Real World Accuracy Issues
Leica Scan vs Recon3D Scan Comparison

by Daniel W. Vomhof III - 4N6XPRT Systems

ISSUE:

In the current world of Vehicle Accident Investigation and Reconstruction. Scanning vehicles and the use of Point Clouds is becoming more and more important and common place. In addition to the more "high end" scanners provided by Leica, Trimble, FARO, Topcon (etc) there are a number of scanning apps provided for the Apple iPhone/iPad when they have LIDAR functionality. These apps are more affordable by the individuals who do not have heavy case loads or high volume clients. The question now becomes "What am I giving up in accuracy if I use one of these Apps?"

PROCESS:

In an effort to provide a "Real World" analysis of the differences, and how it effects the results, a crush analysis was completed for Vehicle 4, a 2019 Volvo S60 AWD, that was crash tested at the WREX 2023 conference. The specific test was a head-on impact with 60-70% overlap between Vehicle 3, a 2018 Chevrolet Silverado K1500 and Vehicle 4. Impact speeds based on CDR was 35-37 mph for both vehicles resulting in a closing speed of 70-72 mph at impact.

Scans of Vehicle 4 were completed, both Pre-crash and Post-crash using a Leica Scanner and the Recon-3D app on a Apple iPhone 12.

In order to obtain a crush profile, three different alignment overlays were conducted. Recon3D post on Recon3D pre, Recon3D post on Leica pre, and Leica post on Leica pre. The thought process of the Recon3D post on the Leica pre is that (A) many of the exemplar scans have been conducted with higher end scanners and (B) there is a belief that the higher end scanner will be more accurate than the App will be, thus, it is expected that if there are differences they will be emphasized with this match up.

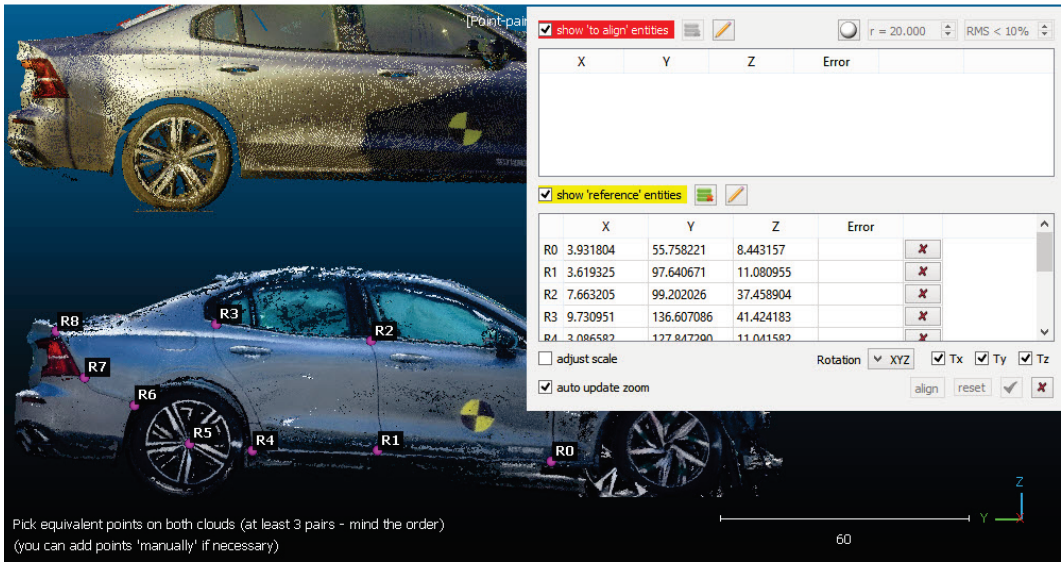
Two sets of crush profile measurements were obtained from each alignment set. One set of crush measurements were measured and obtained within the Cloud Compare program. This set is a 10 point, non-equally spaced crush profile. This crush profile was then used in the Force Balance module that is a part of the 4N6XPRT StifCalcs® program published by 4N6XPRT Systems®. The second set of crush measurements were obtained by first printing the Pre-Post slice from each alignment set, and then scaling off a set of 6 equally spaced measurements. These 6 measurements were then input into a Crush Calculator spreadsheet available from CG Consulting's website (at https://collisionrecon.com/crush-analysis/). From there, various metrics important in calculating speed from crush were obtained and compared to see what "Real World" effects any differences in scanning methods may have when calculating speeds from crush measurements.

ALIGNMENT:

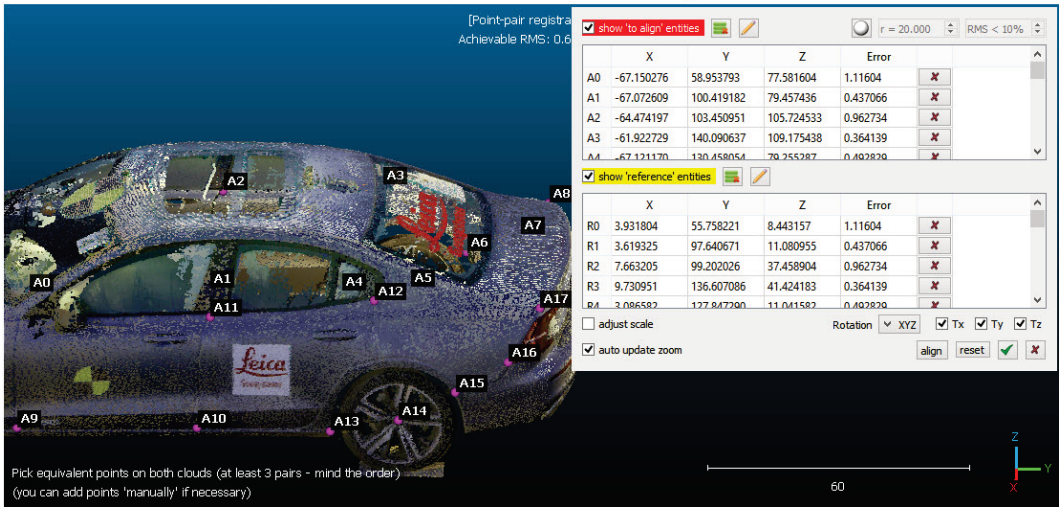
To align the two scans within Cloud compare, 18 points were identified for the Recon3D-on-Recon3D point clouds, and 19 points were identified for the other two alignments. The

difference is due to the Recon3D-on-Recon3D being completed first and point 9, located at the bottom front of the Driver Side Front Door was not identified on that set. Screen shots showing the location of the alignment points are shown below -

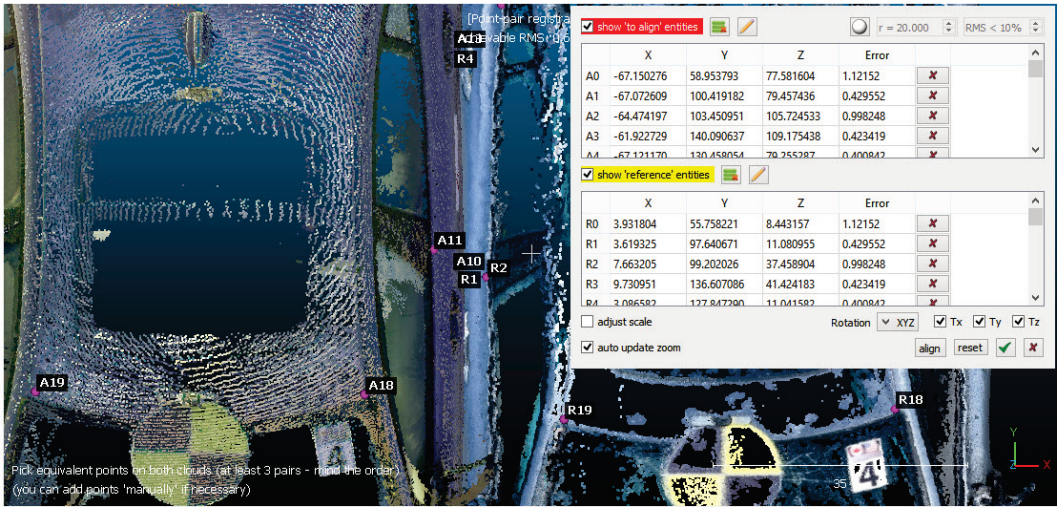
Leica pre - Recon3D post - Passenger Side Alignment Points



Leica pre - Recon3D post - Driver Side Alignment Points



Leica pre - Recon3D post - Top Down Alignment Points



The Alignment RMS values for each alignment are

Alignment	RMS value (in)	RMS value (cm)
Recon3D (post) on Recon3D (pre)	0.75	1.91
Recon3D (post) on Leica (pre)	0.62	1.57
Leica (post) on Leica (pre)	0.64	1.63

In general, the closer the RMS value is to a value of zero (0), the better the "fit"

SLICE:

When taking the "slice" for the crush profile for these measurements were basically the top and bottom of the front bumper cover immediately below the grille. WHERE you take the slice can significantly alter the crush profile that is obtained.

CRUSH PROFILE:

The crush profiles were measured in two ways. Within Cloud Compare 10 non-equally spaced measurements were taken for each alignment set. Each measurement was taken to an inflection point within the crushed surface or the undamaged bumper. If the vehicle is oriented with care, then the delta-x and delta-y measurements can be used for the depth and length measurements for input into the crush measurement algorithm. The benefit of a non-equally spaced set of measurements is that the crush profile can be more closely represented in the calculations.

The more commonly seen crush profile due to software constraints is with 6 equally spaced measurement points. To obtain these the "bare" overlay for each set was printed and then the crush positions and depth measurements were scaled off using pen and a ruled scale. More variation is expected with this method due to "missing" many of the bend points within the crush surface.

CALCULATIONS:

Two calculation programs were used to analyze the "Real World" effect of the differences in measurements due to the different scanning tools.

One calculation program method was to apply a Force Balance calculation to the Volvo crush based upon the Chevrolet crush profile and calculation results.

Historically, the purpose of the Force Balance calculation method is to determine A & B values for one vehicle based on the crush profiles of the two vehicles involved in the collision and the A & B

stiffness values for the other vehicle for which the analyst has more confidence in. This method will typically determine A & B values for the "Unknown" vehicle which are lower than the A & B values calculated based upon impacting a non-deformable barrier due in part to the underride/override effects of one vehicles bumper sliding over/under the other vehicles stiff points.

The other calculation program method was to calculate the crush data using a Spreadsheet which calculates the crush values (centroid, Area, Average Crush, etc) and then the crush speed based purely upon the vehicle in question and the A & B values input into the spreadsheet. To equalize the calculated speed between the two programs, the Average of the A & B values calculated for the Volvo based on the Average A & B values for the Chevrolet were used.

A summary of the calculation results which illustrate the "real world" effects of the differences between the two scanning tools are shown below.

Force Balance Analysis				
Alignment	Damage Centroid (x) (in)	Average Crush (in)	Area of Damage (in^2)	Volvo KE Speed (mph)
R3D (post) on R3D (pre)	7.28	13.05	912.20	29.2
R3D (post) on Leica (pre)	7.35	13.09	913.68	29.4
Leica (post) on Leica (pre)	7.42	13.66	975.62	29.7

CG Consulting Crush Calculator				
Alignment	Damage Centroid (x) (in)	Average Crush (in)	Area of Damage (in^2)	Volvo BEV Speed (mph)
R3D (post) on R3D (pre)	7.68	13.26	904.4	29.4
R3D (post) on Leica (pre)	8.08	13.90	948.1	30.6
Leica (post) on Leica (pre)	7.89	13.60	927.5	30.6

SUMMARY:

An examination of the results from the 3 alignment sets and 2 calculation methods revel very little difference in the real world results between the two scanning methods. The observed differences in the Damage Centroid (x), Average Crush, and Area of Damage are as much a result of the different profile methods as anything else. Further, between the 3 sets and 2 methods, there is less than 1.4 mph in calculated KE/BEV speed between the minimum and maximum calculated speeds. If you look at the sets, there is less than 0.5 mph difference in calculated KE/BEV speed between the minimum and maximum calculated speeds within the Force Balance set, and 1.2 mph within the CG Consulting Crush Calculator set. The greater difference in the CG Consulting Crush Calculator calculations is attributed to

the difference in the measurement methods. The non-equally spaced method used in the Force Balance calculations more nearly matches the actual crush profile, which lends itself to “tighter” calculations all the way around, including the KE/BEV speed..

This analysis illustrates that as long as care is taken by the investigator in properly using their tools, which tool(s) they choose to use will not have a major effect on the results they obtain.

The underestimation of the Closing Speed in the Force Balance calculations is a function of the collision alignment and the calculation method and is a separate issue from the crush measurements taken and the tools used to take them.

Factors which can and will have a larger effect on the crush measurements obtained than the tools used are -

- where the “slice” is taken as that will affect where the damage will be found
- how much time elapses between various parties measuring the damage and what is done to the damaged vehicle between the measurement processes

The crush profiles, measurements, and calculations are attached for those wishing to review the “Raw” data.

***** Brand names are used in this analysis to help in the reader in evaluating the tools used, both hardware and software, and are not an endorsement of any specific product.***

Attachments

Recon-3D (Pre) - Recon-3D (Post)

Crush Profile for Force Balance Calculations

Force Balance Calculations - 2 Pages on 1

Force Balance Calculations - 1 Page each

Crush Profile for Crush Calculator Calculations

Crush Calculator Calculations

Leica (Pre) - Recon-3D (Post)

Crush Profile for Force Balance Calculations

Force Balance Calculations - 2 Pages on 1

Force Balance Calculations - 1 Page each

Crush Profile for Crush Calculator Calculations

Crush Calculator Calculations

Leica (Pre) - Leica (Post)

Crush Profile for Force Balance Calculations

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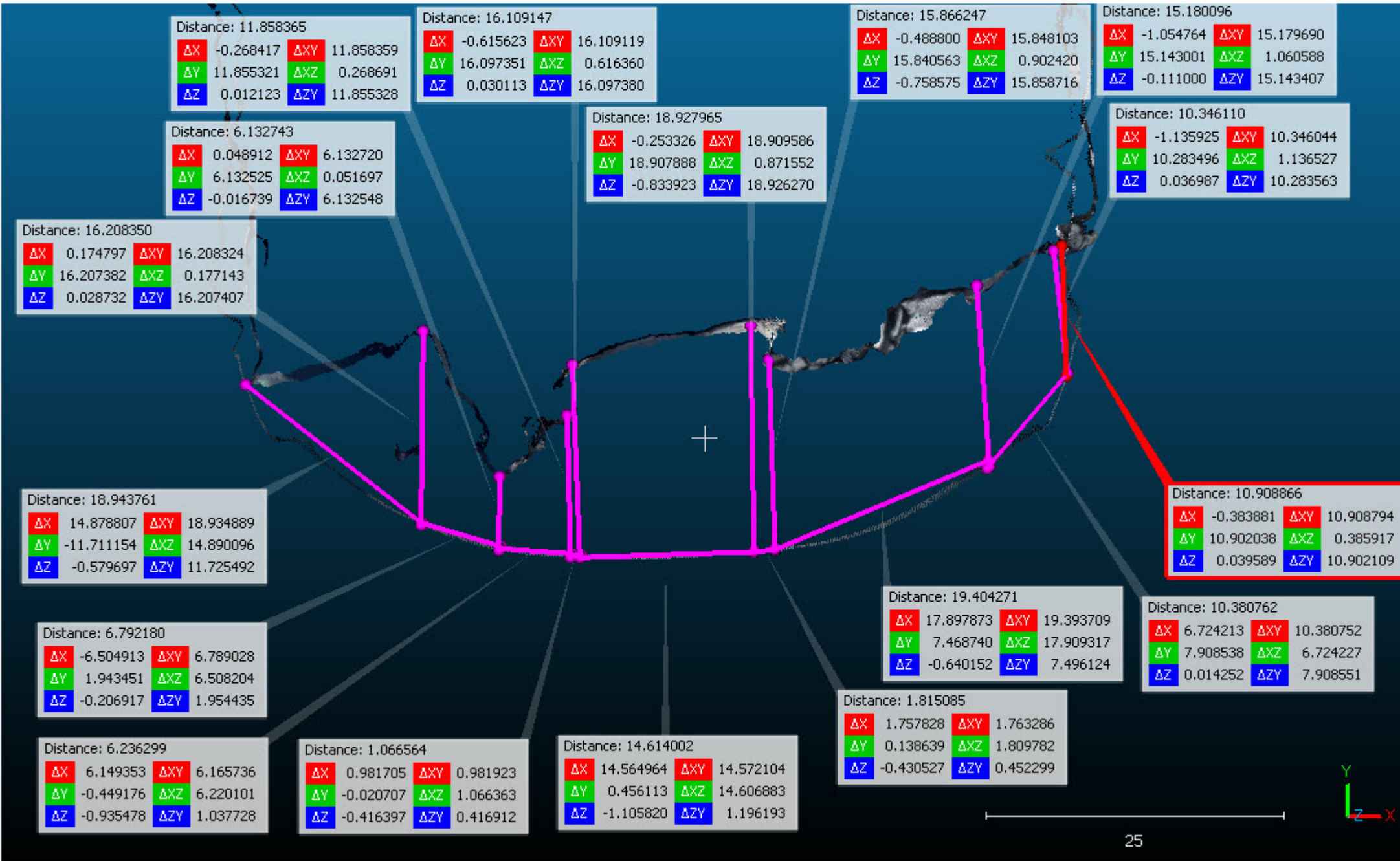
Force Balance Calculations - 1 Page each

Crush Profile for Crush Calculator Calculations

Crush Calculator Calculations

Recon3D(Pre) - Recon3D(Post) Damage
delta y = depth / delta x = length
Units = inches



Volvo Crush - Recon-3D on Recon-3D

2025 CHEVROLET SILVERADO K1500 DOUBLE CAB 144WB - Front Impact

Curb Weight (pounds):	5104
Occupant + Cargo Weight (pounds):	2451
Total Weight (pounds):	7555
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.68
Damage Length (inches):	74.2
Crush Profile Measurements:	8

PDOF

Lever Arm Distance (inches):	16.80
Yaw Moment of Inertia (lb-ft-sec²)	6575.65

"Known" Stiffness Values

	A	B
Average	465.5	121.5
Minimum	410.3	101.5
Maximum	536.2	149.2
Std. Devation	47.1	18.1

		Unequal Spacing (inches)	Zone Area (inches²)	Zone Depth(x) (inches)	Area Depth(x) (inches³)	Zone Depth(y) (inches)	Area Depth(y) (inches³)
C1 (inches)	8.80	3.83	31.98	4.18	133.65	1.88	60.14
C2 (inches)	7.90	20.43	138.92	3.43	476.46	30.09	4180.81
C3 (inches)	5.70	13.63	133.57	5.19	692.70	35.03	4678.48
C4 (inches)	13.90	11.29	228.62	10.46	2390.68	40.11	9168.92
C5 (inches)	26.60	10.00	205.50	10.57	2172.52	44.51	9146.67
C6 (inches)	14.50	11.55	200.39	8.75	1754.04	63.84	12793.30
C7 (inches)	20.20	3.48	76.39	11.00	840.11	22.67	1731.38
C8 (inches)	23.70						
C9 (inches)							
C10 (inches)							

Average Crush (inches): 13.68

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	410.3	101.5	66736.22	111370.25	21.0	16.2	50.9
Avg - 2 Std. Deviations	371.3	85.3	57067.37	96522.79	19.6	15.1	47.4
Avg - 1 Std. Deviations	418.4	103.4	68001.04	113500.99	21.2	16.3	51.4
Average	465.5	121.5	78934.70	130521.35	22.8	17.5	55.1
Avg + 1 Std. Deviations	512.6	139.6	89868.37	147567.47	24.2	18.6	58.5
Avg + 2 Std. Deviations	559.7	157.7	100802.04	164630.48	25.6	19.6	61.7
Maximum	536.2	149.2	95616.20	156468.19	24.9	19.1	60.2

Damage Centroid Depth (x) (inches)	8.33	k^2	4035.73
Damage Centroid Depth (y) (inches)	41.13	Eff. Mass Ratio (gamma)	0.93
Area of Damage (inches²):	1015.06		

2019 VOLVO S60 AWD - Front Impact

Curb Weight (pounds):	3907
Occupant + Cargo Weight (pounds):	42
Total Weight (pounds):	3949
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.05
Damage Length (inches):	69.9
Crush Profile Measurements:	10

PDOF

Lever Arm Distance (inches):	17.00
Yaw Moment of Inertia (lb-ft-sec²)	2861.47

		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	14.90	120.69	5.40	651.73	9.93	1198.85
C2 (inches)	16.20	6.50	72.48	5.96	431.68	9.26	671.07
C3 (inches)	6.10	6.10	54.90	4.66	255.60	15.58	855.21
C4 (inches)	11.90	1.00	14.00	7.05	98.74	3.53	49.35
C5 (inches)	16.10	14.60	255.50	8.77	2240.39	65.89	16836.09
C6 (inches)	18.90	1.80	31.23	8.70	271.64	9.87	308.34
C7 (inches)	15.80	17.90	276.56	7.73	2136.75	116.28	32158.48
C8 (inches)	15.10	6.70	85.09	6.43	546.75	50.04	4257.82
C9 (inches)	10.30	0.40	2.06	3.43	7.07	3.33	6.87
C10 (inches)	0.00						

Average Crush (inches): 13.05

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	366.1	118.3	66736.22	96553.60	27.1	31.0	28.4
Avg - 2 Std. Deviations	335.7	99.4	57067.37	83802.20	25.2	28.8	26.1
Avg - 1 Std. Deviations	369.9	120.7	68001.04	98216.06	27.3	31.2	28.7
Average	401.6	142.3	78934.70	112541.36	29.2	33.5	31.2
Avg + 1 Std. Deviations	431.1	164.0	89868.37	126795.82	31.0	35.6	33.5
Avg + 2 Std. Deviations	458.9	185.8	100802.04	140991.94	32.7	37.5	35.6
Maximum	446.0	175.5	95616.20	134265.35	31.9	36.6	34.6

Damage Centroid Depth (x) (inches)	7.28	k^2	3359.85
Damage Centroid Depth (y) (inches)	61.74	Eff. Mass Ratio (gamma)	0.92
Area of Damage (inches²):	912.20		

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Total Weight (pounds):	7555
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.68
Damage Length (inches):	74.2
Crush Profile Measurements:	8

PDOF

Lever Arm Distance (inches):	16.80
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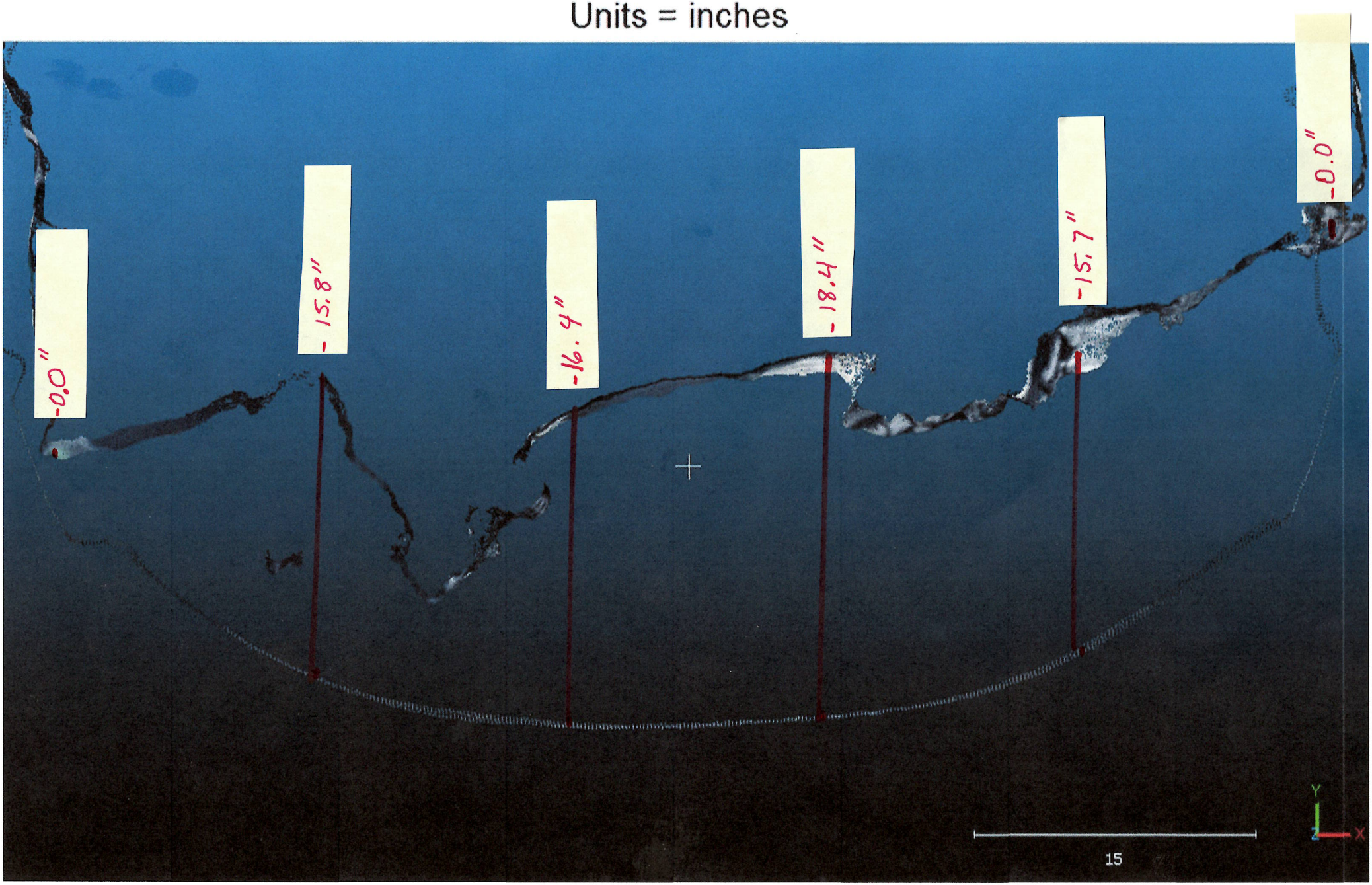


Volvo Crush - Recon-3D on Recon-3D

CRUSH ANALYSIS

$$E = \frac{L}{c_z} \times \left(c_z \times G + A \times \frac{x_1}{2} + B \times \frac{x_2 + x_3}{6} \right) \times \left(1 + TAN^{\,2}\theta\right)$$

Input Cells
Calculations

Crush Measurements	
c_1	0.0 in
c_2	15.8 in
c_3	16.4 in
c_4	18.4 in
c_5	15.7 in
c_6	0.0 in
c_7	
c_8	
c_9	
c_{10}	
c_{11}	
c_{12}	

Crush Zone Measurements			
Zone #	Area	X×area	Y×area
1	107.8 in²	567.5 in³	979.9 in³
2	219.6 in²	1768.0 in³	4502.4 in³
3	237.3 in²	2067.1 in³	8124.2 in³
4	232.6 in²	1986.7 in³	11060.6 in³
5	107.1 in²	560.4 in³	6328.8 in³
6			
7			
8			
9			
10			
11			

Damage Width	68.2 in
PDOF	0.0°
Vehicle Weight	3949 lbs

Centroid Measurements	
Centroid Depth (X)	**7.68 in**
Cetroid Width (Y)	**34.27 in**
Offset from Center	**0.17 in**

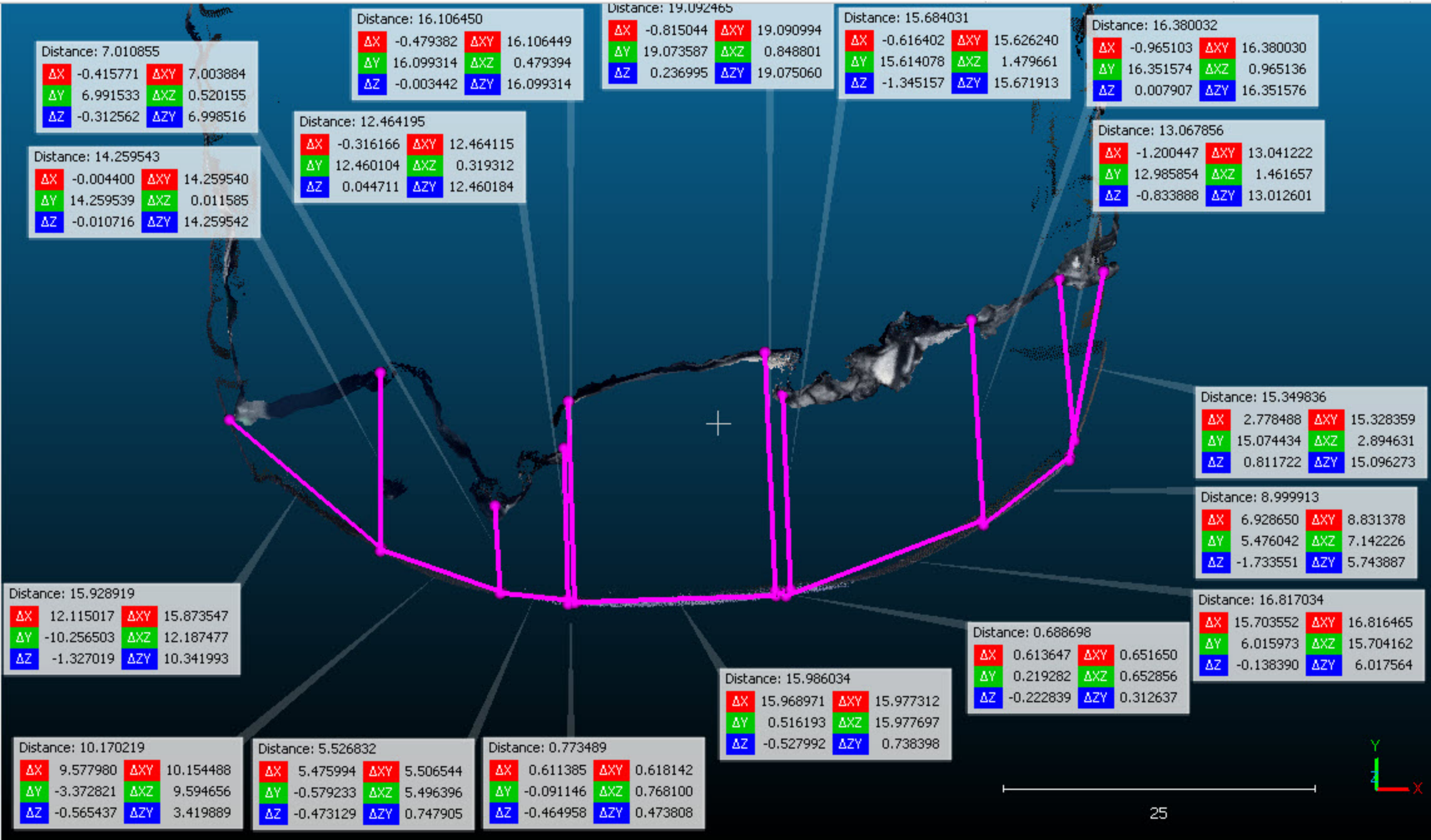
Stiffness Coefficients	
A stiffness	397.2 lb/in
B stiffness	139.7 lb/in²
G stiffness	**564.67 lbs**

Crush (damage) Energy	
inch pounds	**1,368,586.31 in/lb**
foot pounds	**114,048.86 ft/lbs**

Average Crush	**13.26 in**
Average Force	**76,712.11 lbs**
g value	**19.43**

Barrier Equivalent Velocity (BEV)	
Velocity	**43.13 fps**
Speed	**29.4 mph**

Leica(Pre) - R3D(Post)
delta-y = depth / delta-x = length
Units = inches



Volvo Crush - Recon-3D on Leica

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		Unequal Spacing (inches)	Zone Area (inches²)	Zone Depth(x) (inches)	Area Depth(x) (inches³)	Zone Depth(y) (inches)	Area Depth(y) (inches³)
C1 (inches)	8.80						
C2 (inches)	7.90	3.83	31.98	4.18	133.65	1.88	60.14
C3 (inches)	5.70	20.43	138.92	3.43	476.46	30.09	4180.81
C4 (inches)	13.90	13.63	133.57	5.19	692.70	35.03	4678.48
C5 (inches)	26.60	11.29	228.62	10.46	2390.68	40.11	9168.92
C6 (inches)	14.50	10.00	205.50	10.57	2172.52	44.51	9146.67
C7 (inches)	20.20	11.55	200.39	8.75	1754.04	63.84	12793.30
C8 (inches)	23.70	3.48	76.39	11.00	840.11	22.67	1731.38
C9 (inches)							
C10 (inches)							

Average Crush (inches): 13.68

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	410.3	101.5	66736.22	111370.25	21.0	16.2	51.0
Avg - 2 Std. Deviations	371.3	85.3	57067.37	96522.79	19.6	15.1	47.5
Avg - 1 Std. Deviations	418.4	103.4	68001.04	113500.99	21.2	16.4	51.5
Average	465.5	121.5	78934.70	130521.35	22.8	17.5	55.2
Avg + 1 Std. Deviations	512.6	139.6	89868.37	147567.47	24.2	18.6	58.6
Avg + 2 Std. Deviations	559.7	157.7	100802.04	164630.48	25.6	19.7	61.9
Maximum	536.2	149.2	95616.20	156468.19	24.9	19.2	60.3

Damage Centroid Depth (x) (inches)	8.33	k^2	4035.73
Damage Centroid Depth (y) (inches)	41.13	Eff. Mass Ratio (gamma)	0.93
Area of Damage (inches²):	1015.06		

2019 VOLVO S60 AWD - Front Impact

Curb Weight (pounds):	3907
Occupant + Cargo Weight (pounds):	42
Total Weight (pounds):	3949
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.09
Damage Length (inches):	69.8
Crush Profile Measurements:	10

PDOF

Lever Arm Distance (inches):	17.00
Yaw Moment of Inertia (lb-ft-sec²)	2861.47

		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						
C2 (inches)	14.30	12.10	86.52	4.77	412.39	8.07	697.89
C3 (inches)	7.00	9.60	102.24	5.53	565.74	13.85	1416.19
C4 (inches)	12.50	5.50	53.63	5.00	268.35	14.01	751.21
C5 (inches)	16.10	0.60	8.58	7.19	61.67	2.11	18.13
C6 (inches)	19.10	16.00	281.60	8.82	2484.08	72.23	20339.20
C7 (inches)	15.60	0.60	10.41	8.70	90.61	3.29	34.25
C8 (inches)	16.40	15.70	251.20	8.00	2010.02	102.12	25651.39
C9 (inches)	13.00	6.90	101.43	7.38	748.83	51.62	5235.51
C10 (inches)	0.00	2.80	18.20	4.33	78.87	23.33	424.67

Average Crush (inches): 13.09

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	366.1	118.1	66736.22	97318.31	27.2	31.0	28.4
Avg - 2 Std. Deviations	335.7	99.3	57067.37	84450.31	25.3	28.9	26.0
Avg - 1 Std. Deviations	370.0	120.6	68001.04	98996.07	27.4	31.3	28.7
Average	401.6	142.1	78934.70	113453.97	29.4	33.5	31.1
Avg + 1 Std. Deviations	431.2	163.8	89868.37	127841.59	31.2	35.6	33.4
Avg + 2 Std. Deviations	459.0	185.6	100802.04	142171.35	32.9	37.6	35.6
Maximum	446.0	175.2	95616.20	135381.32	32.1	36.7	34.6

Damage Centroid Depth (x) (inches)	7.35	k^2	3359.85
Damage Centroid Depth (y) (inches)	59.72	Eff. Mass Ratio (gamma)	0.92
Area of Damage (inches²):	913.68		

2025 CHEVROLET SILVERADO K1500 DOUBLE CAB 144WB - Front Impact

Curb Weight (pounds):	5104
Occupant + Cargo Weight (pounds):	2451
Total Weight (pounds):	7555
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.68
Damage Length (inches):	74.2
Crush Profile Measurements:	8

PDOF

Lever Arm Distance (inches):	16.80
Yaw Moment of Inertia (lb-ft-sec^2)	6575.65

"Known" Stiffness Values

	A	B
Average	465.5	121.5
Minimum	410.3	101.5
Maximum	536.2	149.2
Std. Devation	47.1	18.1

		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)	8.80	3.83	31.98	4.18	133.65	1.88	60.14
C2 (inches)	7.90	20.43	138.92	3.43	476.46	30.09	4180.81
C3 (inches)	5.70	13.63	133.57	5.19	692.70	35.03	4678.48
C4 (inches)	13.90	11.29	228.62	10.46	2390.68	40.11	9168.92
C5 (inches)	26.60	10.00	205.50	10.57	2172.52	44.51	9146.67
C6 (inches)	14.50	11.55	200.39	8.75	1754.04	63.84	12793.30
C7 (inches)	20.20	3.48	76.39	11.00	840.11	22.67	1731.38
C8 (inches)	23.70						
C9 (inches)							
C10 (inches)							

Average Crush (inches): 13.68

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	410.3	101.5	66736.22	111370.25	21.0	16.2	51.0
Avg - 2 Std. Deviations	371.3	85.3	57067.37	96522.79	19.6	15.1	47.5
Avg - 1 Std. Deviations	418.4	103.4	68001.04	113500.99	21.2	16.4	51.5
Average	465.5	121.5	78934.70	130521.35	22.8	17.5	55.2
Avg + 1 Std. Deviations	512.6	139.6	89868.37	147567.47	24.2	18.6	58.6
Avg + 2 Std. Deviations	559.7	157.7	100802.04	164630.48	25.6	19.7	61.9
Maximum	536.2	149.2	95616.20	156468.19	24.9	19.2	60.3

Damage Centroid Depth (x) (inches)	8.33	k^2	4035.73
Damage Centroid Depth (y) (inches)	41.13	Eff. Mass Ratio (gamma)	0.93
Area of Damage (inches^2):	1015.06		

2019 VOLVO S60 AWD - Front Impact

Curb Weight (pounds):	3907
Occupant + Cargo Weight (pounds):	42
Total Weight (pounds):	3949
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.09
Damage Length (inches):	69.8
Crush Profile Measurements:	10

PDOF

Lever Arm Distance (inches):	17.00
Yaw Moment of Inertia (lb-ft-sec^2)	2861.47

		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)	14.30	12.10	86.52	4.77	412.39	8.07	697.89
C3 (inches)	7.00	9.60	102.24	5.53	565.74	13.85	1416.19
C4 (inches)	12.50	5.50	53.63	5.00	268.35	14.01	751.21
C5 (inches)	16.10	0.60	8.58	7.19	61.67	2.11	18.13
C6 (inches)	19.10	16.00	281.60	8.82	2484.08	72.23	20339.20
C7 (inches)	15.60	0.60	10.41	8.70	90.61	3.29	34.25
C8 (inches)	16.40	15.70	251.20	8.00	2010.02	102.12	25651.39
C9 (inches)	13.00	6.90	101.43	7.38	748.83	51.62	5235.51
C10 (inches)	0.00	2.80	18.20	4.33	78.87	23.33	424.67

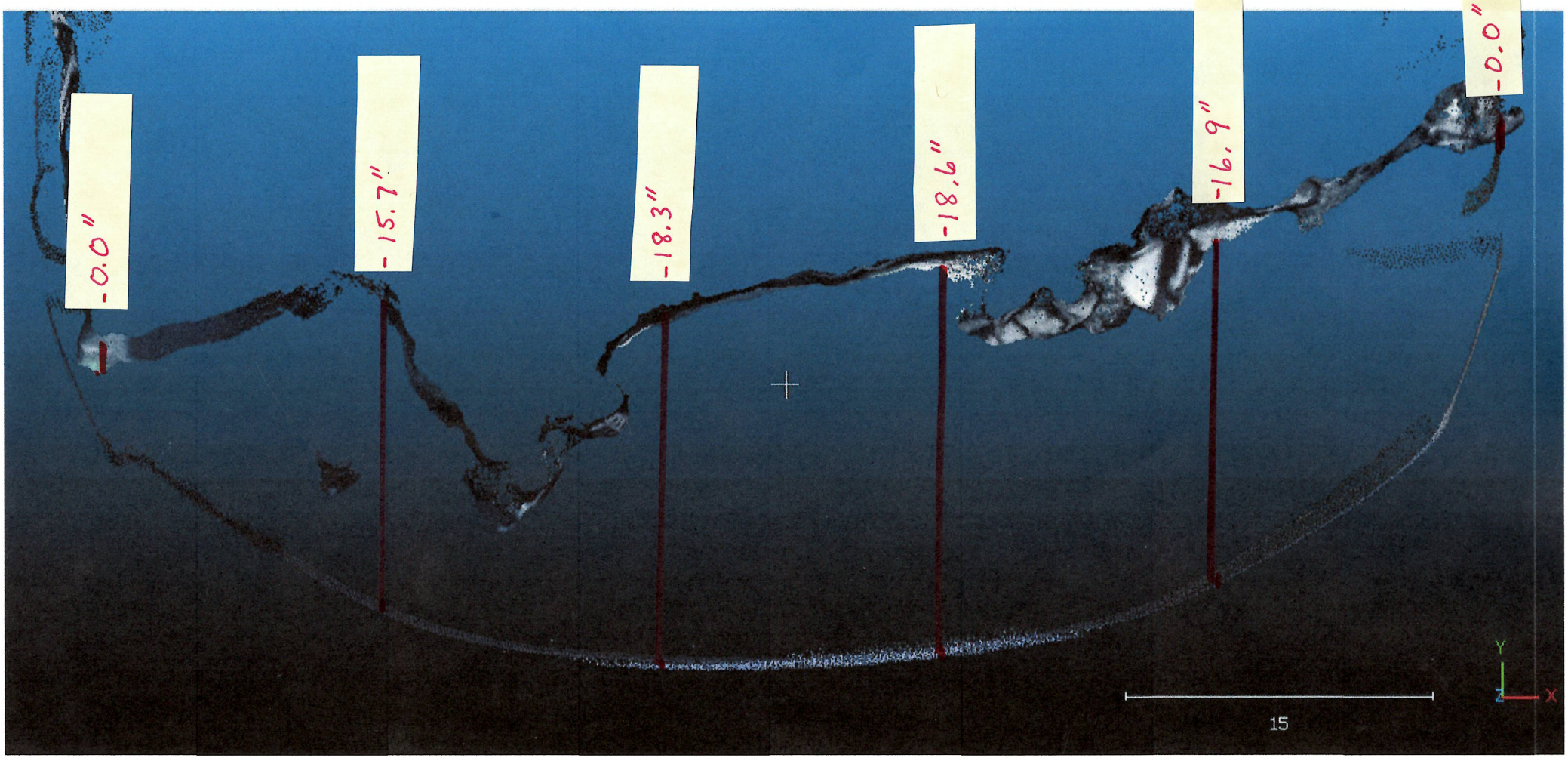
Average Crush (inches): 13.09

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	366.1	118.1	66736.22	97318.31	27.2	31.0	28.4
Avg - 2 Std. Deviations	335.7	99.3	57067.37	84450.31	25.3	28.9	26.0
Avg - 1 Std. Deviations	370.0	120.6	68001.04	98996.07	27.4	31.3	28.7
Average	401.6	142.1	78934.70	113453.97	29.4	33.5	31.1
Avg + 1 Std. Deviations	431.2	163.8	89868.37	127841.59	31.2	35.6	33.4
Avg + 2 Std. Deviations	459.0	185.6	100802.04	142171.35	32.9	37.6	35.6
Maximum	446.0	175.2	95616.20	135381.32	32.1	36.7	34.6

Damage Centroid Depth (x) (inches)	7.35	k^2	3359.85
Damage Centroid Depth (y) (inches)	59.72	Eff. Mass Ratio (gamma)	0.92
Area of Damage (inches^2):	913.68		

Leica(Pre) - R3D(Post)
delta-y = depth / delta-x = length
Units = inches



Volvo Crush - Recon-3D on Leica

CRUSH ANALYSIS

$$E = \frac{L}{c_z} \times \left(c_z \times G + A \times \frac{x_1}{2} + B \times \frac{x_2 + x_3}{6} \right) \times \left(1 + TAN^{\,2}\theta\right)$$

Input Cells
Calculations

Crush Measurements	
c_1	0.0 in
c_2	15.7 in
c_3	18.3 in
c_4	18.6 in
c_5	16.9 in
c_6	0.0 in
c_7	
c_8	
c_9	
c_{10}	
c_{11}	
c_{12}	

Crush Zone Measurements			
Zone #	Area	X×area	Y×area
1	107.1 in²	560.4 in³	973.7 in³
2	231.9 in²	1974.8 in³	4784.6 in³
3	251.7 in²	2321.6 in³	8586.2 in³
4	242.1 in²	2150.4 in³	11532.0 in³
5	115.3 in²	649.3 in³	6812.5 in³
6			
7			
8			
9			
10			
11			

Damage Width	68.2 in
PDOF	0.0°
Vehicle Weight	3949 lbs

Centroid Measurements	
Centroid Depth (X)	**8.08 in**
Cetroid Width (Y)	**34.48 in**
Offset from Center	**0.38 in**

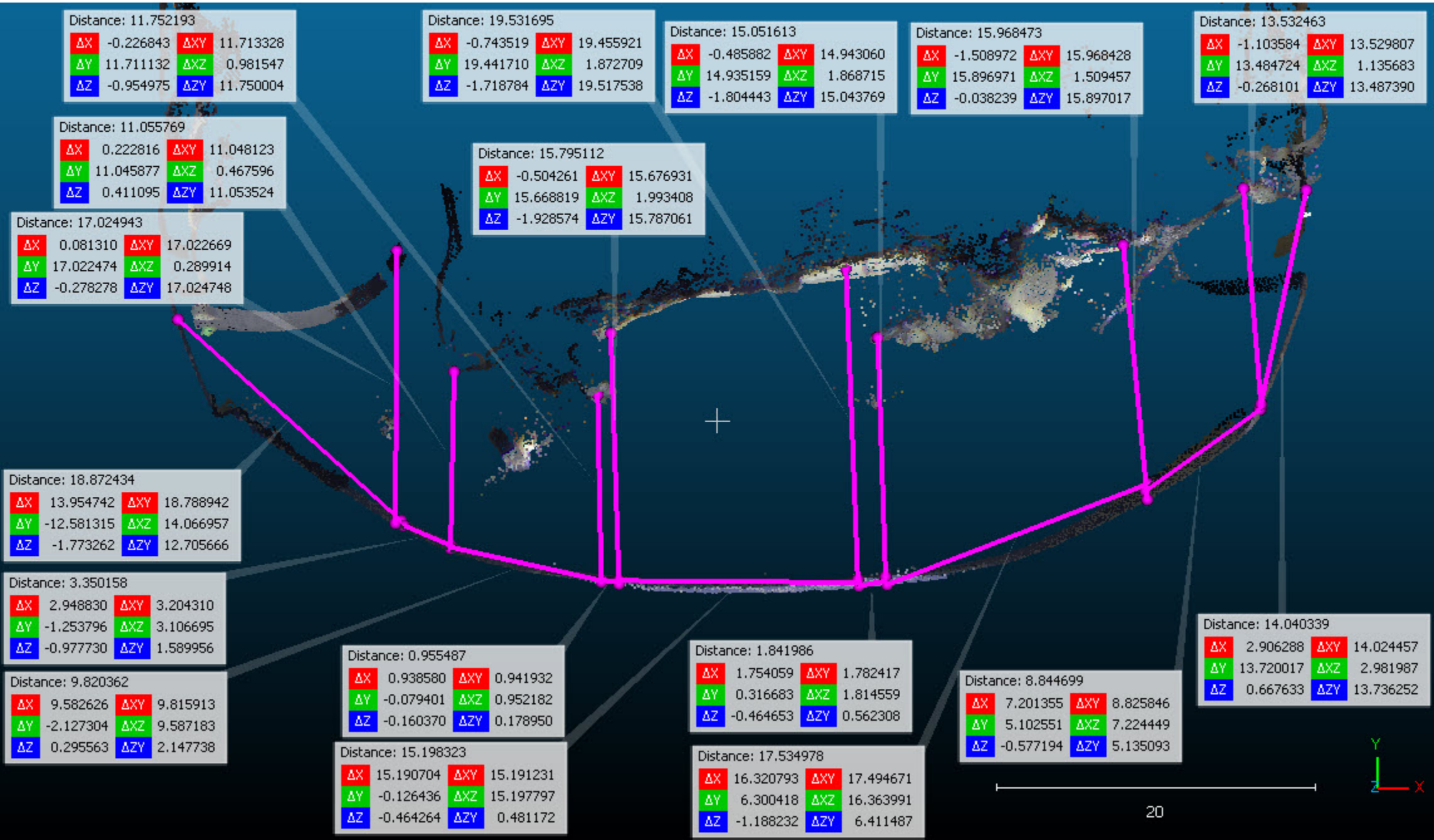
Stiffness Coefficients	
A stiffness	397.2 lb/in
B stiffness	139.7 lb/in²
G stiffness	**564.67 lbs**

Crush (damage) Energy	
inch pounds	**1,484,650.84 in/lb**
foot pounds	**123,720.9 ft/lbs**

Average Crush	**13.9 in**
Average Force	**79,760.92 lbs**
g value	**20.2**

Barrier Equivalent Velocity (BEV)	
Velocity	**44.92 fps**
Speed	**30.63 mph**

Leica(Pre) - Leica(Post)
delta-y = depth / delta-x = length
Units = inches



Volvo Crush - Leica on Leica

2025 CHEVROLET SILVERADO K1500 DOUBLE CAB 144WB - Front Impact

Curb Weight (pounds):	5104
Occupant + Cargo Weight (pounds):	2451
Total Weight (pounds):	7555
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.68
Damage Length (inches):	74.2
Crush Profile Measurements:	8

PDOF

Lever Arm Distance (inches):	16.80
Yaw Moment of Inertia (lb-ft-sec²)	6575.65

"Known" Stiffness Values

	A	B
Average	465.5	121.5
Minimum	410.3	101.5
Maximum	536.2	149.2
Std. Devation	47.1	18.1

		Unequal Spacing (inches)	Zone Area (inches²)	Zone Depth(x) (inches)	Area Depth(x) (inches³)	Zone Depth(y) (inches)	Area Depth(y) (inches³)
C1 (inches)	8.80						
C2 (inches)	7.90	3.83	31.98	4.18	133.65	1.88	60.14
C3 (inches)	5.70	20.43	138.92	3.43	476.46	30.09	4180.81
C4 (inches)	13.90	13.63	133.57	5.19	692.70	35.03	4678.48
C5 (inches)	26.60	11.29	228.62	10.46	2390.68	40.11	9168.92
C6 (inches)	14.50	10.00	205.50	10.57	2172.52	44.51	9146.67
C7 (inches)	20.20	11.55	200.39	8.75	1754.04	63.84	12793.30
C8 (inches)	23.70	3.48	76.39	11.00	840.11	22.67	1731.38
C9 (inches)							
C10 (inches)							

Average Crush (inches): 13.68

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	410.3	101.5	66736.22	111370.25	21.0	16.3	51.3
Avg - 2 Std. Deviations	371.3	85.3	57067.37	96522.79	19.6	15.2	47.8
Avg - 1 Std. Deviations	418.4	103.4	68001.04	113500.99	21.2	16.4	51.8
Average	465.5	121.5	78934.70	130521.35	22.8	17.6	55.5
Avg + 1 Std. Deviations	512.6	139.6	89868.37	147567.47	24.2	18.7	58.9
Avg + 2 Std. Deviations	559.7	157.7	100802.04	164630.48	25.6	19.8	62.2
Maximum	536.2	149.2	95616.20	156468.19	24.9	19.3	60.7

Damage Centroid Depth (x) (inches)	8.33	k^2	4035.73
Damage Centroid Depth (y) (inches)	41.13	Eff. Mass Ratio (gamma)	0.93
Area of Damage (inches²):	1015.06		

2019 VOLVO S60 AWD - Front Impact

Curb Weight (pounds):	3907
Occupant + Cargo Weight (pounds):	42
Total Weight (pounds):	3949
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.66
Damage Length (inches):	70.8
Crush Profile Measurements:	10

PDOF

Lever Arm Distance (inches):	17.00
Yaw Moment of Inertia (lb-ft-sec²)	2861.47

		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						
C2 (inches)	17.00	14.00	119.00	5.67	674.33	9.33	1110.67
C3 (inches)	11.00	2.90	40.60	7.11	288.55	4.25	172.41
C4 (inches)	11.70	9.60	108.96	5.68	618.54	24.05	2620.42
C5 (inches)	15.70	0.90	12.33	6.90	85.06	3.17	39.11
C6 (inches)	19.40	15.20	266.76	8.81	2349.49	68.67	18317.62
C7 (inches)	14.90	1.80	30.87	8.62	266.23	9.86	304.40
C8 (inches)	15.90	16.30	251.02	7.70	1933.53	106.04	26617.71
C9 (inches)	13.50	7.20	105.84	7.37	779.65	53.90	5704.99
C10 (inches)	0.00	2.90	19.58	4.50	88.09	24.17	473.06

Average Crush (inches): 13.66

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	354.1	112.1	66736.22	99687.60	27.5	31.2	27.9
Avg - 2 Std. Deviations	324.7	94.2	57067.37	86536.66	25.6	29.0	25.5
Avg - 1 Std. Deviations	357.8	114.4	68001.04	101401.96	27.8	31.5	28.1
Average	388.4	134.8	78934.70	116172.75	29.7	33.7	30.5
Avg + 1 Std. Deviations	416.9	155.3	89868.37	130867.98	31.5	35.8	32.8
Avg + 2 Std. Deviations	443.7	176.0	100802.04	145500.97	33.2	37.8	34.9
Maximum	431.2	166.2	95616.20	138567.61	32.4	36.9	33.9

Damage Centroid Depth (x) (inches)	7.42	k^2	3359.85
Damage Centroid Depth (y) (inches)	57.97	Eff. Mass Ratio (gamma)	0.92
Area of Damage (inches²):	975.62		

2025 CHEVROLET SILVERADO K1500 DOUBLE CAB 144WB - Front Impact

Curb Weight (pounds):	5104
Occupant + Cargo Weight (pounds):	2451
Total Weight (pounds):	7555
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.68
Damage Length (inches):	74.2
Crush Profile Measurements:	8

PDOF

Lever Arm Distance (inches):	16.80
Yaw Moment of Inertia (lb-ft-sec^2)	6575.65

"Known" Stiffness Values

	A	B
Average	465.5	121.5
Minimum	410.3	101.5
Maximum	536.2	149.2
Std. Devation	47.1	18.1

		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)	8.80	3.83	31.98	4.18	133.65	1.88	60.14
C2 (inches)	7.90	20.43	138.92	3.43	476.46	30.09	4180.81
C3 (inches)	5.70	13.63	133.57	5.19	692.70	35.03	4678.48
C4 (inches)	13.90	11.29	228.62	10.46	2390.68	40.11	9168.92
C5 (inches)	26.60	10.00	205.50	10.57	2172.52	44.51	9146.67
C6 (inches)	14.50	11.55	200.39	8.75	1754.04	63.84	12793.30
C7 (inches)	20.20	3.48	76.39	11.00	840.11	22.67	1731.38
C8 (inches)	23.70						
C9 (inches)							
C10 (inches)							

Average Crush (inches): 13.68

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	Closing Speed (MPH)
Minimum	410.3	101.5	66736.22	111370.25	21.0	16.3	51.3
Avg - 2 Std. Deviations	371.3	85.3	57067.37	96522.79	19.6	15.2	47.8
Avg - 1 Std. Deviations	418.4	103.4	68001.04	113500.99	21.2	16.4	51.8
Average	465.5	121.5	78934.70	130521.35	22.8	17.6	55.5
Avg + 1 Std. Deviations	512.6	139.6	89868.37	147567.47	24.2	18.7	58.9
Avg + 2 Std. Deviations	559.7	157.7	100802.04	164630.48	25.6	19.8	62.2
Maximum	536.2	149.2	95616.20	156468.19	24.9	19.3	60.7

Damage Centroid Depth (x) (inches)	8.33	k^2	4035.73
Damage Centroid Depth (y) (inches)	41.13	Eff. Mass Ratio (gamma)	0.93
Area of Damage (inches^2):	1015.06		

2019 VOLVO S60 AWD - Front Impact

Curb Weight (pounds):	3907
Occupant + Cargo Weight (pounds):	42
Total Weight (pounds):	3949
Angle Coll Force to Normal (degrees):	0.0
No Damage Speed (mph):	5.0
Energy Crush Depth (inches):	13.66
Damage Length (inches):	70.8
Crush Profile Measurements:	10

PDOF

Lever Arm Distance (inches):	17.00
Yaw Moment of Inertia (lb-ft-sec^2)	2861.47

		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	14.00	119.00	5.67	674.33	9.33	1110.67
C2 (inches)	17.00	2.90	40.60	7.11	288.55	4.25	172.41
C3 (inches)	11.00	9.60	108.96	5.68	618.54	24.05	2620.42
C4 (inches)	11.70	0.90	12.33	6.90	85.06	3.17	39.11
C5 (inches)	15.70	15.20	266.76	8.81	2349.49	68.67	18317.62
C6 (inches)	19.40	1.80	30.87	8.62	266.23	9.86	304.40
C7 (inches)	14.90	16.30	251.02	7.70	1933.53	106.04	26617.71
C8 (inches)	15.90	7.20	105.84	7.37	779.65	53.90	5704.99
C9 (inches)	13.50	2.90	19.58	4.50	88.09	24.17	473.06
C10 (inches)	0.00						

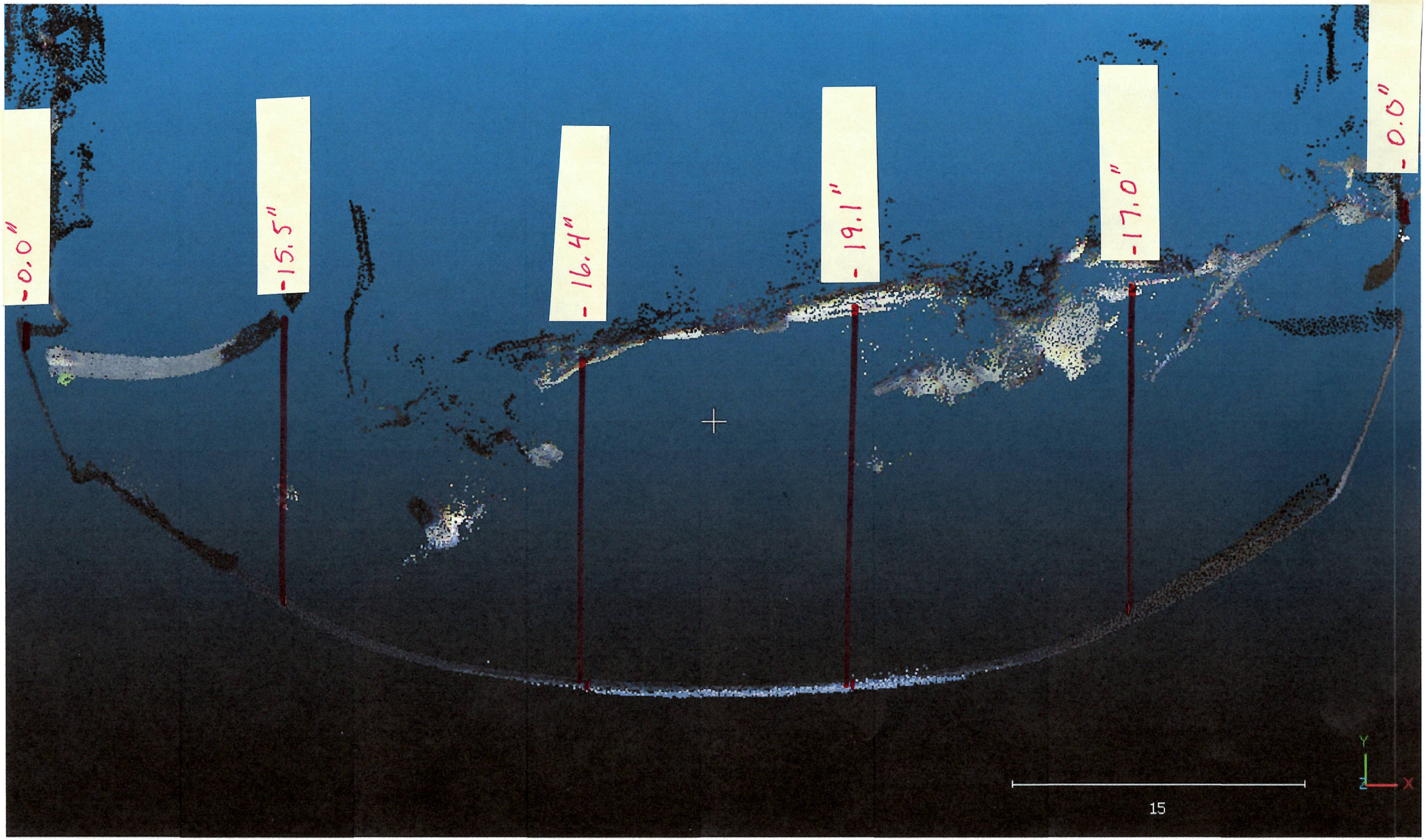
Average Crush (inches): 13.66

Results

	A	B	Average Force (poundsf)	Damage Energy (ft*lbs)	KE Speed (mph)	Delta V (mph)	bsub1
Minimum	354.1	112.1	66736.22	99687.60	27.5	31.2	27.9
Avg - 2 Std. Deviations	324.7	94.2	57067.37	86536.66	25.6	29.0	25.5
Avg - 1 Std. Deviations	357.8	114.4	68001.04	101401.96	27.8	31.5	28.1
Average	388.4	134.8	78934.70	116172.75	29.7	33.7	30.5
Avg + 1 Std. Deviations	416.9	155.3	89868.37	130867.98	31.5	35.8	32.8
Avg + 2 Std. Deviations	443.7	176.0	100802.04	145500.97	33.2	37.8	34.9
Maximum	431.2	166.2	95616.20	138567.61	32.4	36.9	33.9

Damage Centroid Depth (x) (inches)	7.42	k^2	3359.85
Damage Centroid Depth (y) (inches)	57.97	Eff. Mass Ratio (gamma)	0.92
Area of Damage (inches^2):	975.62		

Leica(Pre) - Leica(Post)
delta-y = depth / delta-x = length
Units = inches



Volvo Crush - Leica on Leica

CRUSH ANALYSIS

$$E = \frac{L}{c_z} \times \left(c_z \times G + A \times \frac{x_1}{2} + B \times \frac{x_2 + x_3}{6} \right) \times \left(1 + TAN^{\,2}\theta\right)$$

Input Cells
Calculations

Crush Measurements	
c_1	0.0 in
c_2	15.5 in
c_3	16.4 in
c_4	19.1 in
c_5	17.0 in
c_6	0.0 in
c_7	
c_8	
c_9	
c_{10}	
c_{11}	
c_{12}	

Crush Zone Measurements			
Zone #	Area	X×area	Y×area
1	109.7 in²	567.0 in³	1035.9 in³
2	225.9 in²	1801.6 in³	4812.1 in³
3	251.3 in²	2234.9 in³	8942.5 in³
4	255.6 in²	2309.3 in³	12631.9 in³
5	120.4 in²	682.0 in³	7385.3 in³
6			
7			
8			
9			
10			
11			

Damage Width	70.8 in
PDOF	0.0°
Vehicle Weight	3949 lbs

Centroid Measurements	
Centroid Depth (X)	**7.89 in**
Cetroid Width (Y)	**36.15 in**
Offset from Center	**0.75 in**

Stiffness Coefficients	
A stiffness	397.2 lb/in
B stiffness	139.7 lb/in²
G stiffness	**564.67 lbs**

Crush (damage) Energy	
inch pounds	**1,483,442.53 in/lb**
foot pounds	**123,620.21 ft/lbs**

Average Crush	**13.6 in**
Average Force	**81,318.05 lbs**
g value	**20.59**

Barrier Equivalent Velocity (BEV)	
Velocity	**44.9 fps**
Speed	**30.61 mph**