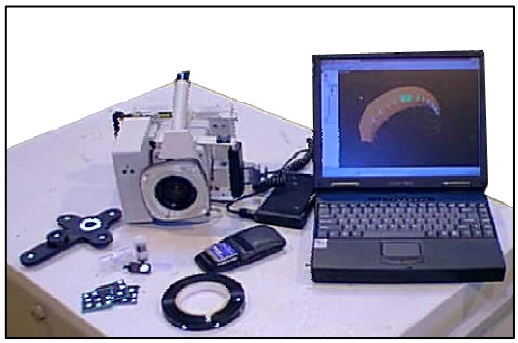
V-STARS Demonstration
FORD Vehicle Body Testing Facility – Dearborn, Michigan.

Introduction:



The following report is a summary of the V-STARS work carried out at the FORD Vehicle Body Testing facility in Dearborn, Michigan. As part of the demonstration two objects were measured.

This report concentrates on the F250 Hood and the U152 door measurements. Both of these components under went a non-destructive deformation test. This report will describe how the V-STARS system was used in different configurations to meet the measurement requirements of the test, while also providing background information of the V-STARS system. A brief summary describing a automotive door verification procedure is also included.

Primary Measurement Requirements:

1. F250 Hood latch loading measurement

- Measure targeted points under various load cases
- Measure targeted points using a single camera (S-Mode) off-line
- Measure targeted points using two cameras (M-Mode) on-line
- Compare measured points from various cases to display to deformation
- Demonstrate procedure
- Report results

2. U152 Door handle pull measurement

- Measure points on door using a new target projector system Pro-Spot
- Repeat measurement after 100 lbs load is applied to the door
- Compared data sets to display movement
- Demonstrate procedure
- Report results

1511 Riverview Drive, Melbourne, Florida, USA 32901
Phone: +1 321 724 6831 Fax: +1 321 724 9253
www.geodetic.com info@geodetic.com

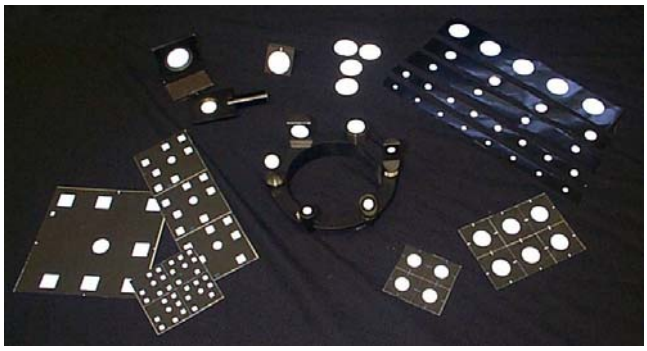
Documentation:
The following documentation is included in this report.

- A report outlining methodology and results.
- Background information on the V-STARS system (Also refer to Appendix 1)

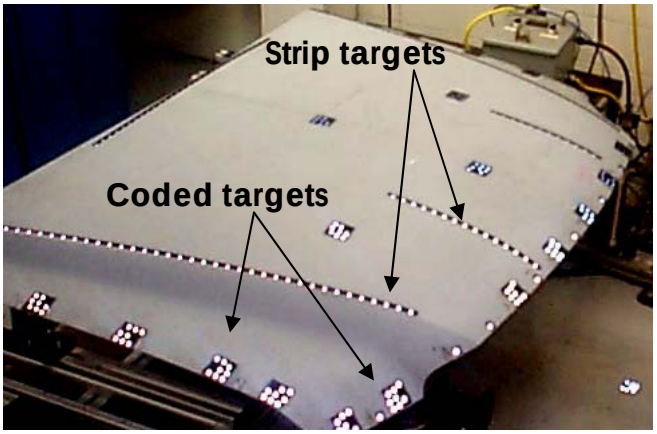
1. F250 Hood latch loading measurement

Measurement Procedure:

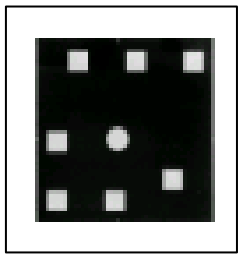
Targeting.



In order to meet the measurement objectives outlined earlier, it was necessary to target the Hood as shown in the image below. In general, targets are placed on points or surfaces that are of interest. For surfaces, strips of retro-reflective tape of variable pitch and dot size are commonly used. They are relatively cheap, disposable and easy to apply. To coordinate tooling datum's such as bushed holes, tooling targets or sphere targets can be used. These come in a variety of shank and dot sizes. They are also available in variable orientations.



To automate the measurement process it was necessary to add "coded" targets to the objects being measured. Each code has a unique number that is assigned to it. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photo was taken. They also help tie the entire object into a uniform coordinate system. The codes were generally placed in areas of high visibility. The codes have a magnetic base, which allows them to be re-used as required.



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Phone: +1 321 724 6831 Fax: +1 321 724 9253
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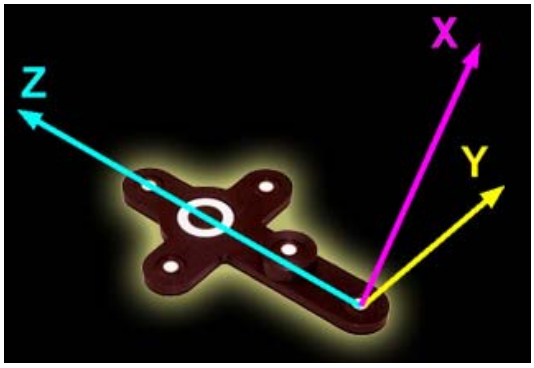
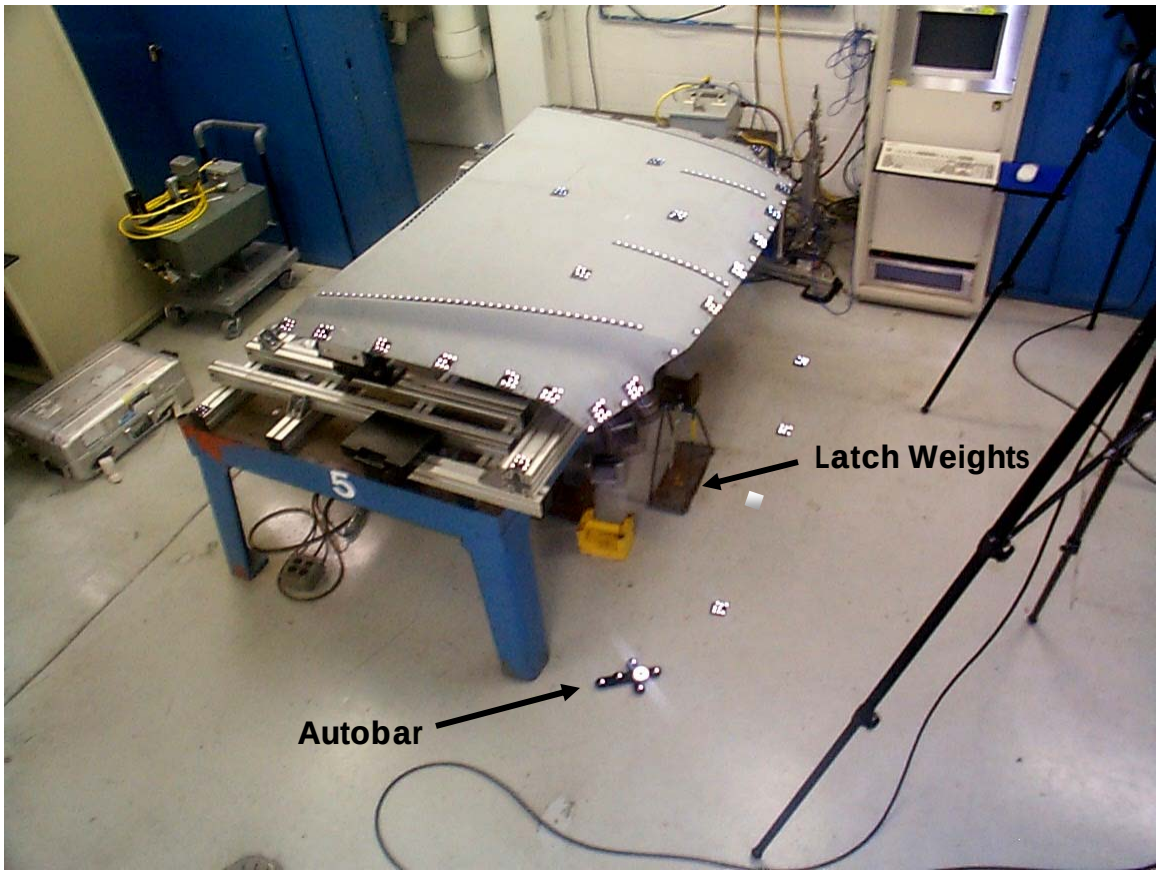


The initial coordinate system and scale is determined via the AutoBar. The AutoBar used by the V-STARS system is a fixture with five targets arranged in the form of a cross. The target's known coordinates are used by the AutoMatch procedure to determine the camera's orientation relative to the AutoBar. The AutoBar is securely attached on or near the measured object, preferably in a highly visible location. The AutoBar's default coordinate system has its origin at Target 1 at the bottom of the AutoBar. The positive Z-axis goes through Target 3 at the top of the bar. The positive X-axis is up out of the AutoBar. The diagram above shows both the AutoBar and its coordinate system.

The image below shows the set up of the Hood in the test fixture.



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Phone: +1 321 724 6831 Fax: +1 321 724 9253
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Photogrammetric measurements are initially dimensionless. An example of this is shown below. The picture of the first car could be a picture of a full-size car or of a matchbox model; there is no way to tell. However, if we know the size of something that is also in the picture, we can now say something about the size of the car.

To scale a photogrammetric measurement, there must be at least one known distance. Two scale distances were used in these measurements. These distances came from a calibrated an invar scale bar. Typically multiple scales are used for redundancy.

Photography

The photography is carried out once the object targeting is completed. Put simply, the aim of the photography is to record each of the targeted points in as many images as possible from as wide a range of angles as possible. To improve the accuracy of the measurement, generally photos are taken both close to the ground and from an elevated position.

The time needed to complete the photography is very short. Typically all the necessary photos can be collected in less than 15 minutes. For example the photography for the F250 Hood was completed in approximately 4 minutes. The U152 Door Study photography was also completed in approximately 5 minutes.

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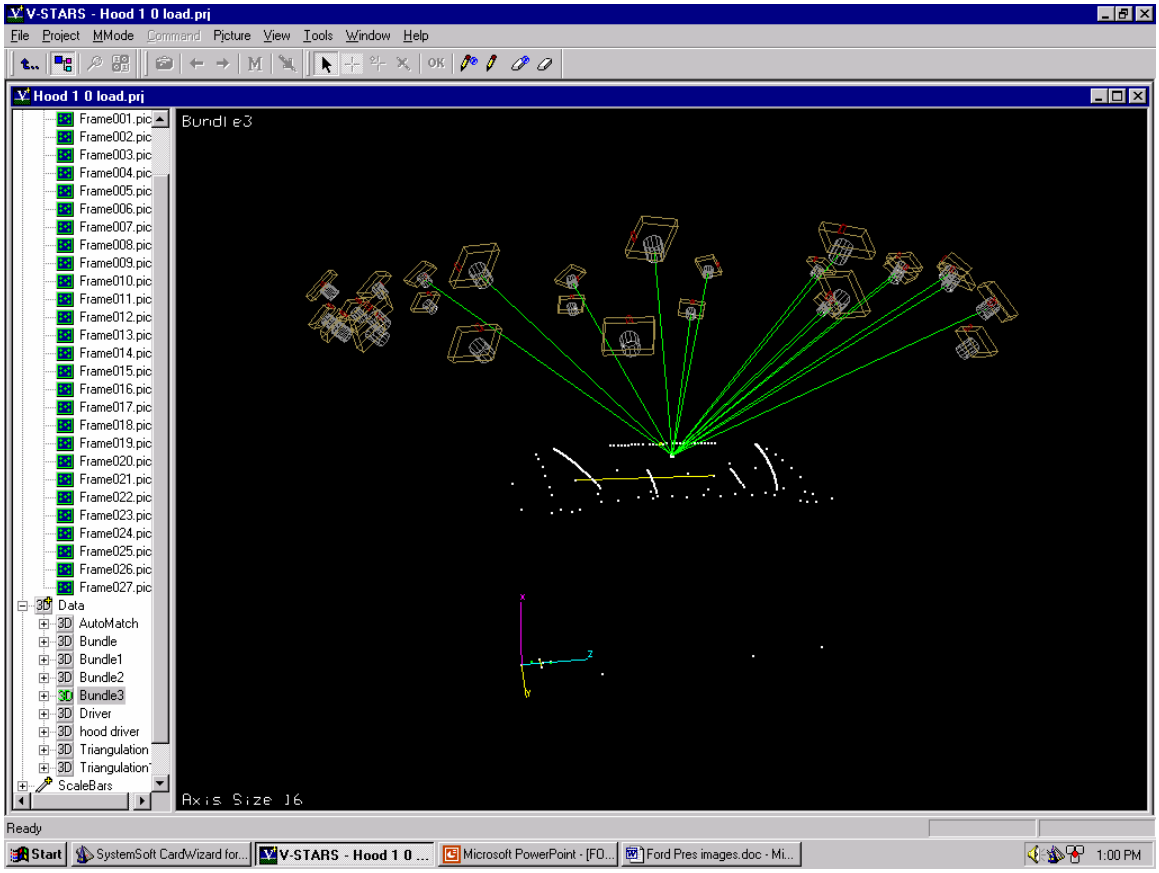
Camera station locations for the F250 Hood measurement are shown in the diagram below. Also shown are sample intersection angles to points of interest.



A total of 30 photographs were taken of the F250 Hood for each load case. The number of photos taken depends on the complexity of the measurement and accuracy requirements. The first load case was static or zero load. This first case was used as a benchmark to which all other cases were compared. The second Case was recorded with100lbs load applied to the latch. Case 3 was a zero load and used to verify that the hood returned to its original configuration: ie, Case 1. In Case 4 the latch was load again this time to 120lbs, and finally Case 5 was zero loading.

Summary of load cases:

Case	Load (lbs)	Images	Photography time
1	0	30	4 min
2	100	30	4 min
3	0	30	4 min
4	120	30	4 min
5	0	30	4 min

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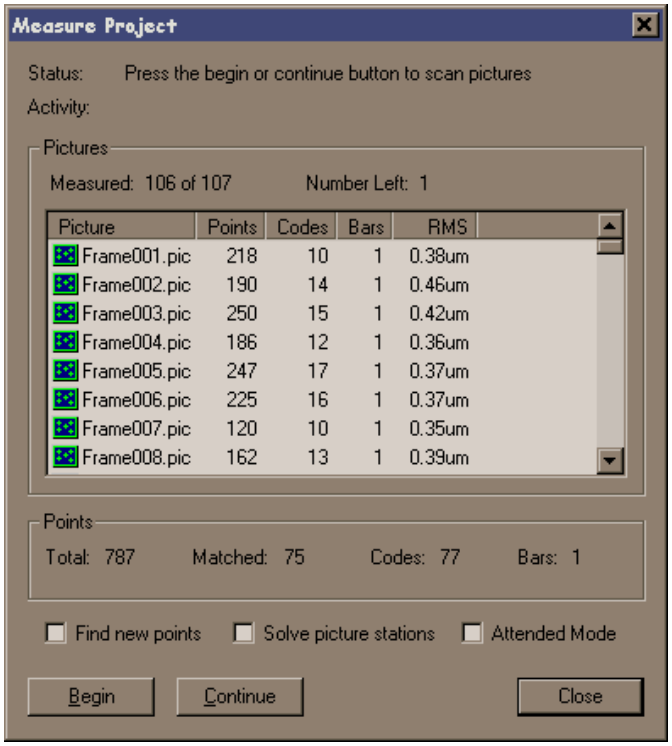
Processing

Once the photography has been completed the images are transferred to the system laptop. The images are stored on a PCMCIA hard drive and V-STARS accesses these images directly from the drive.

Almost all of the measurement process is automated. The images are processed and the coordinates extracted by the "AutoMeasure" command. A typical AutoMeasure dialog box is shown on the right. The AutoMeasure command will open each of the images, determine the camera location, find new target points and finally adjust all the measurements in the "Bundle Adjustment". At the conclusion the user is left with the XYZ coordinates for all the target points in the network. The AutoMeasure procedure is very powerful as it allows the user to continue working while it processes the data. It also means that relatively unskilled workers can be used to process the data.



The AutoMeasure routine will assign random labels to the points it finds. These labels start with the key word "Target" followed by a number. If specific labelling is required the random labels can be easily changed to labels defined by the user. This is possible in both the picture view and the graphical 3D view. For this particular project it was not necessary to relabel the points.

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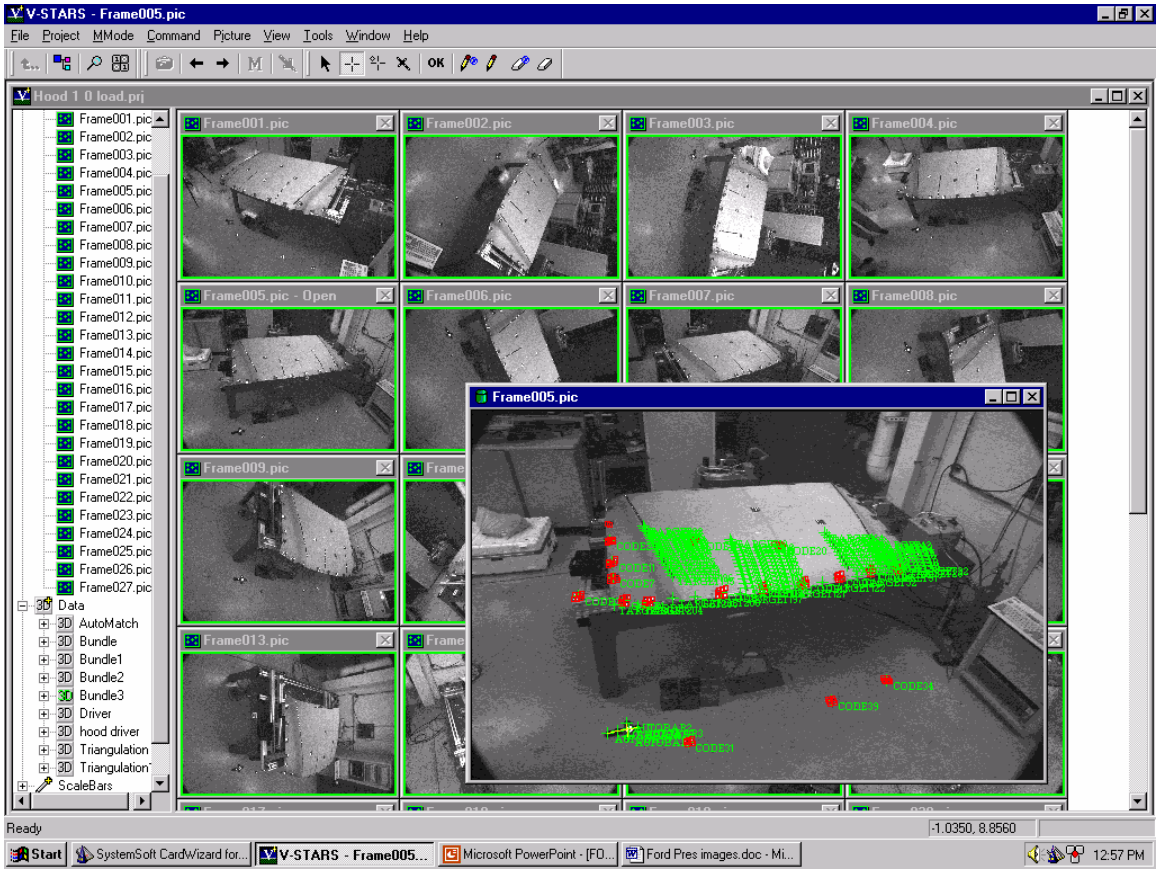
Seen below is an image taken as part of the F250 Hood measurement.



The green crosses represent points that have been located in this particular image. The red squares indicate the location of coded targets. These points were located within the image as part of the AutoMeasure routine.

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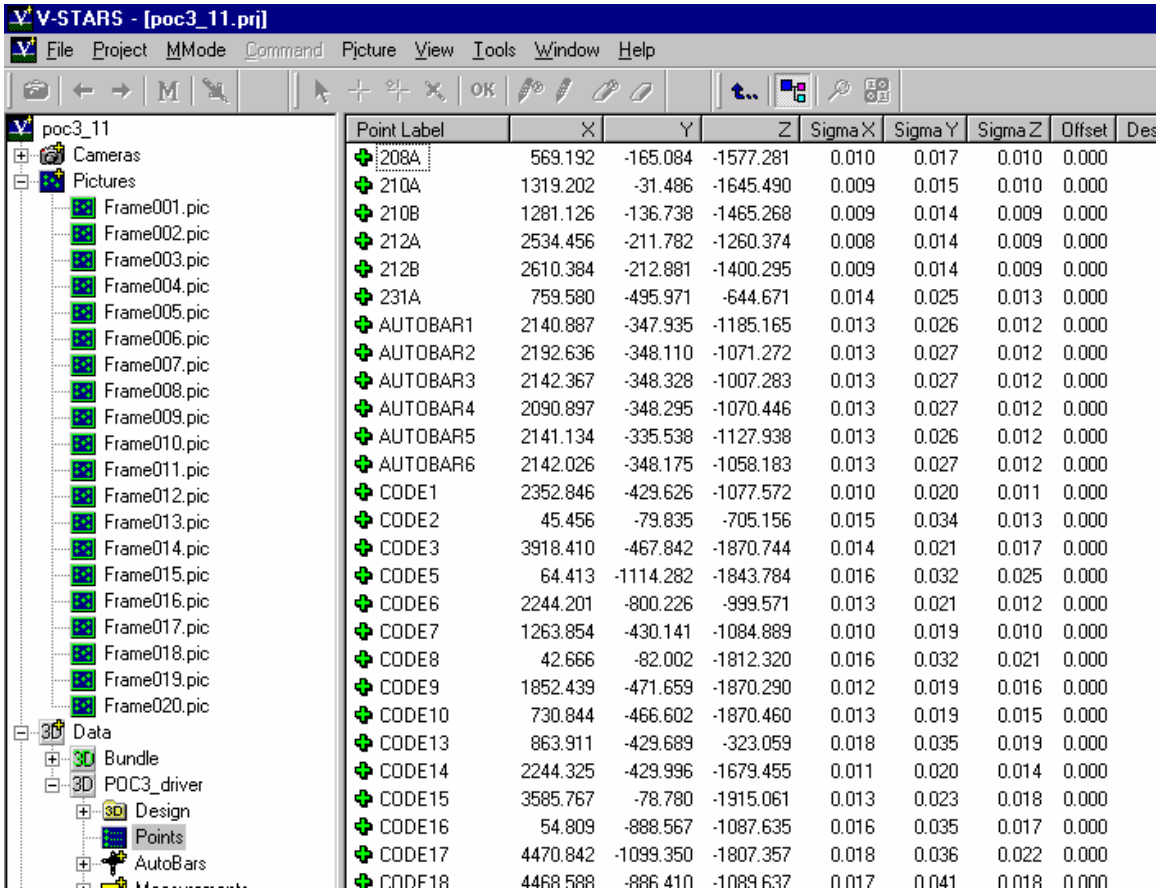
Finally, the points can be listed. A typical point listing is shown below.



Point Label	X	Y	Z	Sigma X	Sigma Y	Sigma Z	Offset	Des
208A	569.192	-165.084	-1577.281	0.010	0.017	0.010	0.000	
210A	1319.202	-31.486	-1645.490	0.009	0.015	0.010	0.000	
210B	1281.126	-136.738	-1465.268	0.009	0.014	0.009	0.000	
212A	2534.456	-211.782	-1260.374	0.008	0.014	0.009	0.000	
212B	2610.384	-212.881	-1400.295	0.009	0.014	0.009	0.000	
231A	759.580	-495.971	-644.671	0.014	0.025	0.013	0.000	
AUTOBAR1	2140.887	-347.935	-1185.165	0.013	0.026	0.012	0.000	
AUTOBAR2	2192.636	-348.110	-1071.272	0.013	0.027	0.012	0.000	
AUTOBAR3	2142.367	-348.328	-1007.283	0.013	0.027	0.012	0.000	
AUTOBAR4	2090.897	-348.295	-1070.446	0.013	0.027	0.012	0.000	
AUTOBAR5	2141.134	-335.538	-1127.938	0.013	0.026	0.012	0.000	
AUTOBAR6	2142.026	-348.175	-1058.183	0.013	0.027	0.012	0.000	
CODE1	2352.846	-429.626	-1077.572	0.010	0.020	0.011	0.000	
CODE2	45.456	-79.835	-705.156	0.015	0.034	0.013	0.000	
CODE3	3918.410	-467.842	-1870.744	0.014	0.021	0.017	0.000	
CODE5	64.413	-1114.282	-1843.784	0.016	0.032	0.025	0.000	
CODE6	2244.201	-800.226	-999.571	0.013	0.021	0.012	0.000	
CODE7	1263.854	-430.141	-1084.889	0.010	0.019	0.010	0.000	
CODE8	42.666	-82.002	-1812.320	0.016	0.032	0.021	0.000	
CODE9	1852.439	-471.659	-1870.290	0.012	0.019	0.016	0.000	
CODE10	730.844	-466.602	-1870.460	0.013	0.019	0.015	0.000	
CODE13	863.911	-429.689	-323.059	0.018	0.035	0.019	0.000	
CODE14	2244.325	-429.996	-1679.455	0.011	0.020	0.014	0.000	
CODE15	3585.767	-78.780	-1915.061	0.013	0.023	0.018	0.000	
CODE16	54.809	-888.567	-1087.635	0.016	0.035	0.017	0.000	
CODE17	4470.842	-1099.350	-1807.357	0.018	0.036	0.022	0.000	
CODE18	4468.588	-886.410	-1089.637	0.017	0.041	0.018	0.000	

Analysis

This point data can be analysed within the V-STARS' Solids module, and or easily exported to almost any CAD platform or other analysis program. The Solids module features a number of very useful options. The user has the ability to compute best-fit planes, lines, circles, spheres as well as measure to these objects. For this Project the Solids module was employed to compute point-to-point, and point to surface deviations.

1511 Riverview Drive, Melbourne, Florida, USA 32901
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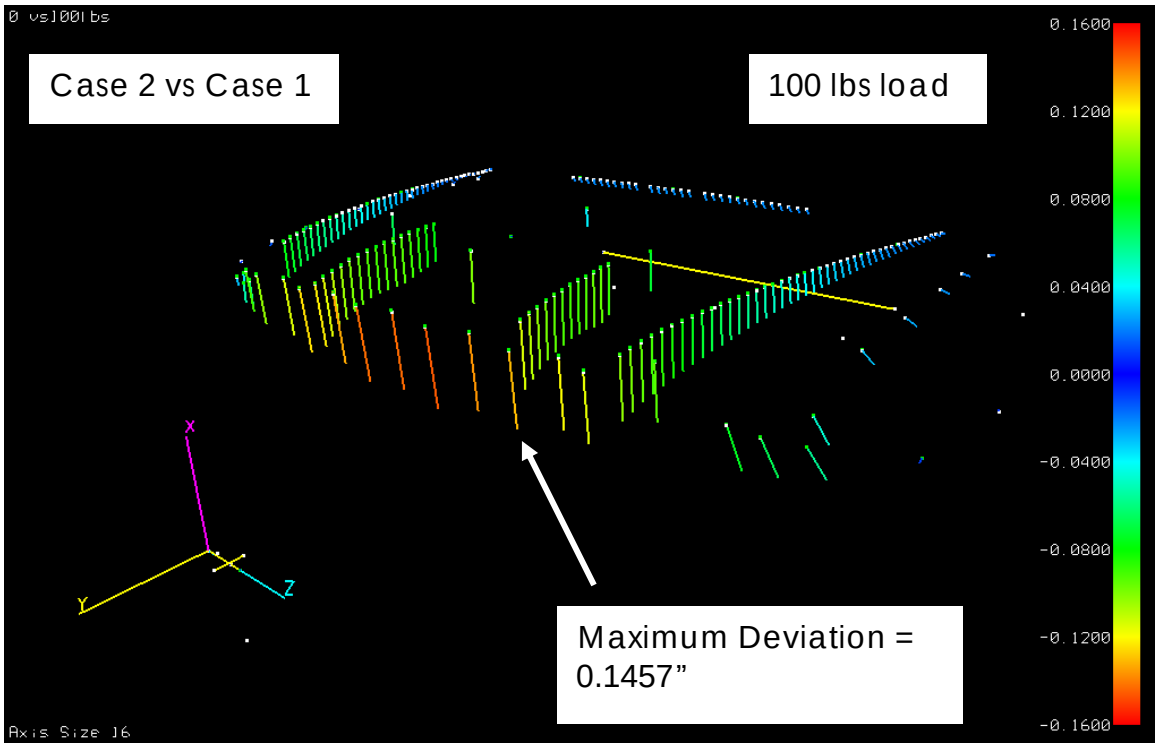
Each of the following Images graphically displays the point-to-point deviations from Case 1.



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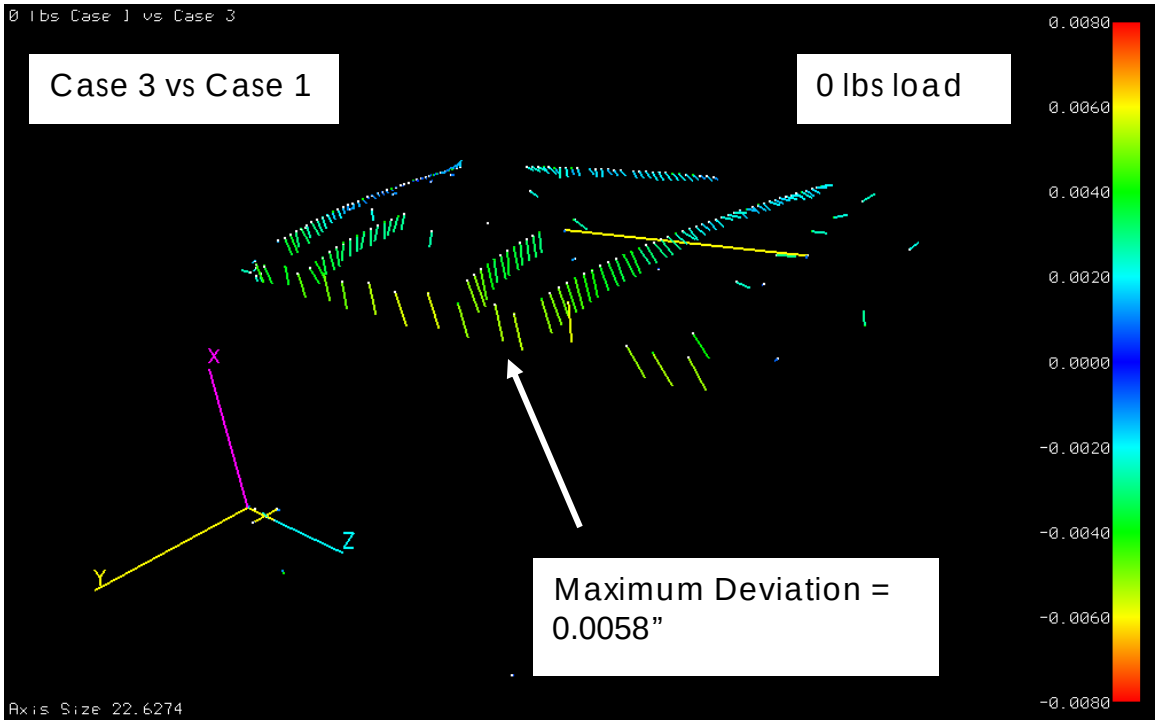

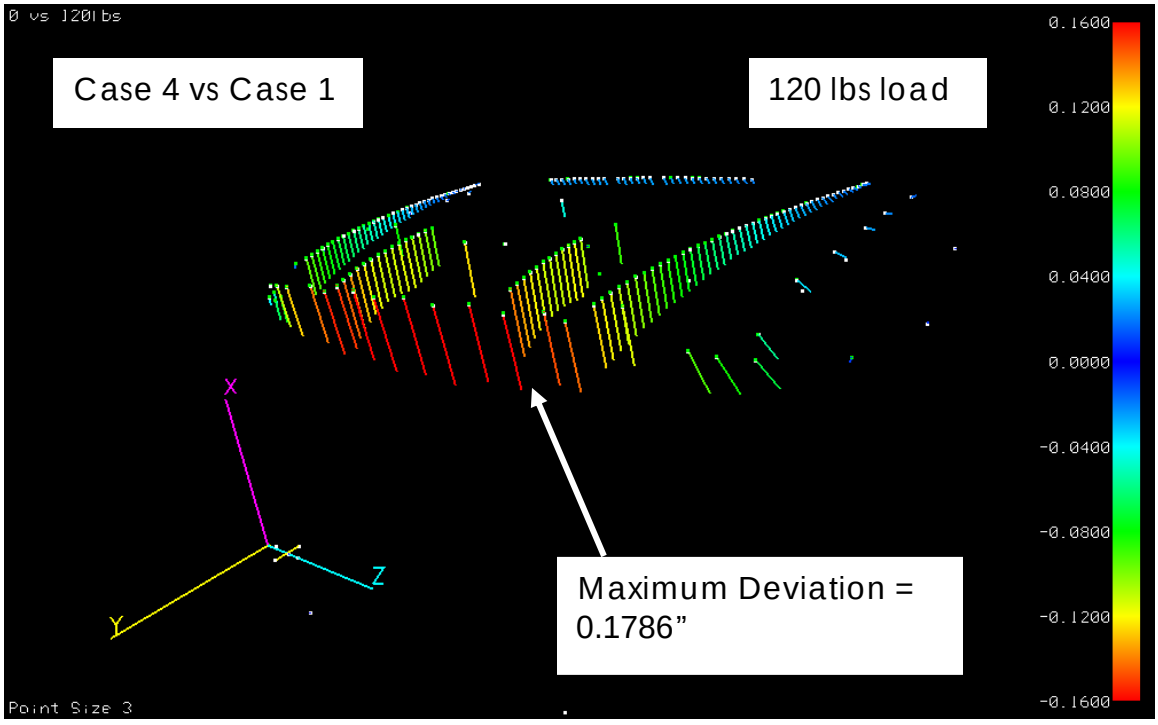

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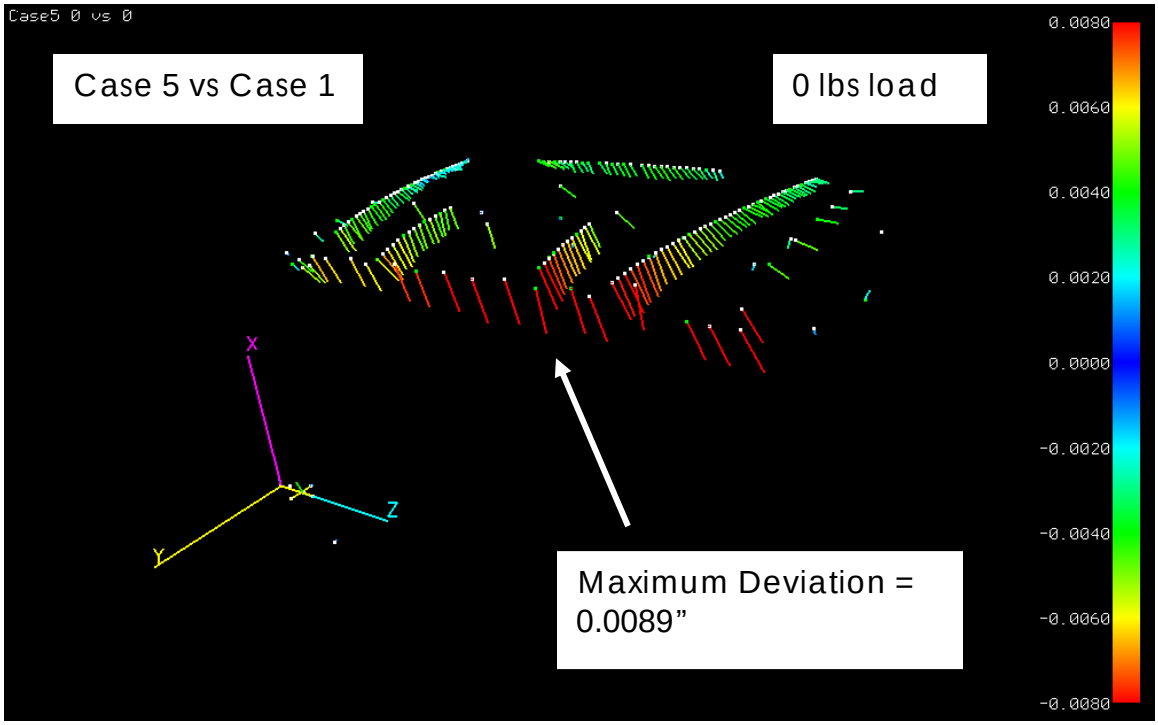


Results Summary.

As seen in the vector plots output from V-Stars SOLIDS above, visualization of the Hood deformation can be a powerful tool. In addition to V-Stars' on-board data analysis, the data can easily exported in variety of output formats to other CAD an Analysis packages.

In Case 2 the measured data was compared to Case 1 (0 vs 100lbs load)
The results show the area of deformation occurring mostly in the forward section of the Hood with the maximum deviation close to the latch (load point) being 0.1457”

In Case 3 the load was removed from the latch and the Hood re-measured. When compared to Case 1 (0 vs 0lbs) it can be shown that the Hood did not return to its previously unloaded state. The Residual deformation in this case is mostly in the range of 0.002” to 0.004” with a maximum of 0.0058”

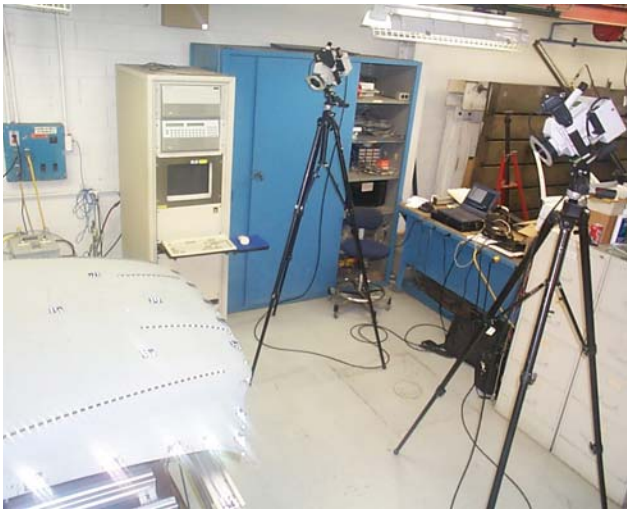
In Case 4 vs Case 1, the load was returned to the hood, this time the load increased to 120lbs. The results show similarities to that of Case 2 vs Case 1, although greater amplitude, with a maximum deviation of 0.1786”

In Case 5 with the load removed the measured points were compared to Case1. Once again the Hood did not return to its original unloaded state. The residual deformation in this case is mostly in the range of 0.003” to 0.006” with a maximum of 0.0089”

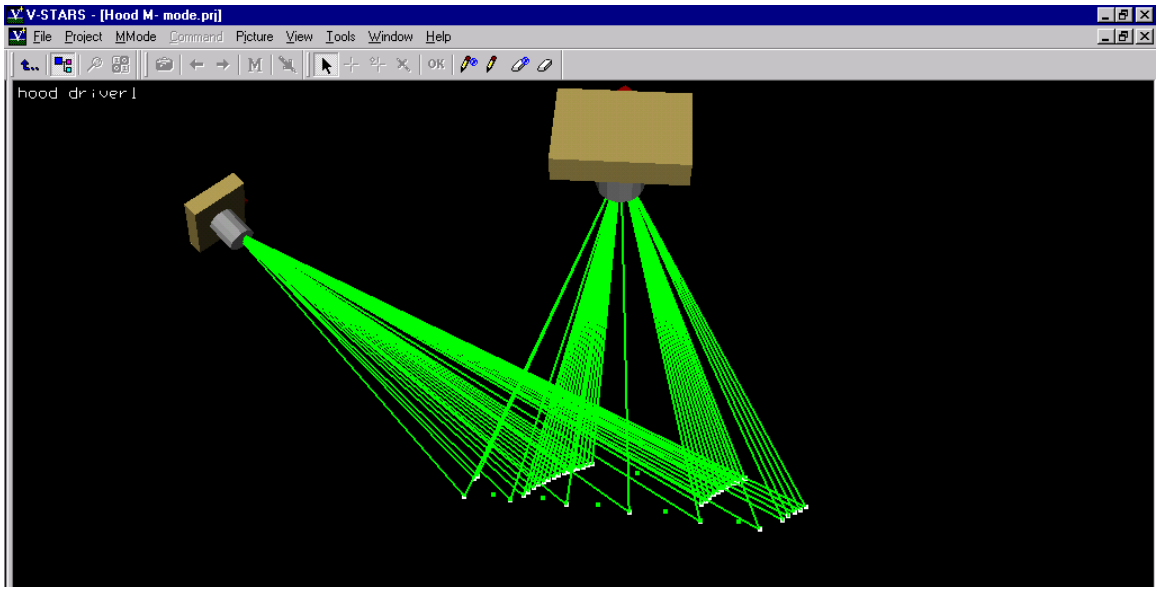
1511 Riverview Drive, Melbourne, Florida, USA 32901
Phone: +1 321 724 6831 Fax: +1 321 724 9253
www.geodetic.com info@geodetic.com

M Mode- Point Probing / Point Triangulation

In addition to the single camera operation the V-Stars System can be configured in M – Mode, which stands for Multi camera mode. (Show right) In this mode two or more cameras are used simultaneously to determine the location of a wireless hand held probe. The use of these probes is typically called for when features that are cannot be readily targeted are required. These features might include edge points, holes or scribe lines.



As well as Probe location measurement, M-Mode can also be used to locate other target points, so long as two or more cameras can see them. In order to work in M-Mode a coordinated reference frame is required. This reference frame is used to determine the location of the cameras after each flash. Fortunately no additional work is required to establish this reference as it was established during the initial single camera network. Once images are acquired in M-Mode the cameras are capable of determining their orientation relative to the object. As a demonstration of this particular measurement the target points on the front half of the hood were measured using the M-Mode method. This information is presented graphically so that the user can decide whether the positioning is suitable for the area of interest. Sample graphical information is shown below.



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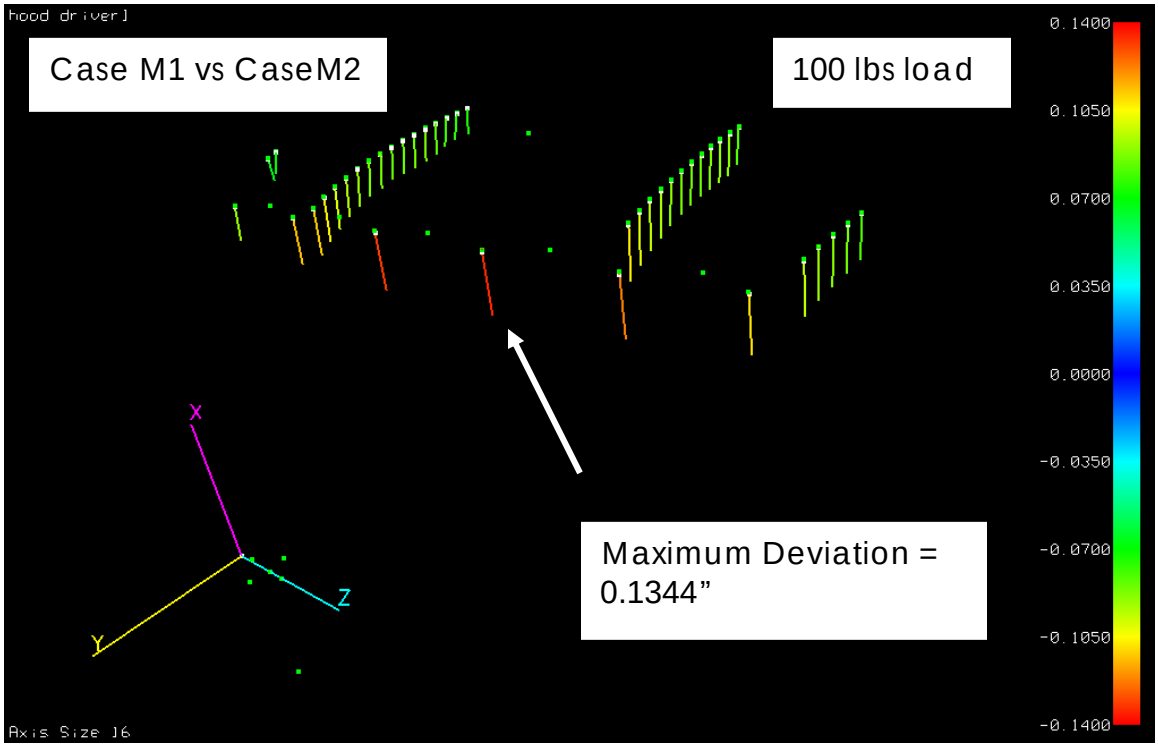
Below is shown the results from the M-Mode Measurement. For this comparison Case M1 (unloaded) is seen with Case M2 (100lbs load) the Primary difference with this method is that all the measured points are captured simultaneously and results are obtained in near real-time. In M-mode this data capture can be repeated every 1 to 2 seconds.



Point Probing

Measuring with the hand held probes is as simple as pointing the cameras roughly at the area of interest, placing the probe on the point of interest and pressing the hand held trigger. Each camera images the probe, determines the type of probe being used and sends this information to the system laptop. V-STARS then takes this data and computes the XYZ location of the probe tip. A variety of probe tips are available. The most common tips are the scribe and 3mm or 6mm ruby ball tips.

Once all the points of interest are measured the cameras are simply moved to the next position. Camera re-orientation is carried out automatically. The cameras orientate themselves during each point measurement which means that the cameras or the object can be vibrating without any ill effect to the resulting point data.

1511 Riverview Drive, Melbourne, Florida, USA 32901
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www.geodetic.com info@geodetic.com

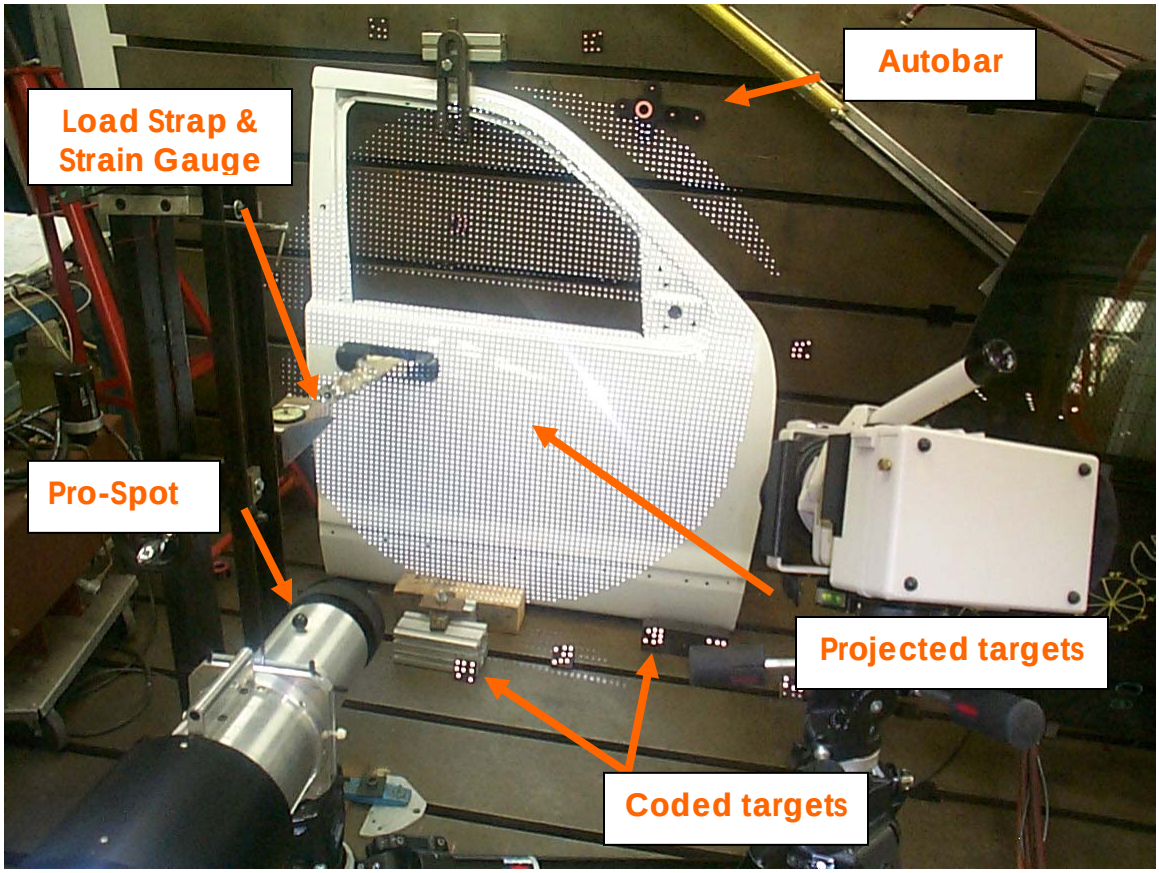
The V-Stars System operating in M-Mode with the Hand Held Probe can be seen below. Data points collected using the Hand Held Probe are not reported as they were collected to demonstrated to methodology only.

2. U152 Cab Door handle pull measurement

The U152 Cab Door was measured using a new target projection system Pro-Spot. (Seen left) The objective of the measurement was to determine the location of multiple points on the surface of the U152 Door, before and after a 100lbs load was applied to the door handle.
The following summarizes the results of the measurements while also providing information on how V-STARS was used to meet the measurement requirements. In this case the primary measurement requirement was to characterize the surface.

Targeting.

For this measurement very little targeting was needed. Only the Autobar and some coded targets were place in the scene. The surface targets required were generated via the use of the target projector Pro-Spot.



The system was setup and used as shown. The Door was clamped to a fixture and a strap connected to the handle of the door. This strap was also connected to a strain gauge that was used to verify the applied load. The projector is placed so that its dots cover the area of interest on the object. Then, the single-camera is used to take pictures from two or more different locations around the object. Each time a picture is taken, the stroboscopic projector also projects the pattern of high-contrast dots onto the surface.

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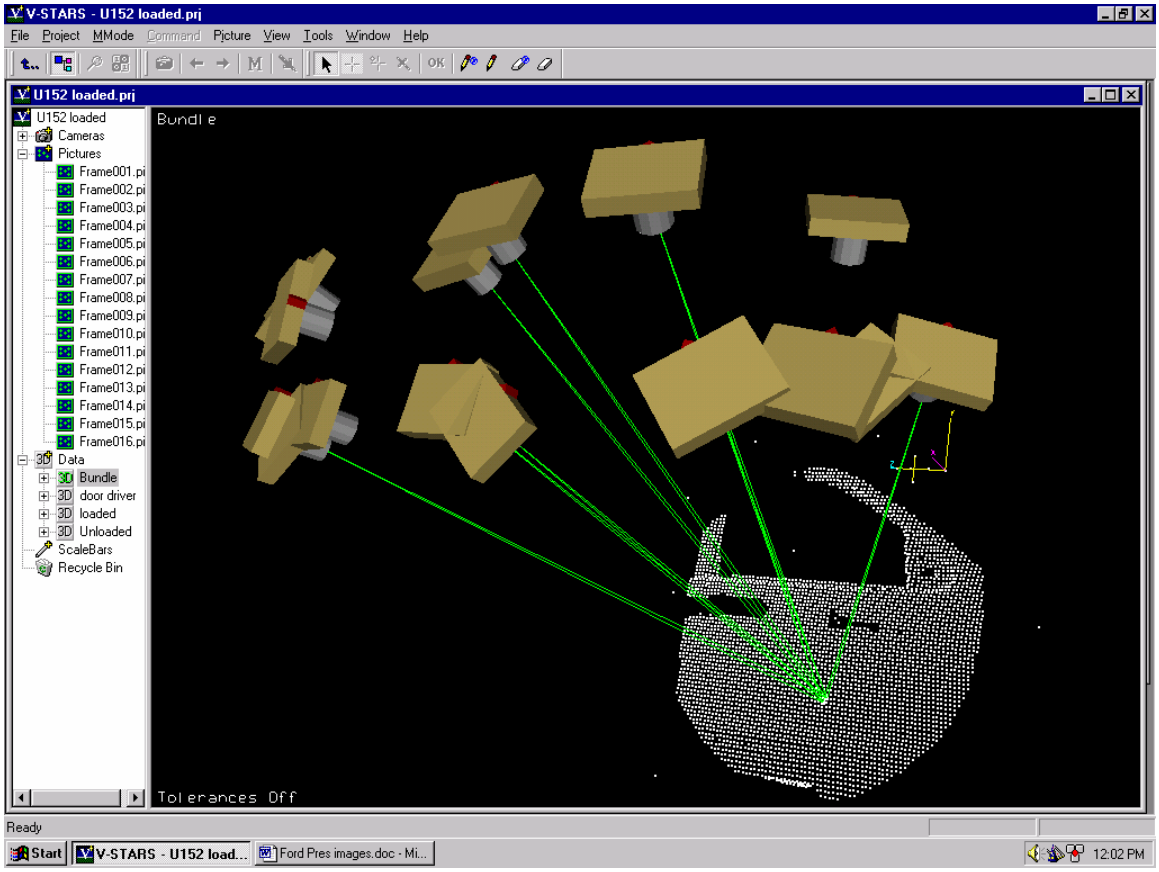
Photography

Once the target projector had been setup (2 minutes) the door was then photographed from 16 locations (2-3 minutes). A load of 100lbs was then applied to the handle and the photography repeated. An example of the Photogrammetric network and target sighting angles to a single point can be seen below.



Processing

Once the photography had been completed the images were then transferred to the system laptop. As with the previous survey the images were then processed automatically using V-Stars' AutoMeasure command. This processing was completed in around 7 minutes for both sets of images.

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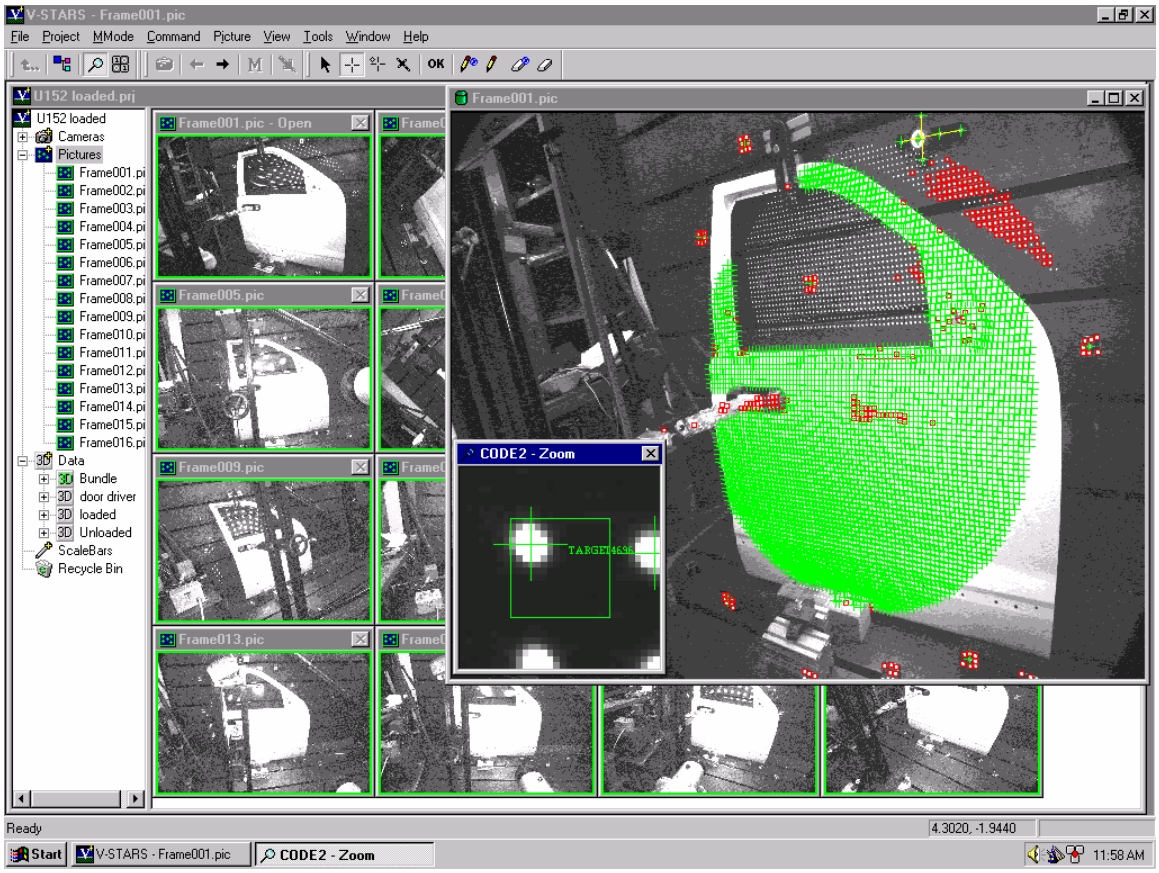
Seen below is an image taken as part of the U152 Door measurement.



The green crosses represent points that have been located in this particular image. Note that the image appears a little dark and difficult to see. This is intentional as the best photogrammetric measurements are made on images that have dark backgrounds and bright targets. Some of these targets are shown in the zoom window in the corner. The Autobar can also been seen in the upper right hand side of the image.

The following is a summary of the measurement statistics from the measurement of the assembly jig.

No of photos	16		
No of points	3900		
No of scales	2		
RMS(inches) X,Y,Z		X	0.0005”
		Y	0.0002”
		Z	0.0002”

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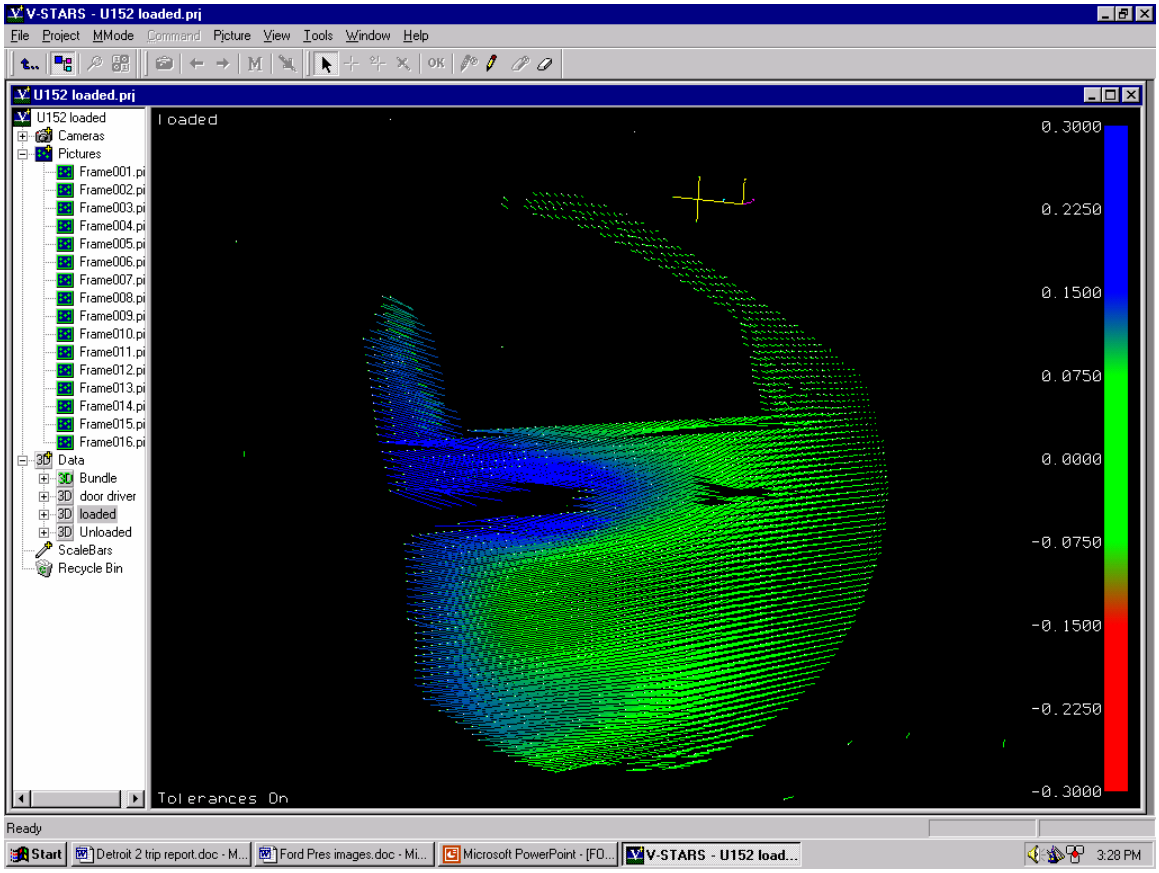
Final the two sets of data were combined and the V-Stars Solids used to compute and display the differences as seen below. Various grades of tolerance band and color can be applied to the data.



The green area indicates deformation ranging from 0.000" to 0.100". The blue areas indicate deformation above 0.100" with a maximum error recorded at 0.214". Once again this data can be easily output to other CAD or Analysis packages.

Time Summary

The following process times were necessary to complete the project.

1) Setup	5 minutes
2) Target placement	0 minutes
3) Photography	5 minutes
4) Processing	7 minutes
Total	**17 minutes**

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www.geodetic.com info@geodetic.com

Additional Measurements:

Jag Door

In addition to the F250 Hood and U152 Door deformation measurements, a Jag door was also measured. This door measurement was performed as an additional demonstration of the V-Stars system and its' capabilities. The primary task was to characterize the shape of the door skin and compare the measured points to a design model for part verification.

As in the previous Hood measurement, a single camera was used to setup up a reference frame or series of control points. The V-Stars system was then configured in Multi Camera Mode or M-Mode. Here two cameras were used simultaneously to locate the position of a hand held probe place on points of interest. In this case the points of interest were datum holes in the inner panel with a known XYZ. These points were used to perform an axis alignment of the measured data so it could be compared to the design model in the vehicle coordinate system. Finally the Pro-Spot projector was used to acquire the surface data. A total of 4976 points were collected on the surface.

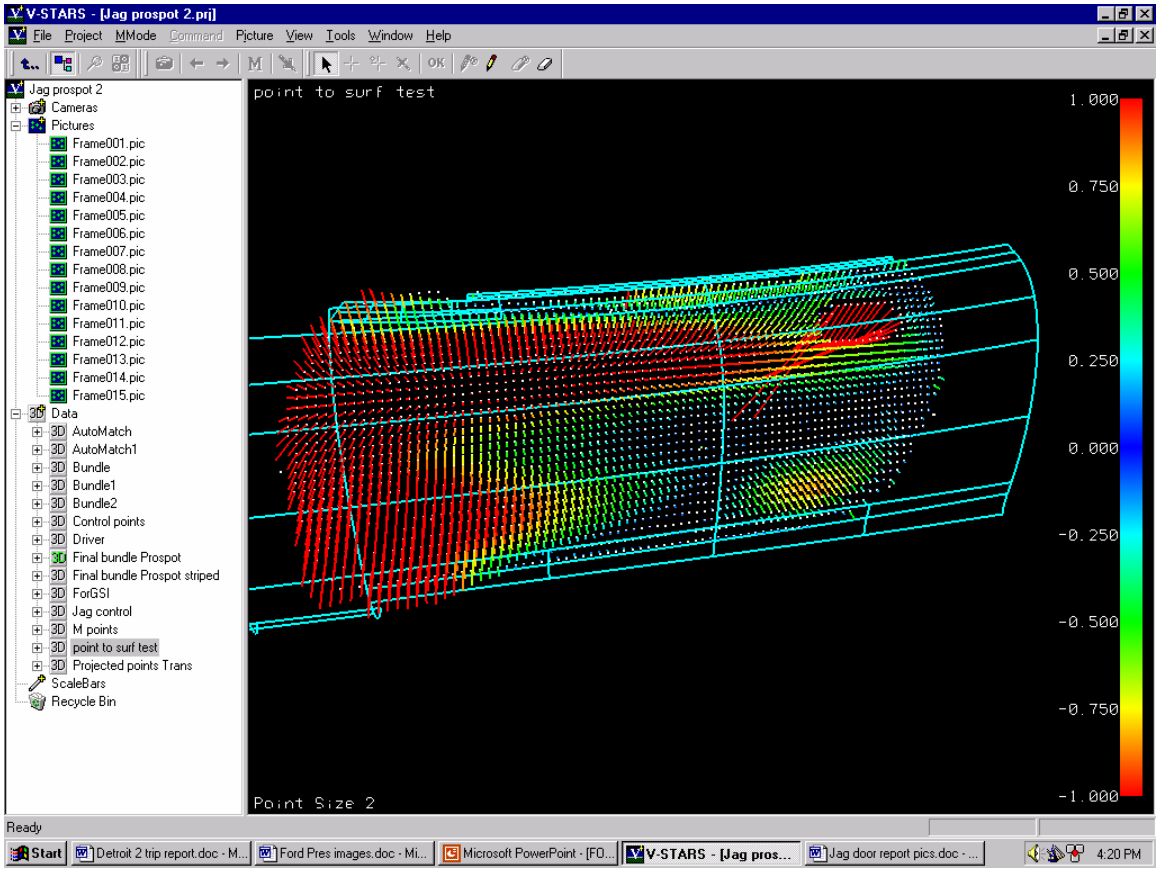
Images of the setup can be seen below.

Probing Datum points in M-Mode

Surface data acquisition using Pro-Spot

1511 Riverview Drive, Melbourne, Florida, USA 32901
Phone: +1 321 724 6831 Fax: +1 321 724 9253
www.geodetic.com info@geodetic.com

A design surface file or model was imported directly into V-Stars, the measured data was then aligned to the model using the datum points. Finally the points were compared to the model. In this example shown below the project data was output in millimeters.



Areas shaded Blue are in the range of 0 to 0.25mm
Areas shaded Green are in the range of 0.25mm to 0.75mm
Areas shaded Yellow/Orange are in the range of 0.75mm to 1.00mm
Areas shaded Red are 1.00mm or greater
The maximum deviation from the design surface was 1.38mm

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Discussion

The PRO-SPOT projector system has demonstrated how large volumes of high accuracy surface data can be collected very quickly. Once again the results of the measurement are very accurate and more importantly were produced quickly.

Advantages of this technology over other measurement technologies include: -

1. *Non-contact*

Once again the measurement technique is completely non-contact. There is no surface deviation due to measurement contact with the surface.

2. *Variable data collection rates*

The number of points collected on the surface can vary from as few as 600 to as many as 6,000. The time needed to collect the point data is the same regardless of the different point densities.

3. *Fast Data Acquisition*

The information necessary to create the point data is collected in a matter of minutes. This makes the system ideal for a production environment where time constraints are critical.

4. *Flexibility*

The PRO-SPOT system is flexible enough to handle a wide variety of surface measurement tasks. For a large component, the projector can be moved to a new set up and the data incorporated together. Alternatively a second projector could be added.

5. *Portability*

The system can easily be packed up and carried to a supplier or customer for on site measurement tasks.

Concluding Remarks:

The Door and Hood measurements undertaken in this demonstration have shown that V-STARS and the target projector can be a very powerful inspection tool. The results of the measurement are very accurate and more importantly were produced quickly. With correct planning and targeting this data acquisition time could even be reduced further. There is also great scope to use this technology for other applications such as jig verification and complete mass inspections.

GSI and Leica would like to thank Ford for welcoming us to their Dearborn facility. We will be happy to discuss the results of this report or any other aspect of the technology presented.

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