded, normal acceleration	Less than 20 mph (30 km per hr)	+ 0.05	+ 0.48	+ 1.6
	20 to 40 mph (30 to 60 km per hr)	+ 0.03	+ 0.29	+ 1.0
	More than 40 mph (60 km per hr)	+ 0.01	+ 0.10	+ 0.3
Pedestrians, normal acceleration in walking		+ 0.05	+ 0.48	+ 1.6
Pedestrians in a hurry		+ 0.10	+ 0.98	+ 3.2
Passenger cars, coasting out of gear	Less than 20 mph (30 km per hr)	- 0.01	- 0.10	- 0.3
	20 to 40 mph (30 to 60 km per hr)	- 0.02	- 0.20	- 0.6
	More than 40 mph (60 km per hr)	- 0.04	- 0.39	- 1.3
Passenger cars, engine braking high gear	Less than 20 mph (30 km per hr)	- 0.04	- 0.39	- 1.3
	20 to 40 mph (30 to 60 km per hr)	- 0.05	- 0.48	- 1.6
	More than 40 mph (60 km per hr)	- 0.08	- 0.78	- 2.6
Gradual slowing, light braking		- 0.10	- 0.98	- 3.2
Normal braking, no skidding		- 0.20	- 1.96	- 6.4
Quick stop, skids on ice or snow		- 0.40	- 3.92	- 12.9
Hard braking, skids on most surfaces		- 0.65	- 6.38	- 20.7
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

ACCELERATION, a
Drag factor $f = a/g$ = μ | 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

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

PDO

"Kno

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 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**

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

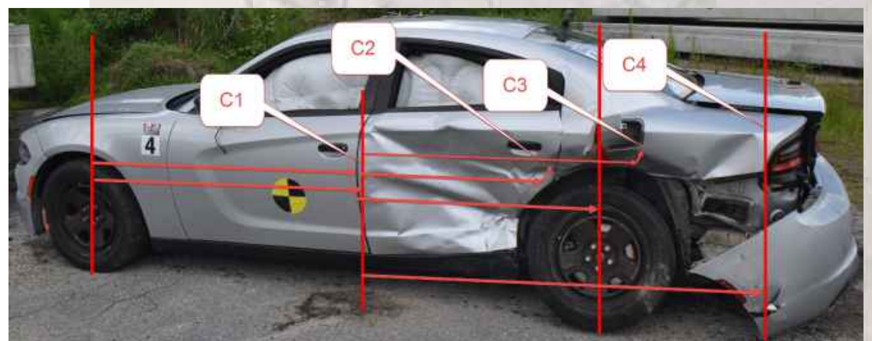
		Equal Spacing (inches)	Zone Area (inches²)
C1 (inches)	18.00	62.00	930.00
C2 (inches)	12.00		

Speed Calculations

Crash Test Examples - CT2

2015 DODGE CHARGER - Side Impact

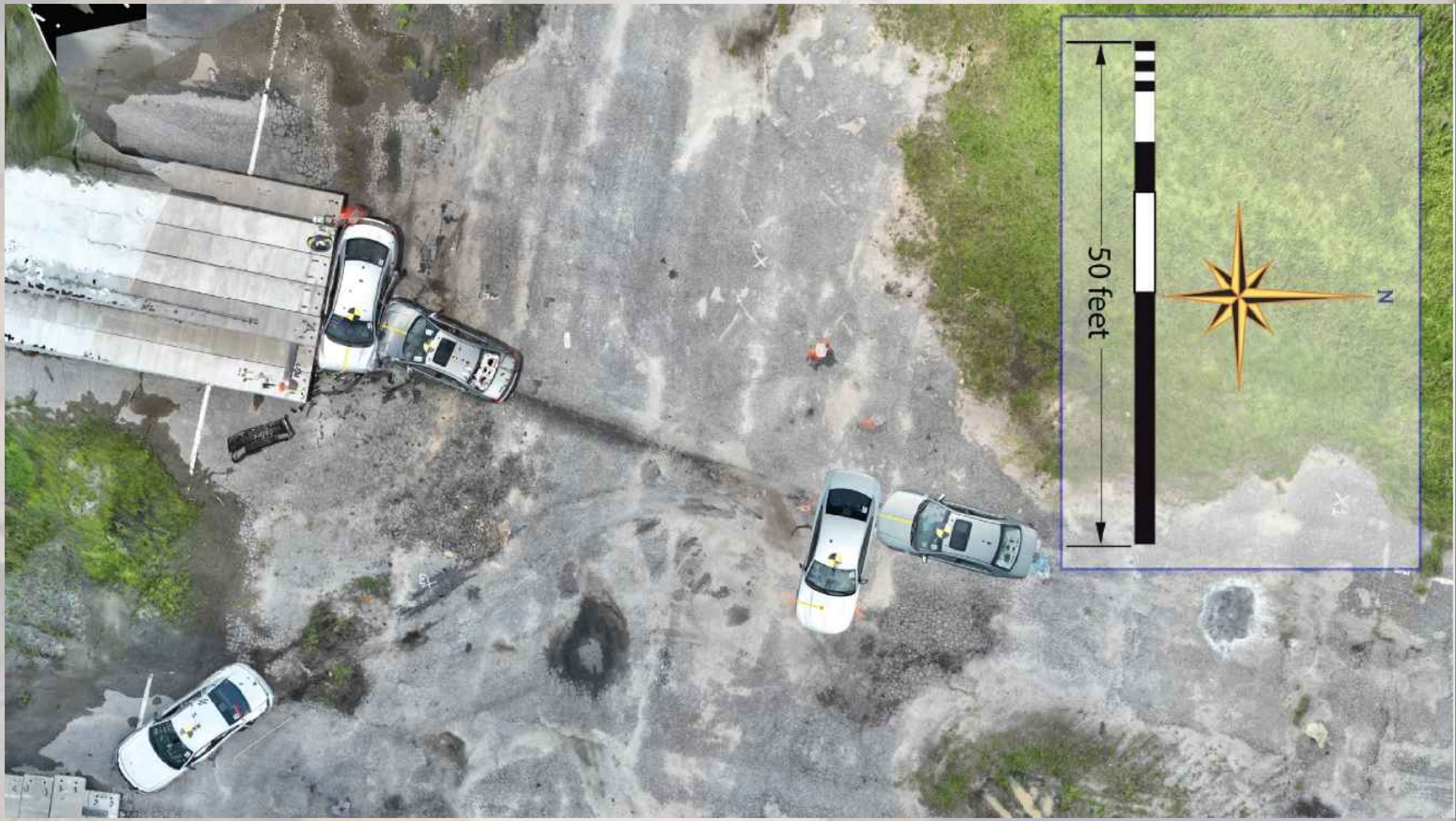
Curb Weight (pounds):	3950
Occupant + Cargo Weight (pounds):	0
Total Weight (pounds):	3950
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	2.0
Energy Crush Depth (inches):	3.38
Damage Length (inches):	82.0
Crush Profile Measurements:	4



		Unequal Spacing (inches)	Zone Area (inches^2)
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

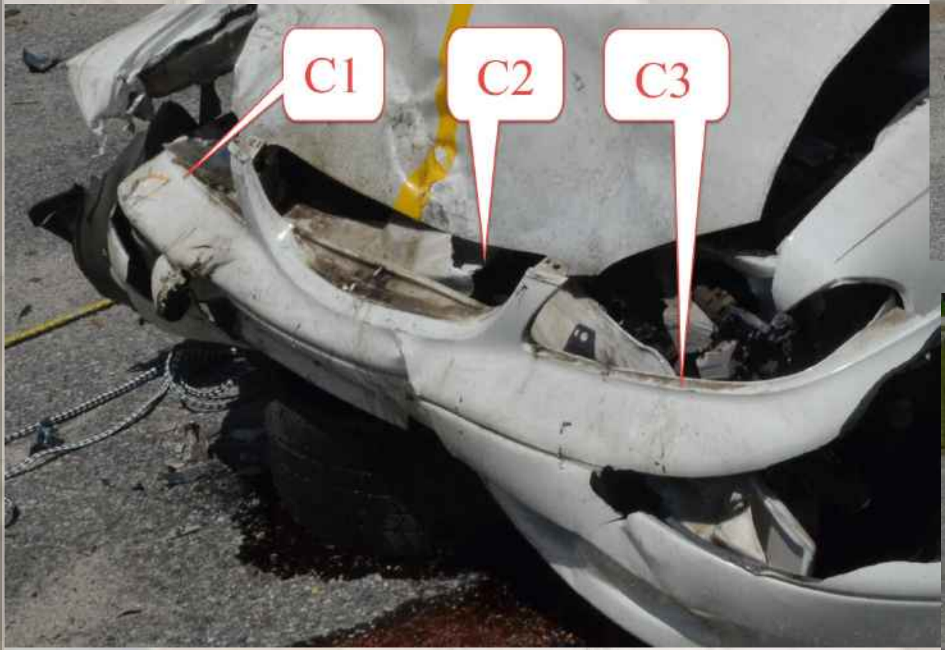
Speed Calculations

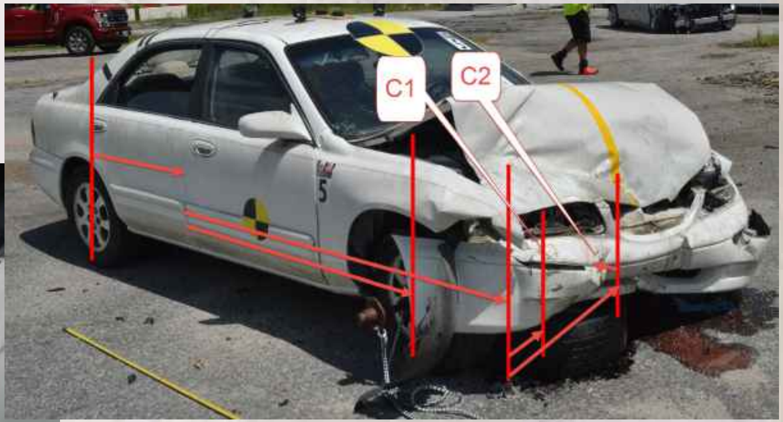
Crash Test Examples - CT2 - Output

		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





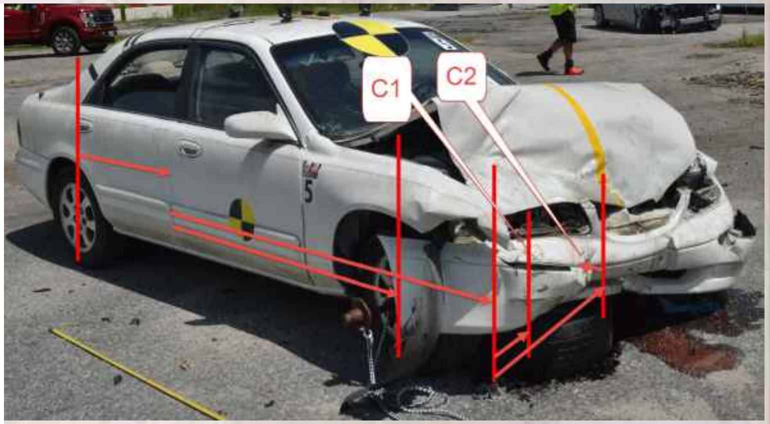
Speed Calculations

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		



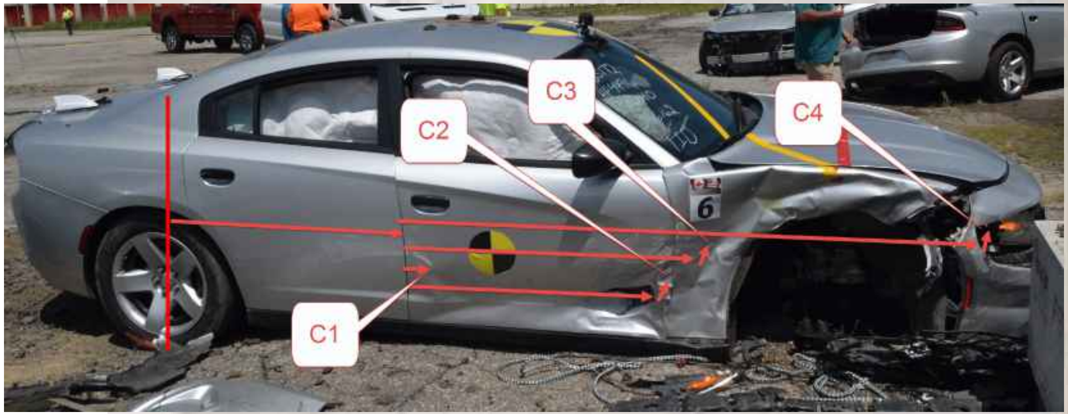
Speed Calculations

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

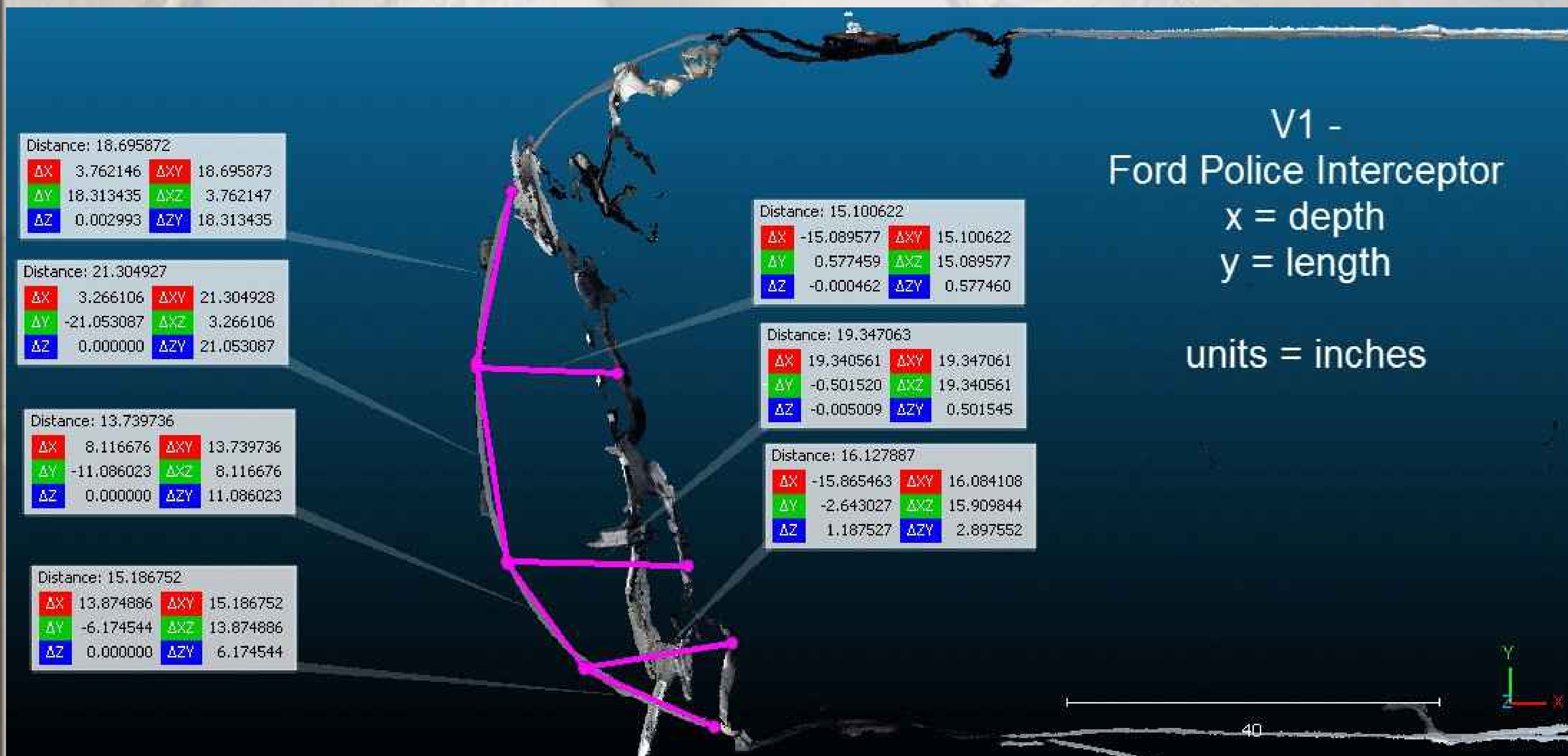
Crash Test Examples - CT3 - Output

		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**

Cloud Compare

Crush Measurements

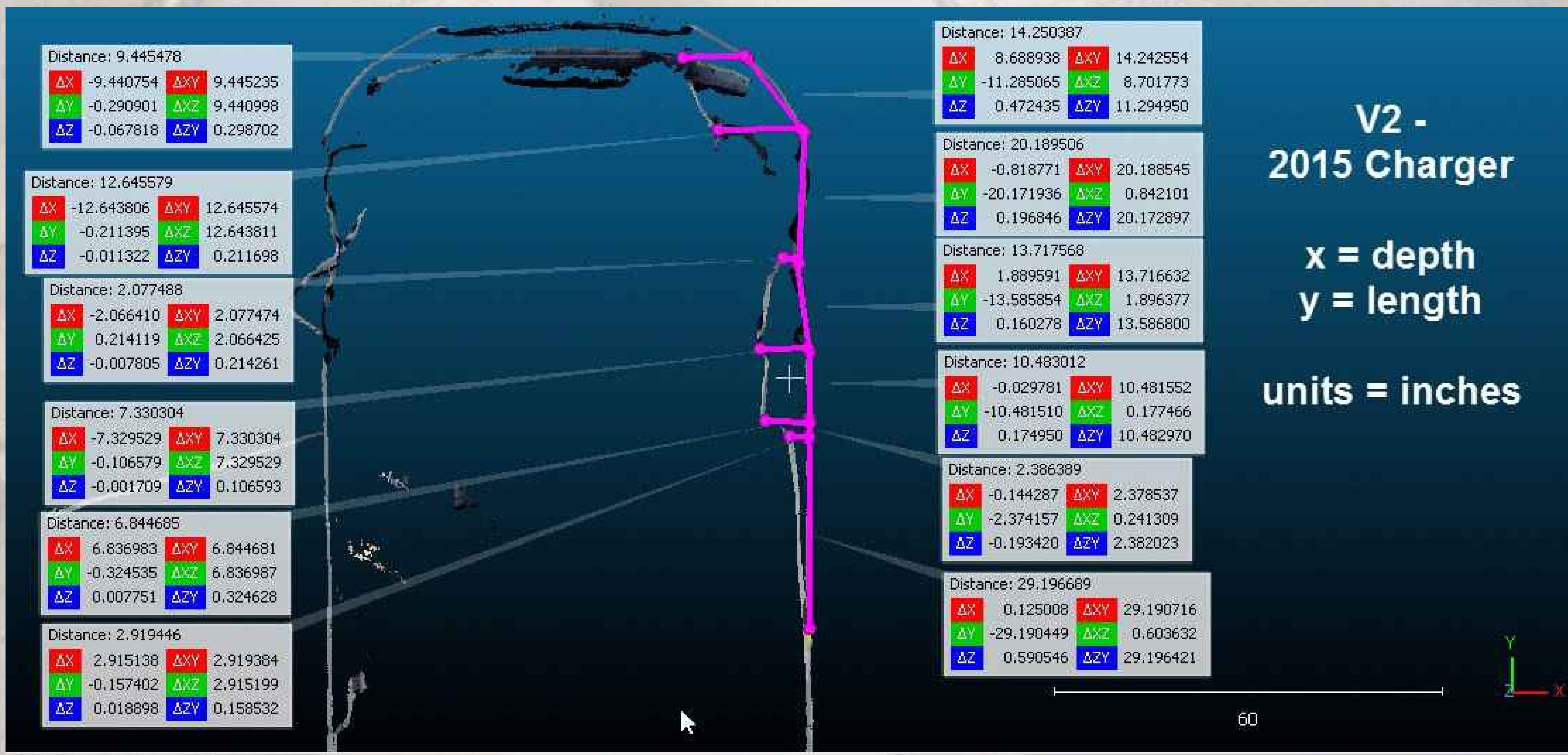
- ★V1 Crush Measurements



Cloud Compare

Crush Measurements

- V2 Crush Measurements



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 - CT1 - Input

									CRASH 3	Noon's
		Weight	Crush Length	Avg Crush	Max Crush	A	B	G	E	k
Bullet	2013 Ford Taurus AWD	4296	56.7	13.15	19.3	348.4	116.2	522.3	859036.6	2748.59
Target	2015 Dodge Charger	3950	87.1	5.32	12.6	249.8	355.9	97.1	562879.2	1469.39

Speed Calculations

Crash Test Examples - CT2 - 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	31.1	**21.2**	46.7	**31.8**	23.3	**15.9**	32.8	**22.3**
Target	2015 Dodge Charger	20.3	**13.9**	37.7	**25.7**	11.3	**7.7**	27.7	**18.9**
Combined Speed			**25.4**		**40.9**		**17.6**		**29.2**
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			**43.5**		**54.1**		**39.5**		**45.9**

Cloud Compare

Crush Measurements

- ★But the question is there ....

Do "better" measurements have a significant effect on the calculated speeds?

- ★The following slides show the crush measurements taken for the same vehicles using Recon-3D and Cloud Compare .... and what the resulting caolculated speeds are.

Cloud Compare

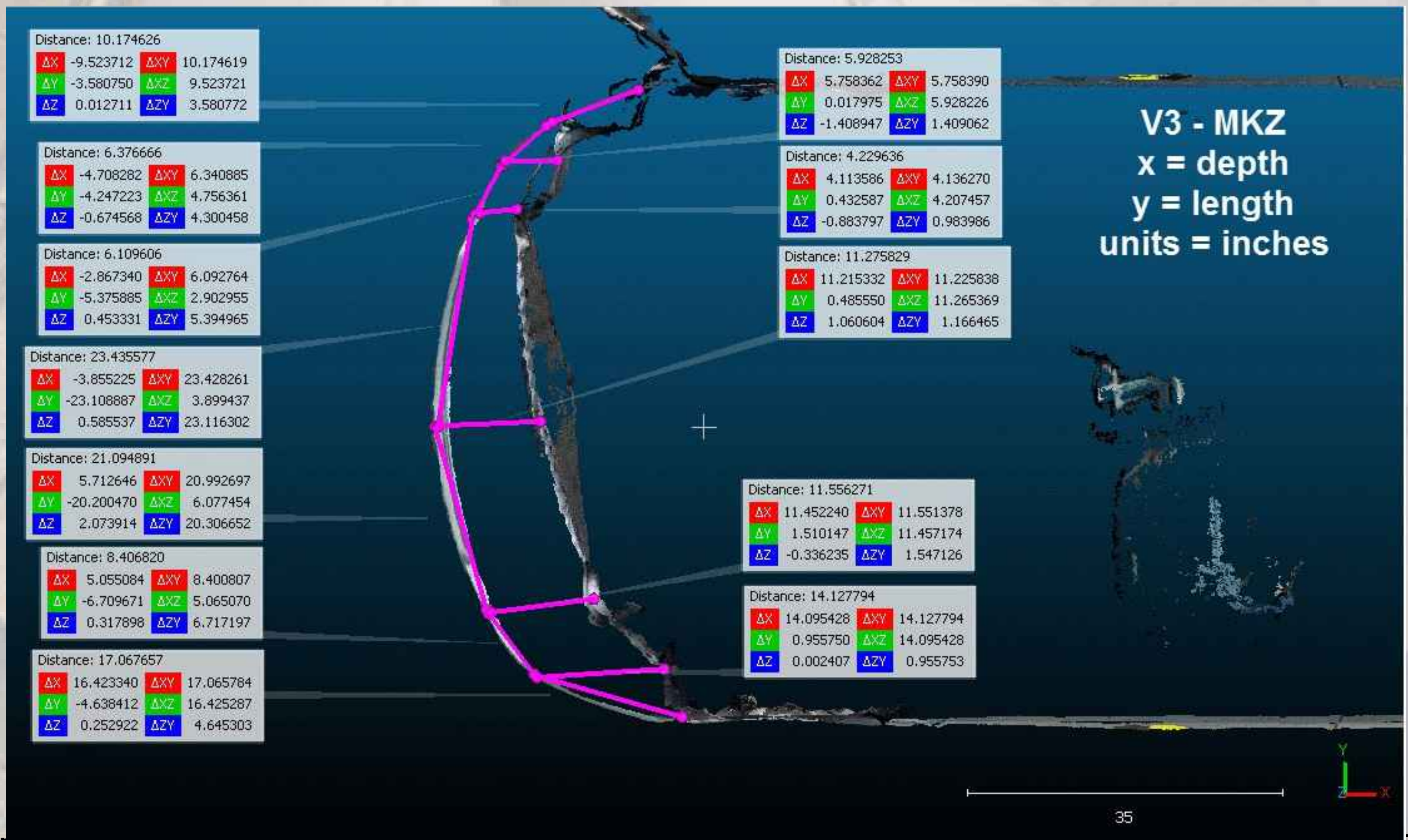
Crush Measurements

- The answer to the question, at least for now, is left to you the reader. Look at the comparative calculations and then draw your own conclusions.

Cloud Compare

Crush Measurements

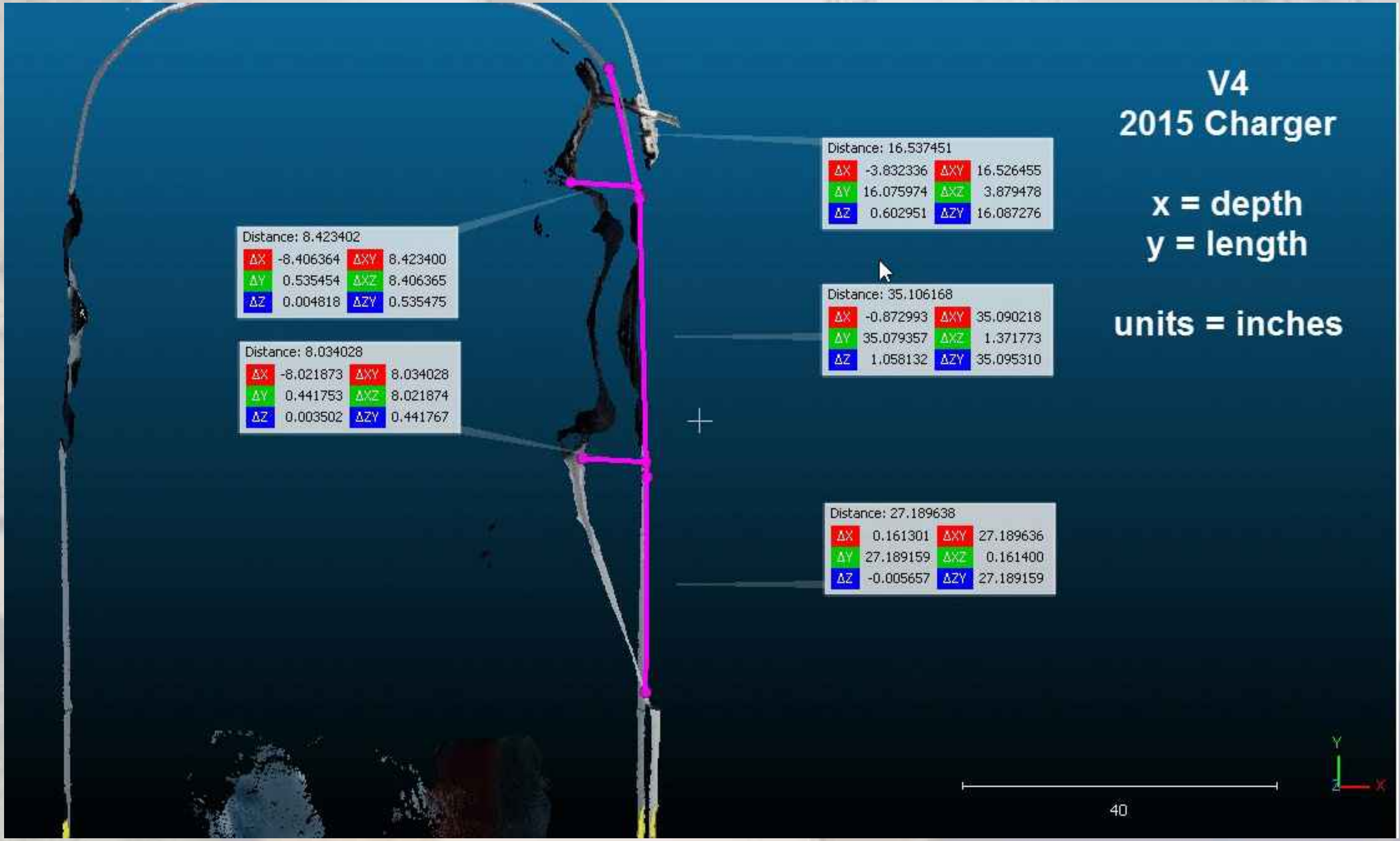
★V3 Crush Measurements



Cloud Compare

Crush Measurements

★V4 Crush Measurements



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
Bullet	2008 Lincoln MKz	3519	64.2	8.74	11.4	356.7	121.7	522.7	532120.6	1875.48
Target	2015 Dodge Charger	3950	78.4	5.92	8.4	249.8	355.9	97.1	612494.0	1469.39

Speed Calculations

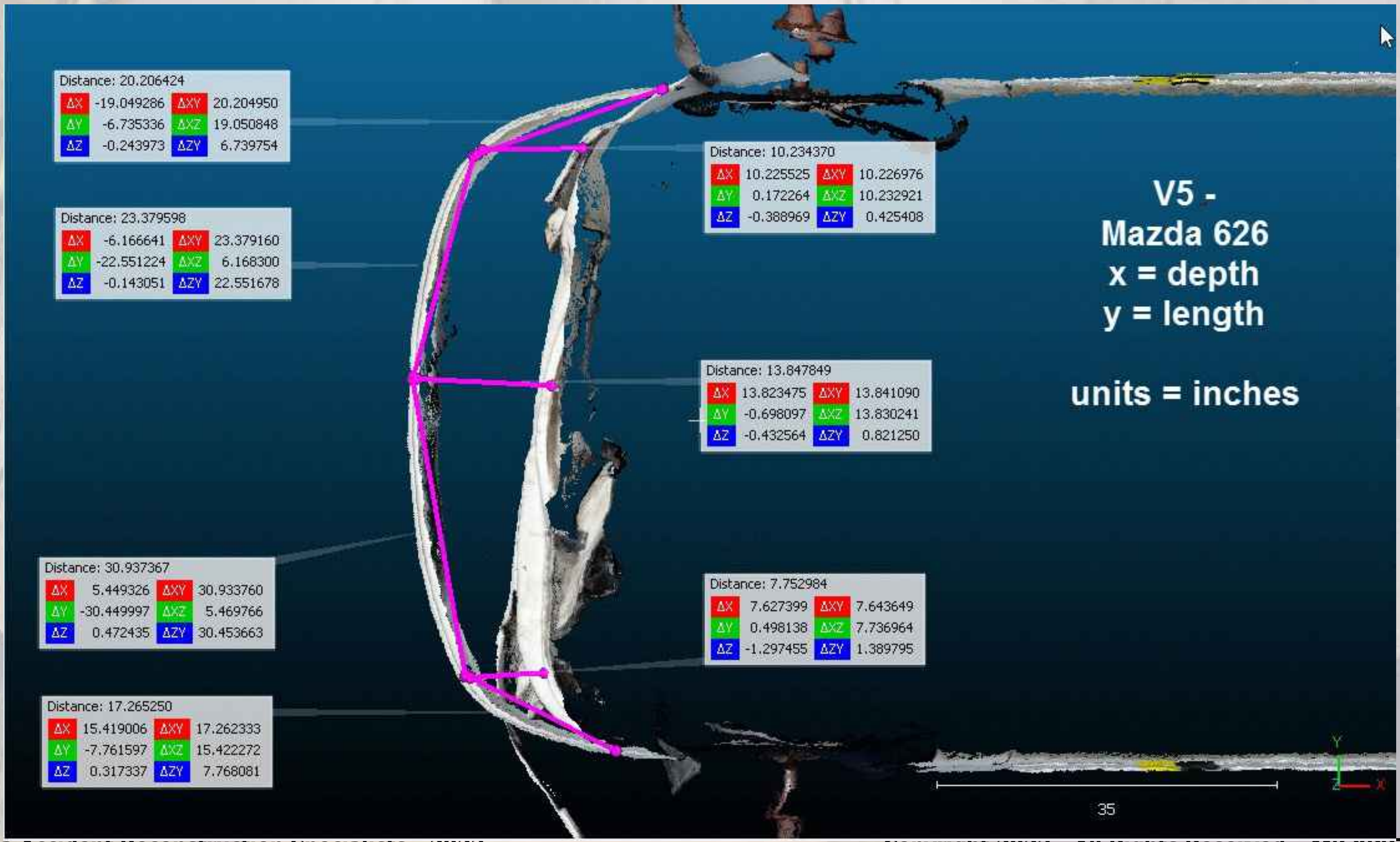
Crash Test Examples - CT2 - Output

		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	2008 Lincoln MKz	18.4	**12.5**	35.9	**24.5**	17.3	**11.8**	28.5	**19.4**
Target	2015 Dodge Charger	13.6	**9.2**	30.8	**21.0**	11.9	**8.1**	28.8	**19.7**
Combined Speed			**15.6**		**32.2**		**14.3**		**27.6**
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			**41.8**		**50.4**		**41.4**		**47.6**

Cloud Compare

Crush Measurements

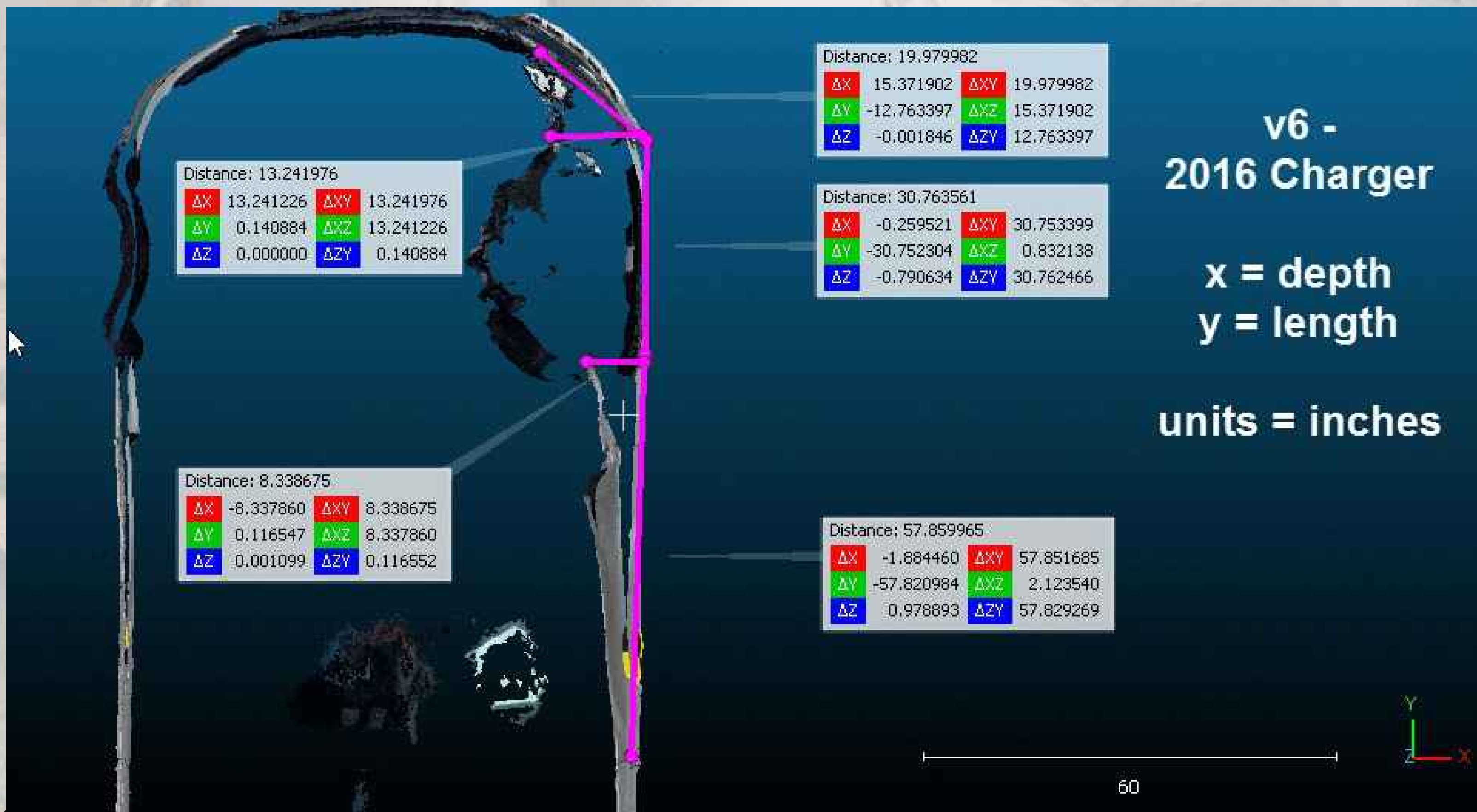
- V5 Crush Measurements



Cloud Compare

Crush Measurements

- V6 Crush Measurements



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 - CT3 - Input

									CRASH 3	Noon's
		Weight	Crush Length	Avg Crush	Max Crush	A	B	G	E	k
Bullet	1996 Mazda 626	2626	67.4	9.78	13.8	287.1	89.3	461.5	508199.6	1577.77
Target	2016 Dodge Charger	3950	101.2	8.17	13.2	249.8	355.9	97.1	1418412.4	1469.39

Speed Calculations

Crash Test Examples - CT3 - 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	1996 Mazda 626	22.3	**15.2**	39.5	**26.9**	19.5	**13.3**	32.2	**22.0**
Target	2016 Dodge Charger	21.3	**14.5**	38.6	**26.3**	14.0	**9.5**	43.9	**29.9**
Combined Crush Speed			**21.0**		**37.6**		**16.3**		**37.1**
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			**33.2**		**45.6**		**30.4**		**45.1**

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

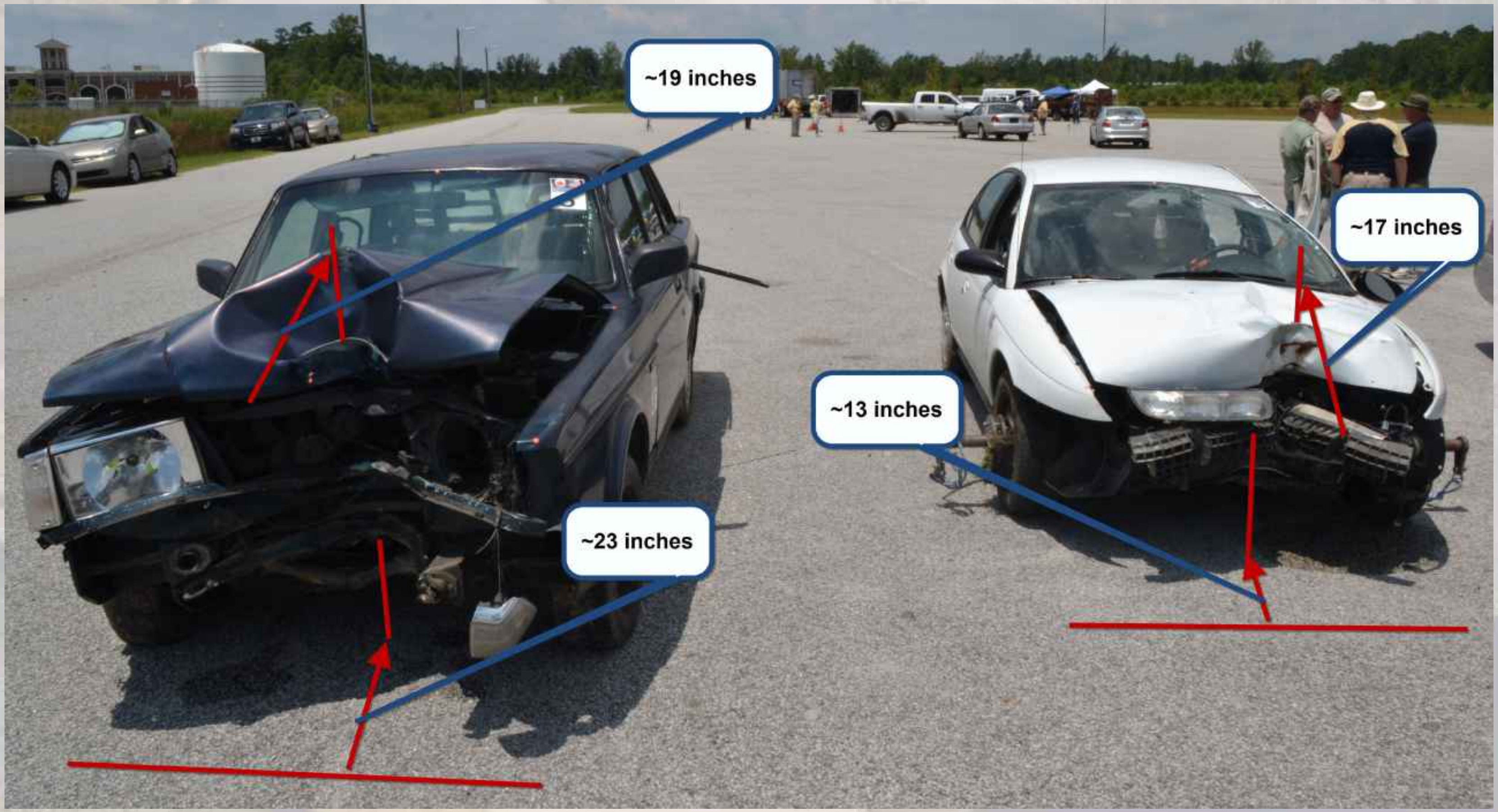
Special Considerations - Narrow Objects

- 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

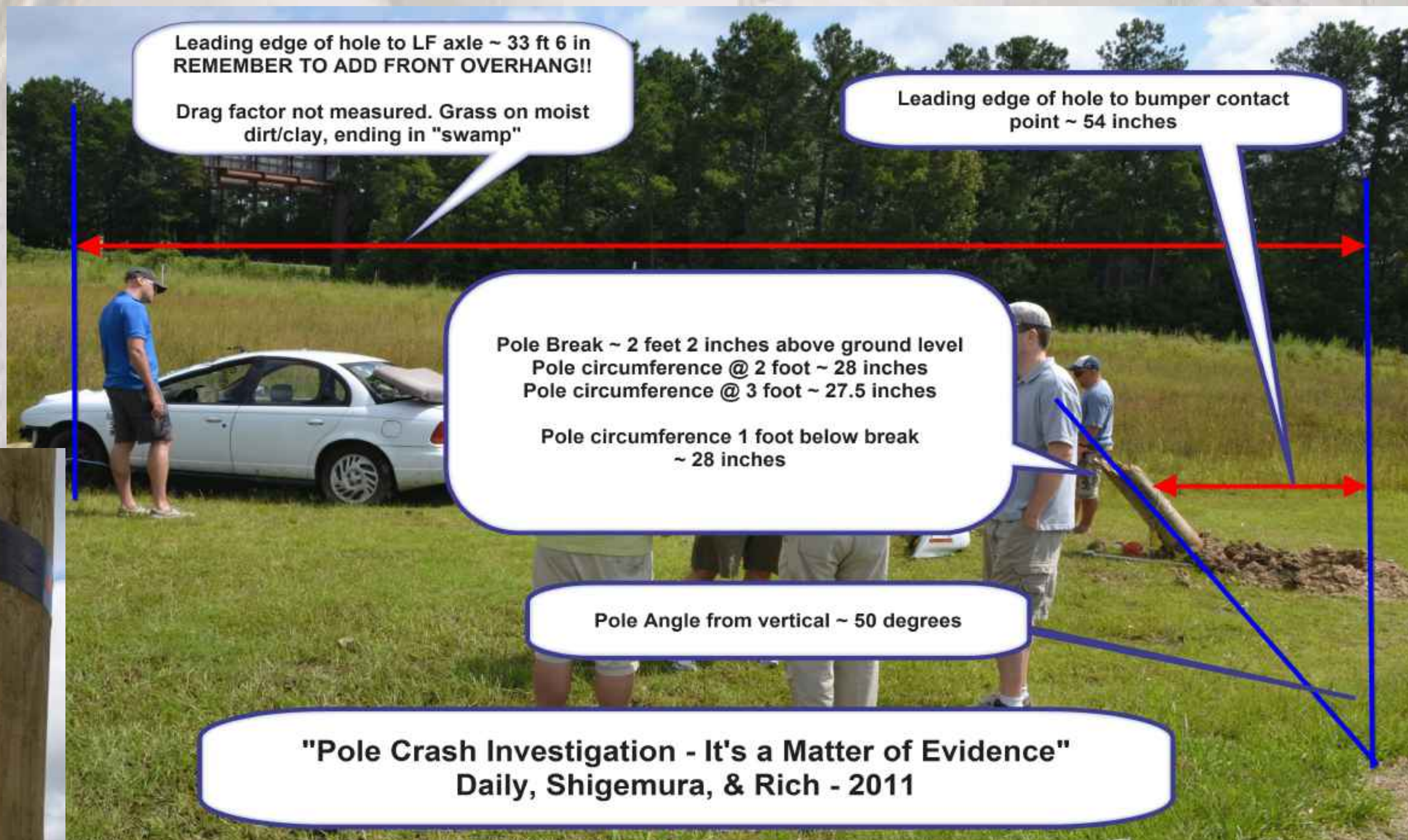
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1998 Saturn SL2 - KEES Speed

- ★ 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

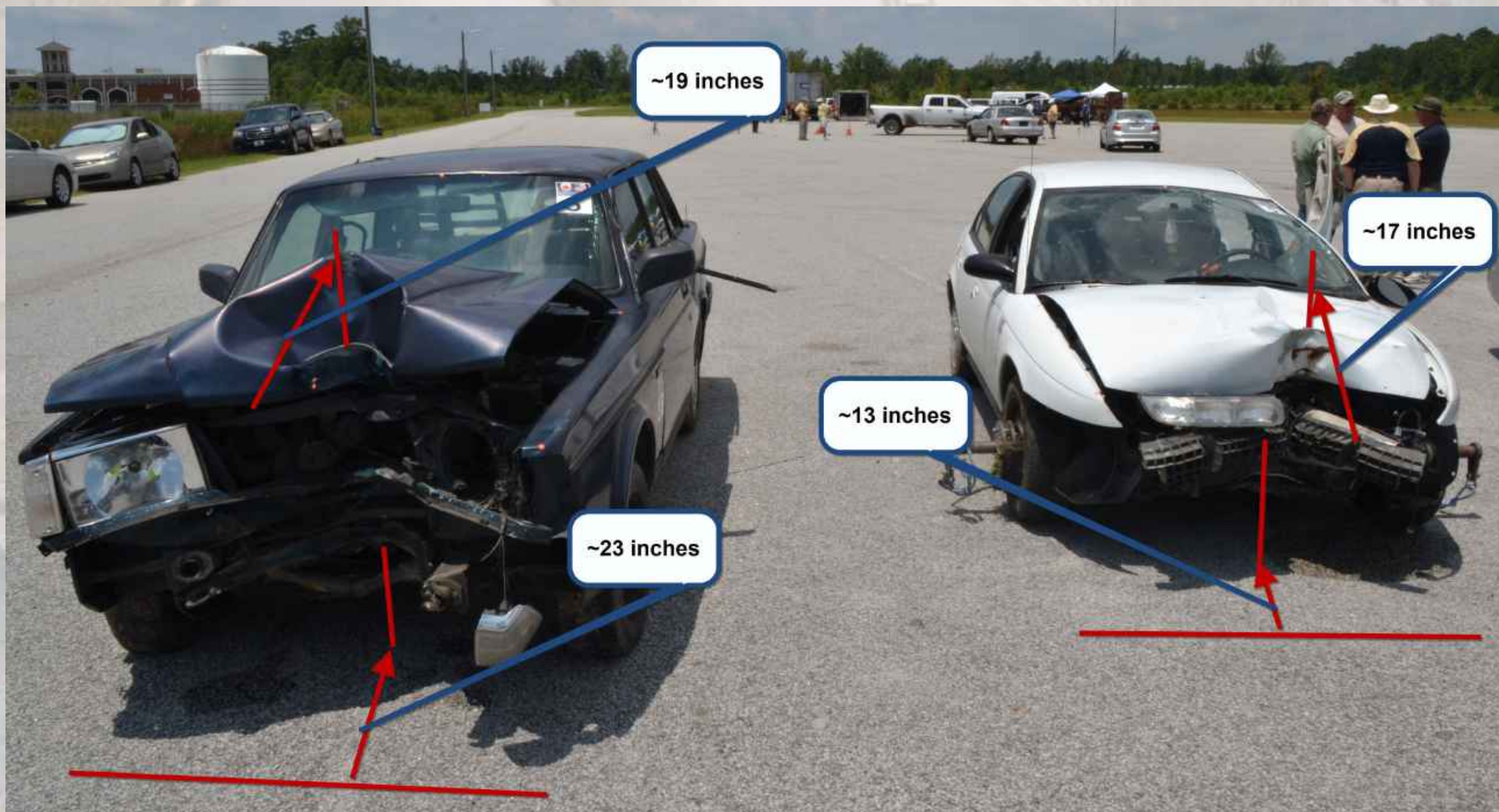
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1998 Saturn SL2 - Impact Speed

- 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



Speed Calculations

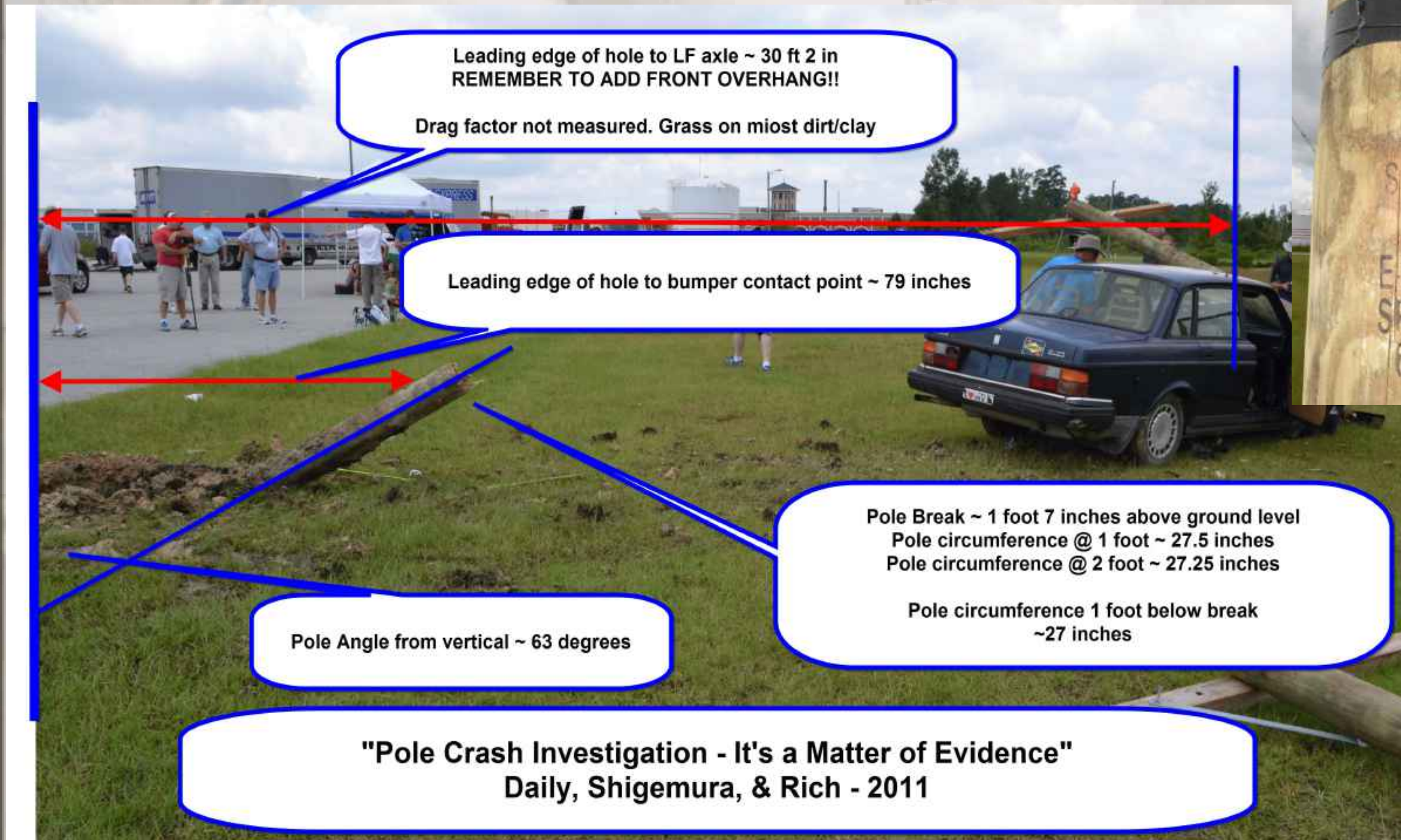
Special Considerations - Narrow Objects
SCARS 2013 Pole Impact Tests
1992 Volvo 240 DL- KEES Speed

- 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

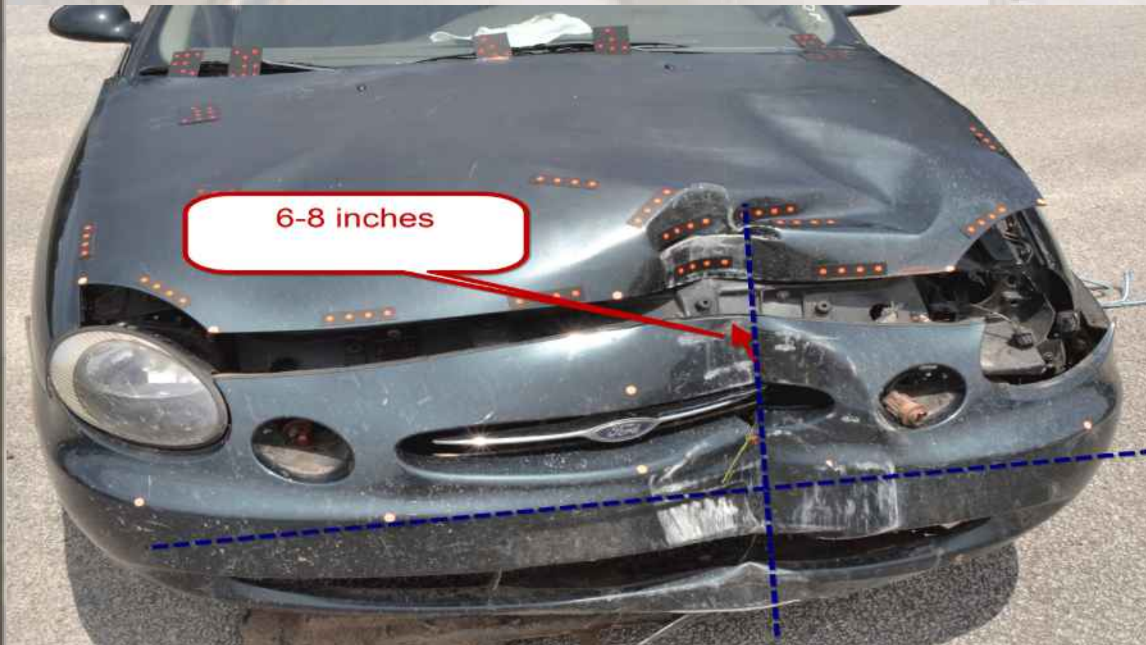
Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus



Speed Calculations

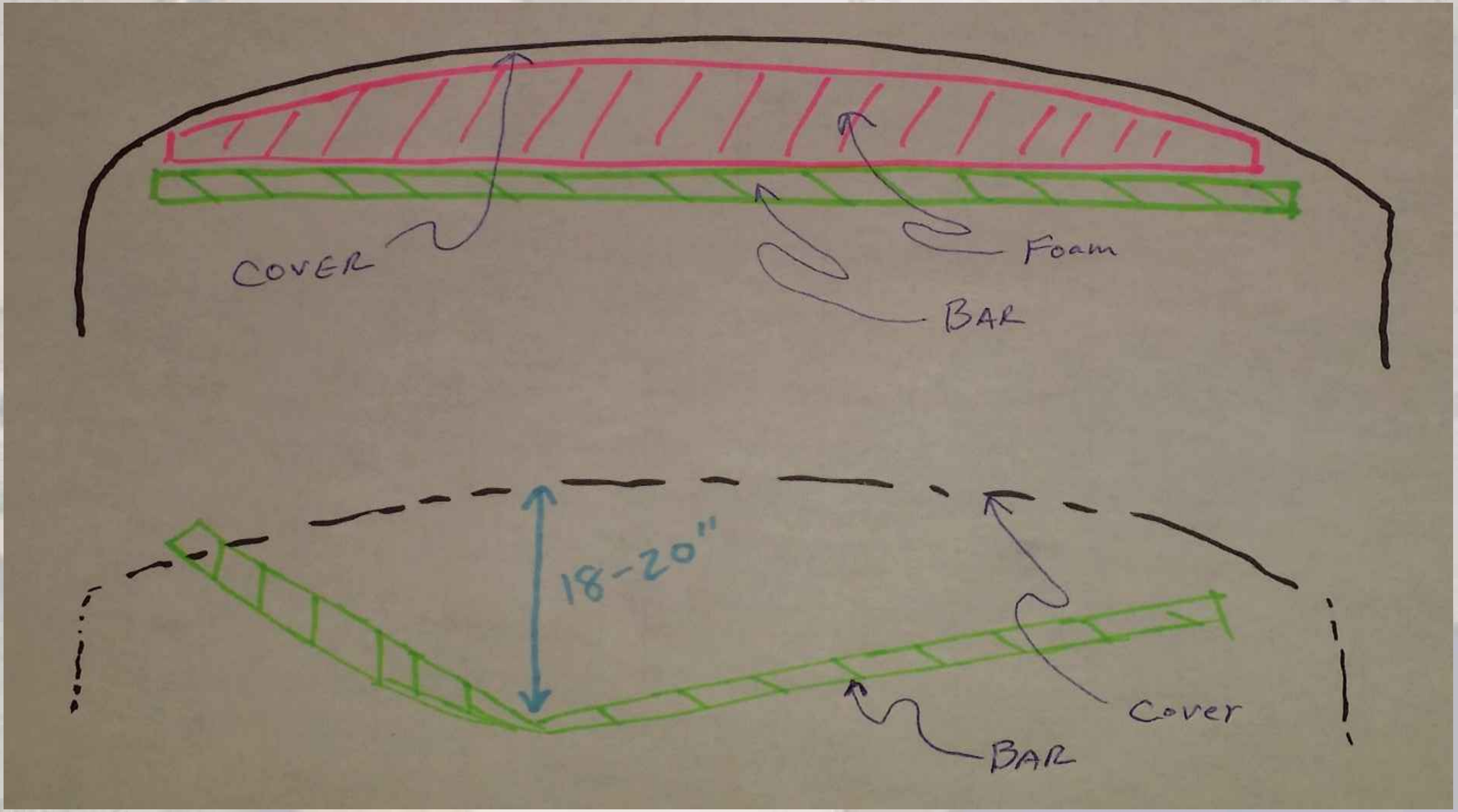
Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Speed Calculations

Special Considerations - Narrow Objects

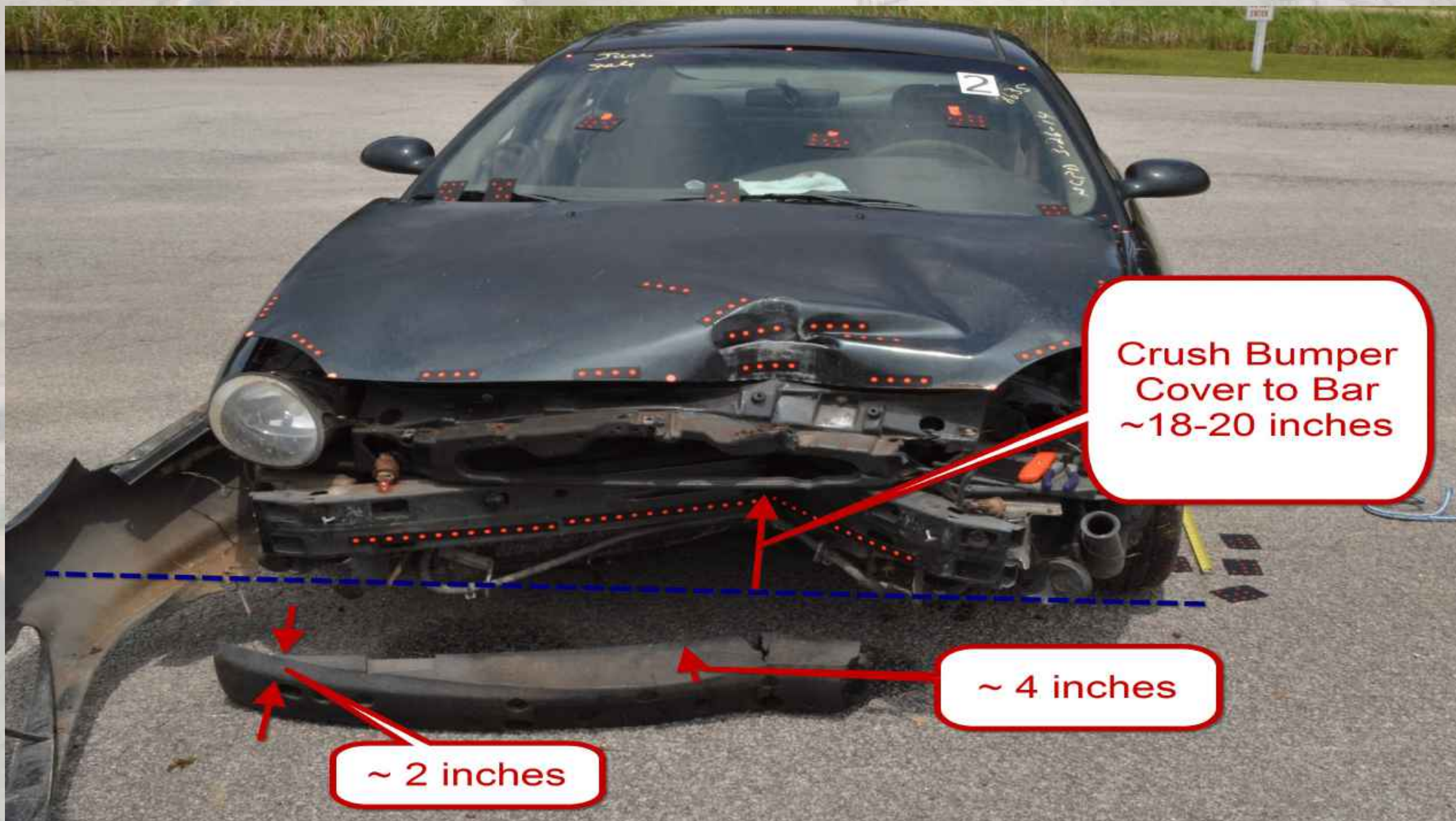
SCARS 2014 Pole Impact Tests - 1999 Ford Taurus



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

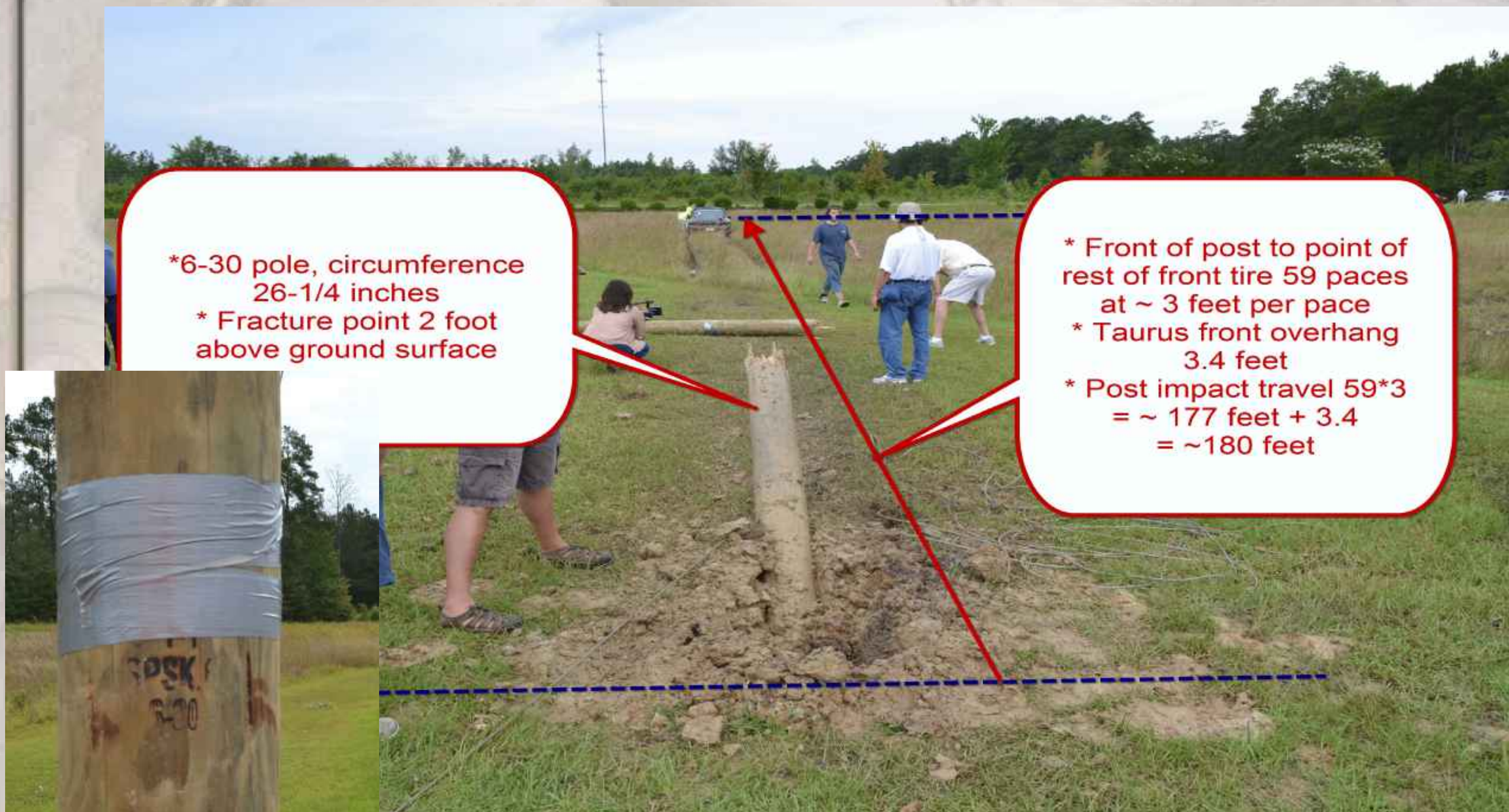
- Max Crush measured from ~ bumper cover to bumper bar ≈19 inches
- Energy absorbing Plastic thickness ≈ 4 inches
- Therefore, Max Crush at Bumper Level ≈ **15 inches** (not 19)
  - KEES = SQR**(**30*(15/12)*21*0.6**)**
  - KEES ~ 21.7 mph

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 1999 Ford Taurus

Field Evidence



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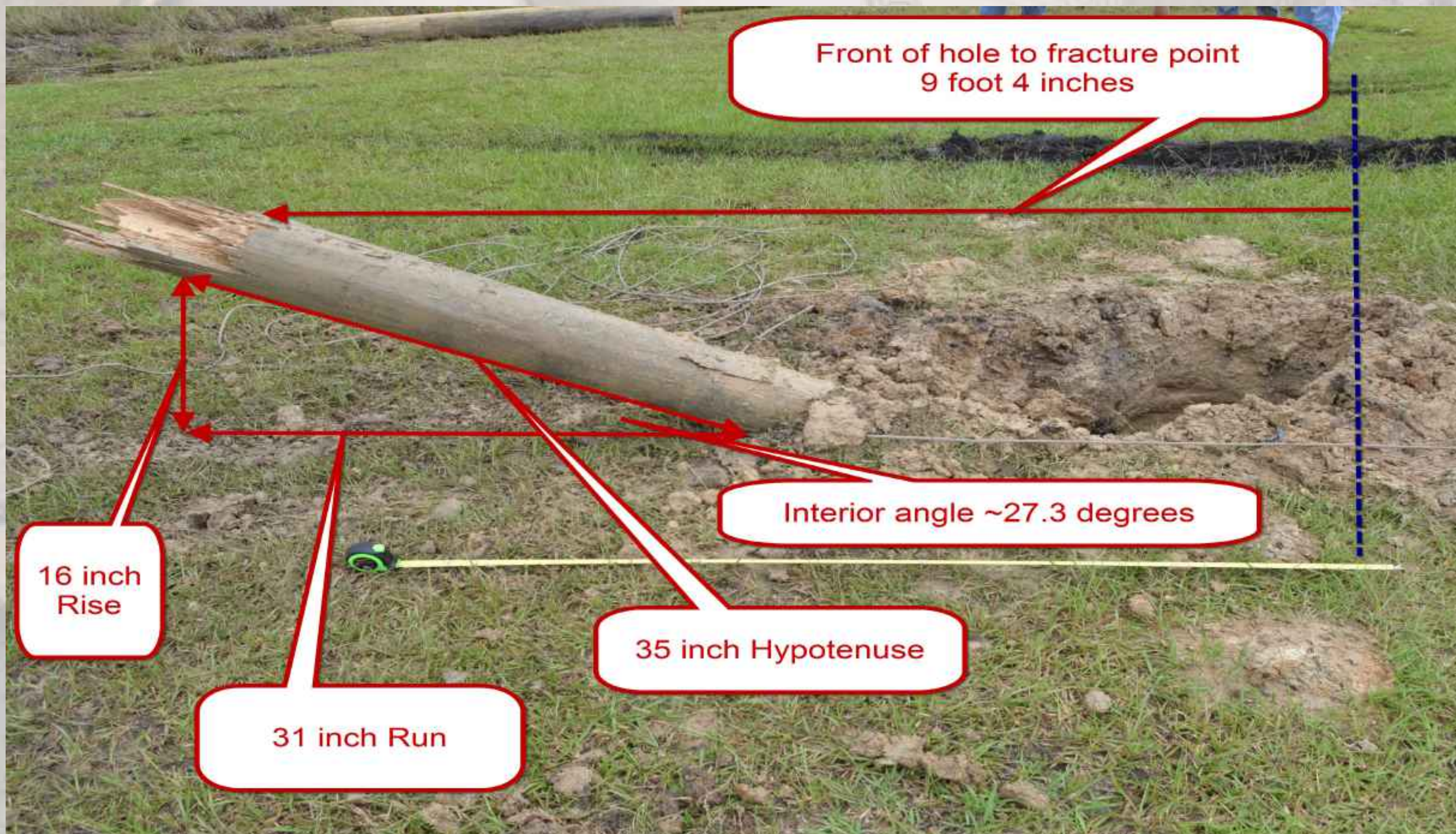
Speed Calculations

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

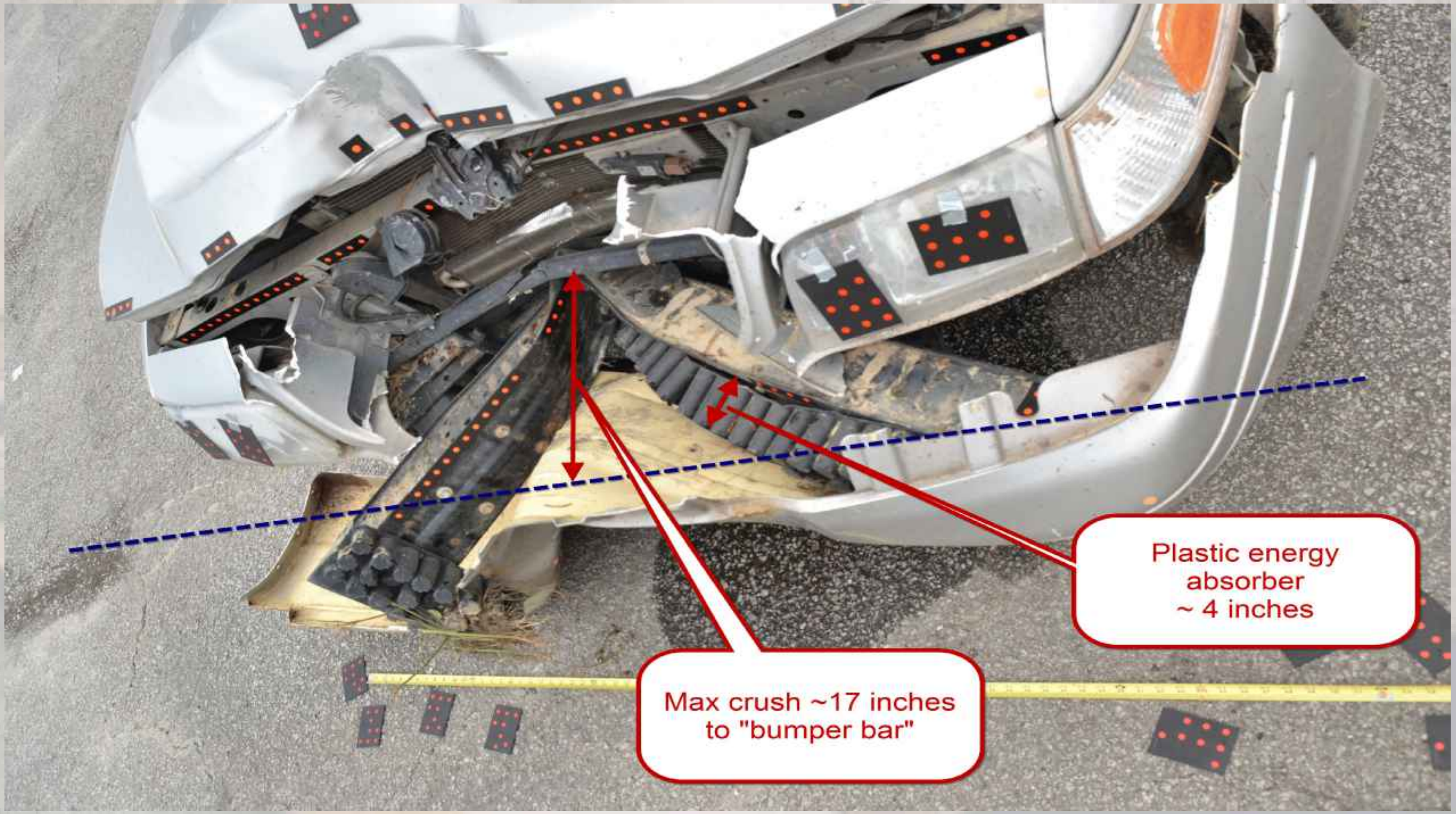
Impact Speed

- 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

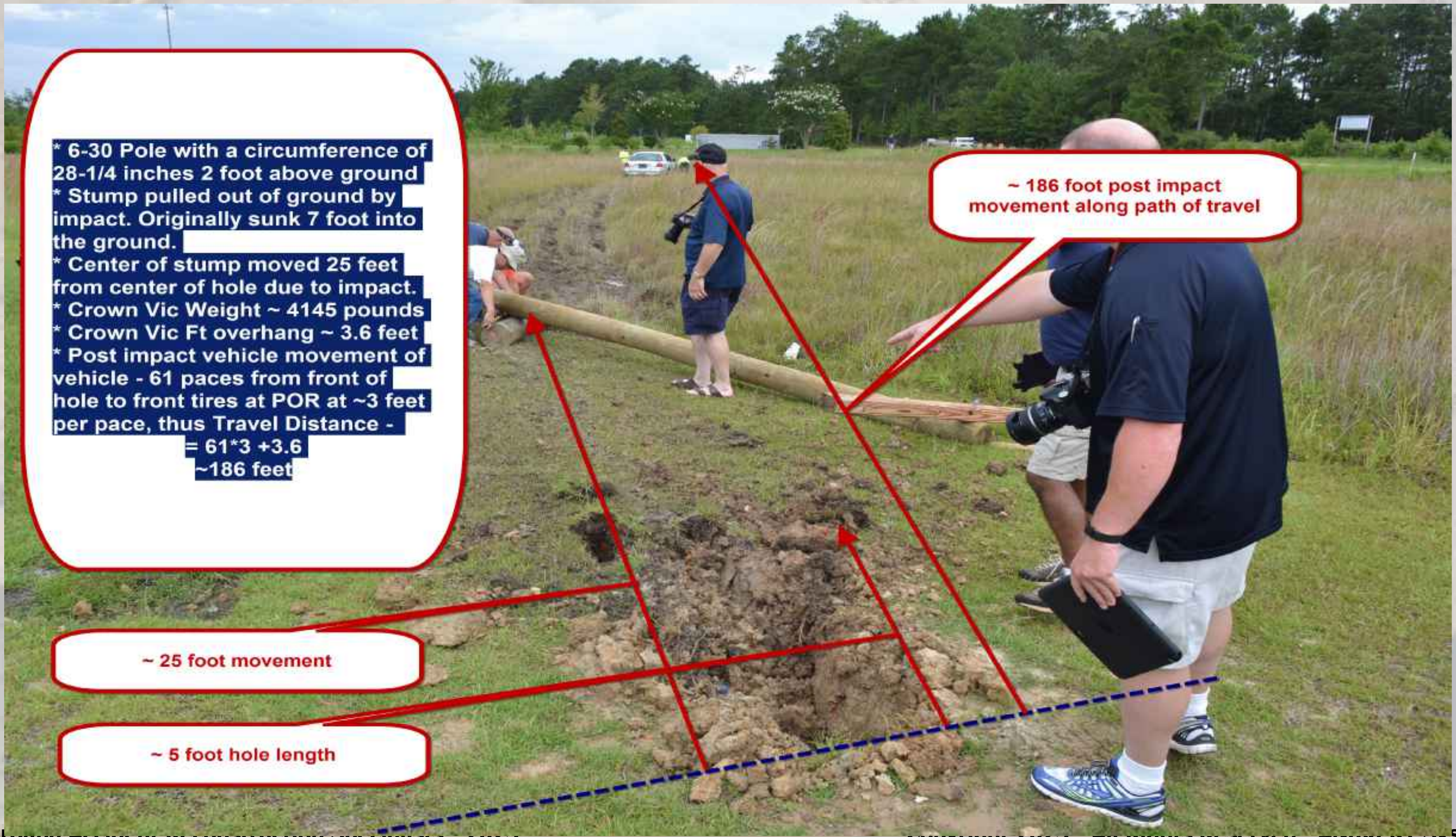
- Max Crush measured from ~ bumper cover to bumper bar ≈17 inches
- Energy absorbing Plastic thickness ≈ 4 inches
- Therefore, Max Crush at Bumper Level ≈ 13 inches
  - KEES = SQR(30*(13/12)*21*0.6)
  - KEES ~ 20 mph

Speed Calculations

Special Considerations - Narrow Objects

SCARS 2014 Pole Impact Tests - 2008 Ford Crown Victoria

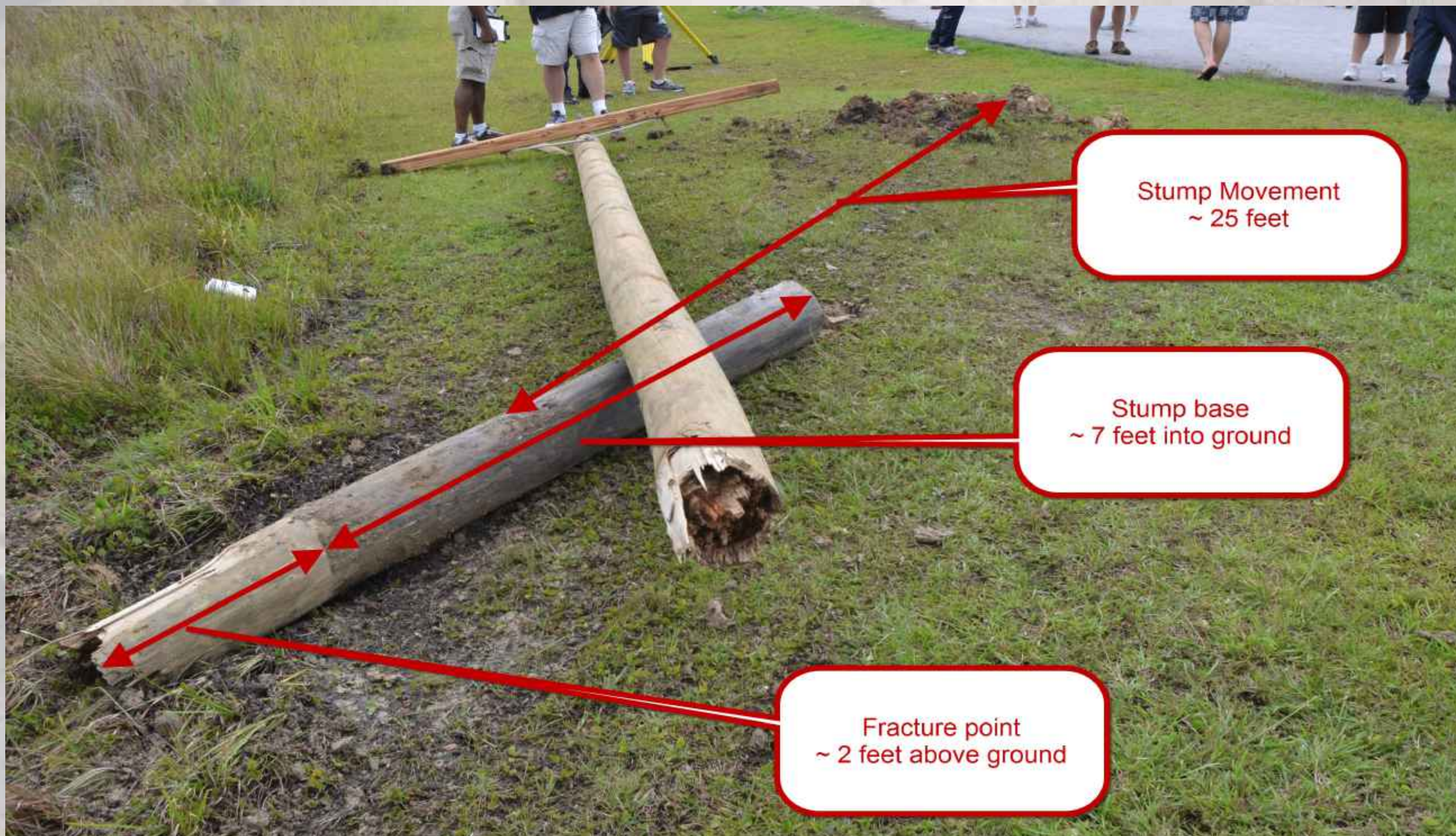
Field Evidence



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/SCARS-2023.htm

Daniel W. Vomhof III

Presentation Materials for

SCARS 2023

Crush Analysis Considerations

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

Download Crush Analysis Considerations Presentation - 1 Slide per page

Additional Materials

Please note that the videos may take some time to download

	SCARS 2022 Crash Test 1	SCARS 2022 Crash Test 2	SCARS 2022 Crash Test 3
Download Excel Spreadsheet with Crush Calculations	Download Video 11 - Overhead	Download Video 21 - Overhead	Download Video 31 - Overhead
Download SCARS 2022 Force Balance Analysis and Commentary (this is also included with the Presentations)	Download Video 12 - Angled Overhead	Download Video 22 - Angled Overhead	
	Download Video 13 - Driver View with Speedometer	Download Video 23 - Driver View with Speedometer	Download Video 33 - Driver View with Speedometer
	Download Video 14 - Combination of all DV3 cameras	Download Video 24 - Combination of all DV3 cameras	Download Video 34 - Combination of all DV3 cameras

Web site References

Precision vs Accuracy

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

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

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

Crush Analysis Considerations

Summary

- ★However, sometimes ...

Crush Analysis Considerations

Summary

- No matter how hard you try ....

Crush Analysis Considerations

Summary

- ★You have those cases ....

Crush Analysis Considerations
Summary

- ★Where no matter what you do ....




Crush Analysis Considerations

Summary

★Something is going to "trip" you up ....

Crush Analysis Considerations

Summary

- In which case ....

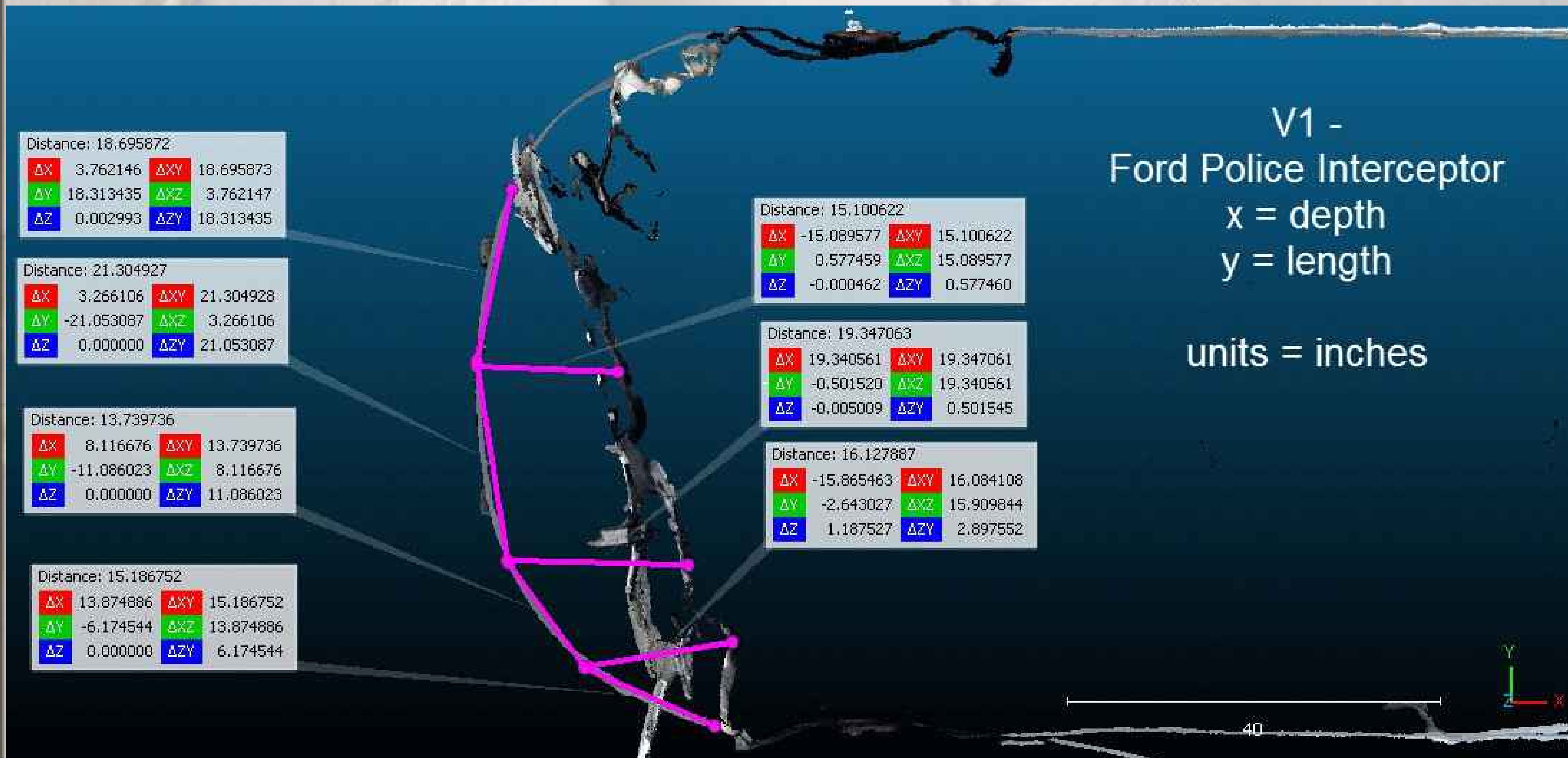
Some days all you can do is smile and wait for some kind soul
to come pull your ass out of the bind you've gotten yourself into.

MMMMMWAH ... Good bye!

Cloud Compare

Crush Measurements

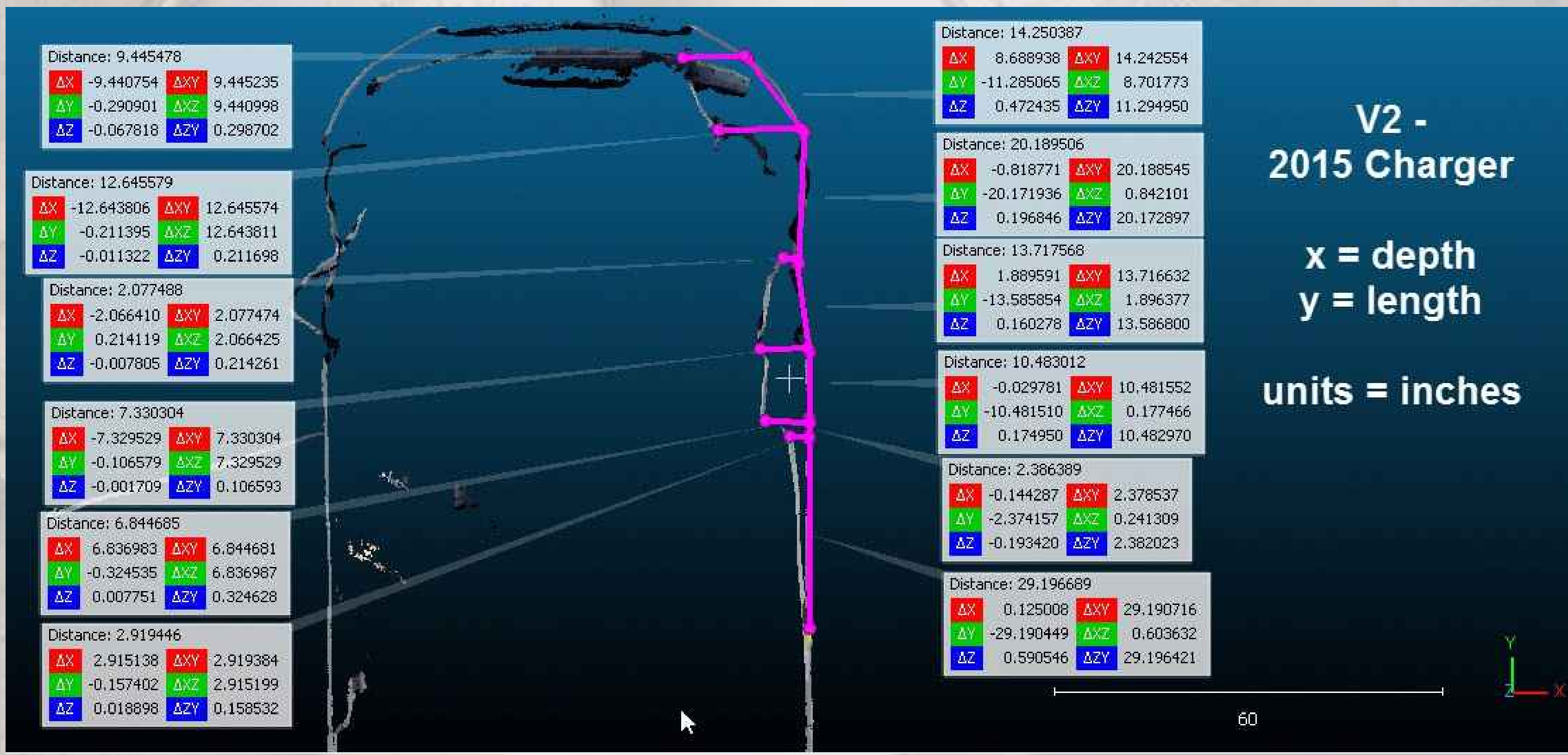
- V1 Crush Measurements



Cloud Compare

Crush Measurements

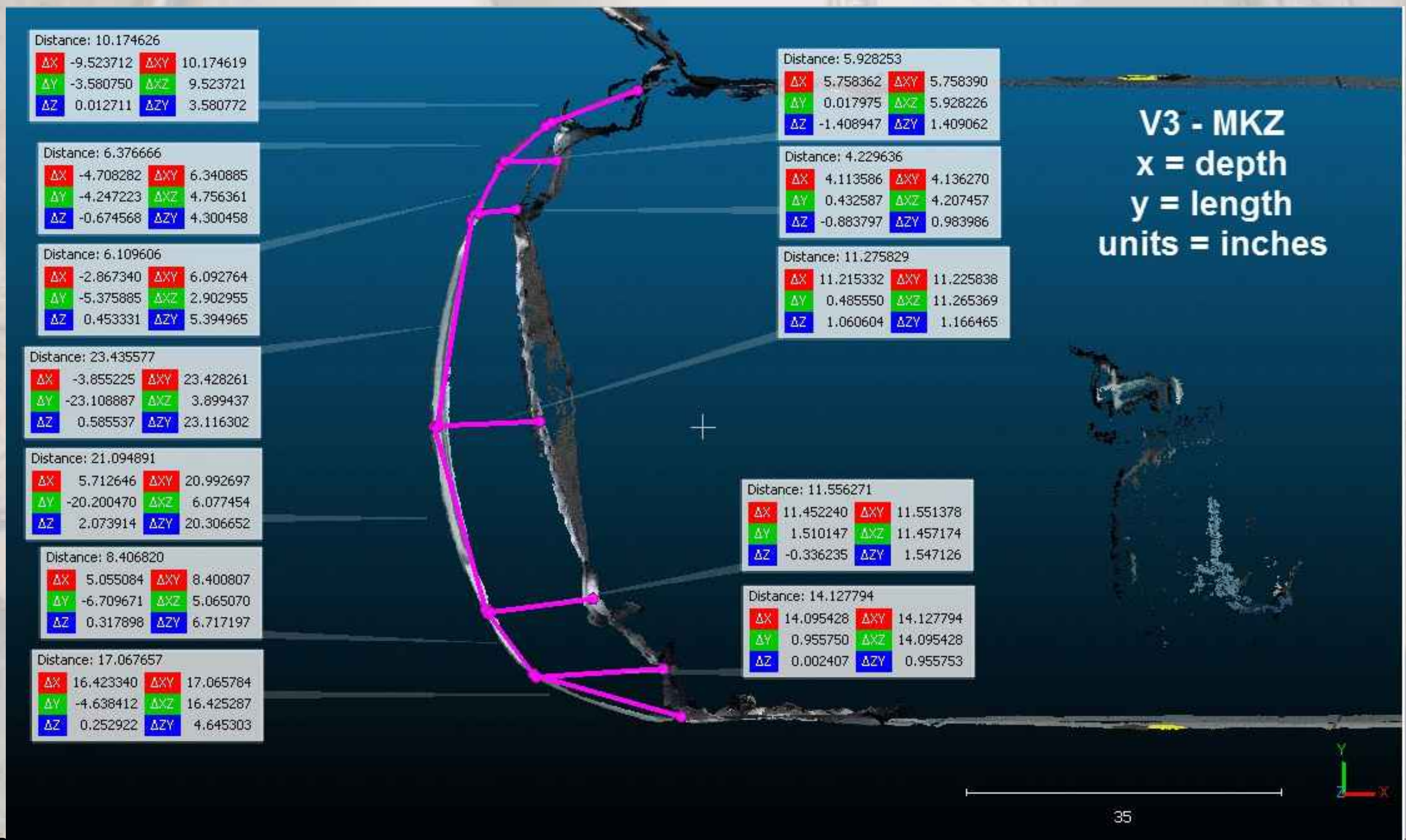
★V2 Crush Measurements



Cloud Compare

Crush Measurements

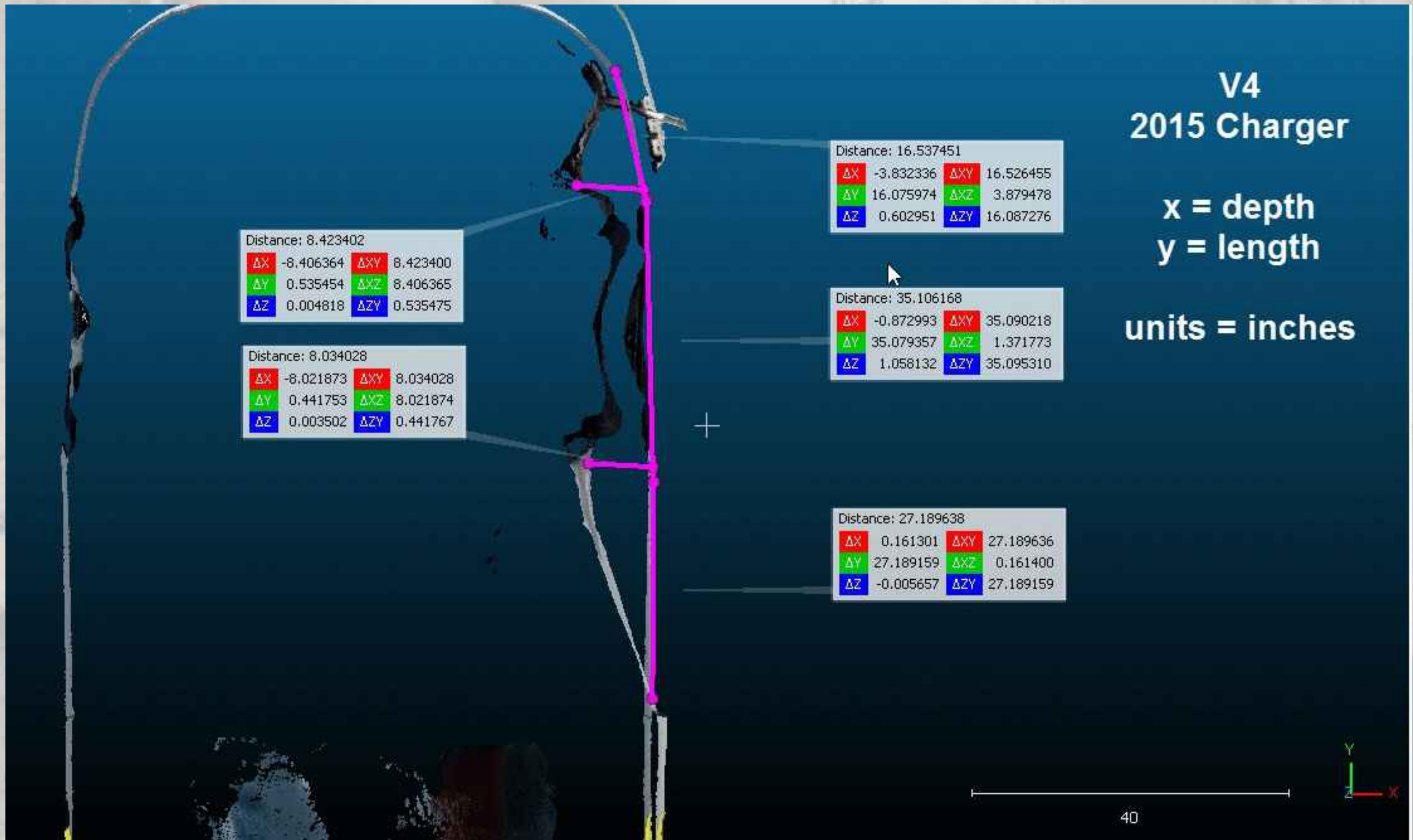
★V3 Crush Measurements



Cloud Compare

Crush Measurements

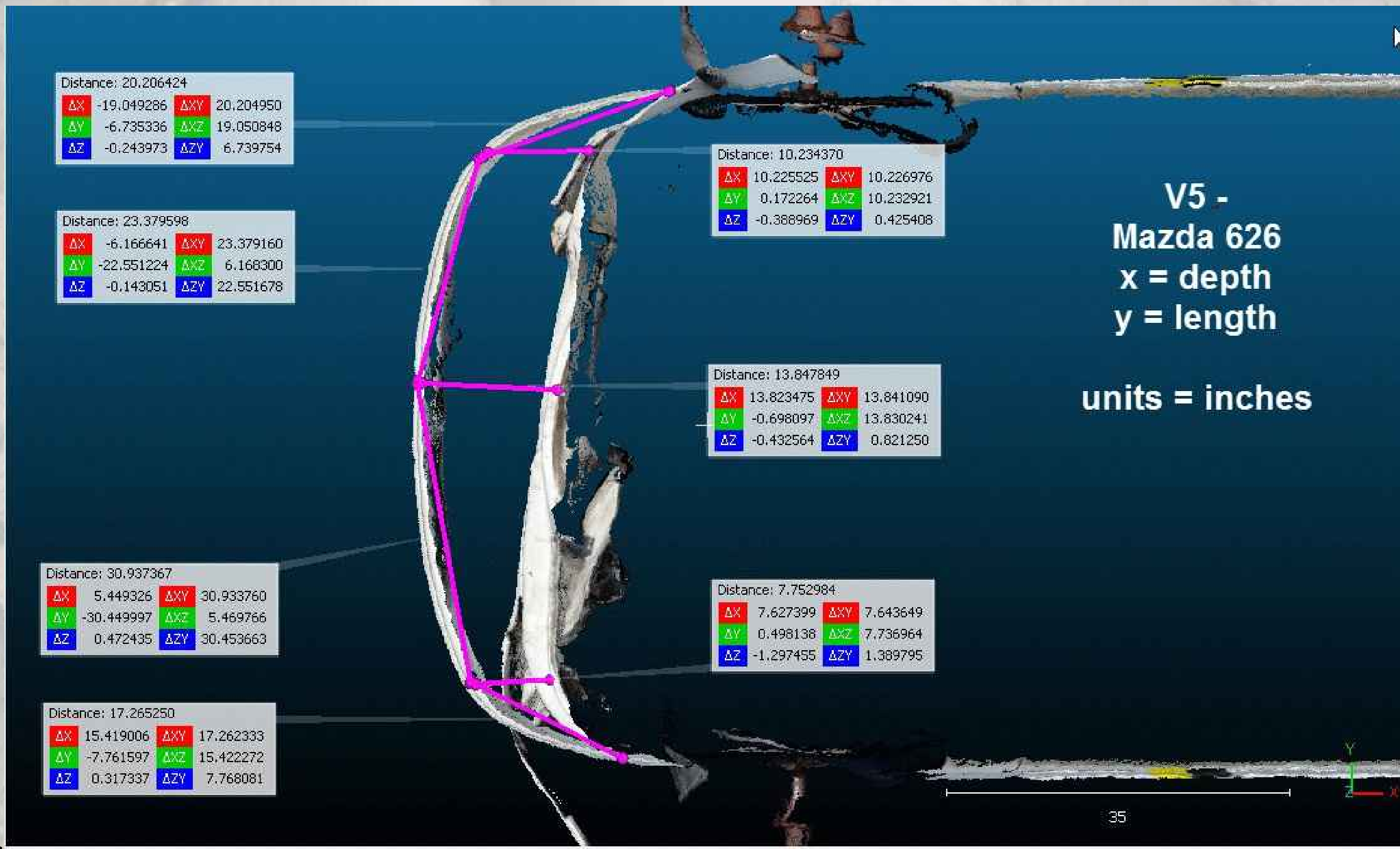
★V4 Crush Measurements



Cloud Compare

Crush Measurements

★V5 Crush Measurements



Cloud Compare

Crush Measurements

- V6 Crush Measurements