# V-STARS Measurement Report

## Introduction:


The following report is a summary of the V-STARS work carried out at an Aerospace facility in Winnipeg Canada. Four measurements were undertaken using the V-STARS camera system and the PRO-SPOT target projection system.

The measurements undertaken are summarized in TABLE 1

| Object | Description | Requirements | Equipment |
|---|---|---|---|
| Boeing Wing to body fairing Jig | Approximately 20' long and 5' high.<br> | 1. Verify the location of Water Line, Butt Line and Station Pads.<br>2. Determine location of End Stops<br>3. Determine Best-fit Waterline plane.<br>4. Determine best-fit Butt Line. | V-STARS/S<br>V-STARS/M |

TABLE 1 – Measurement Summary

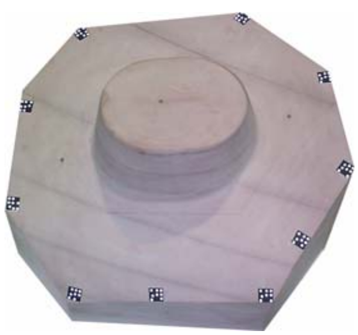
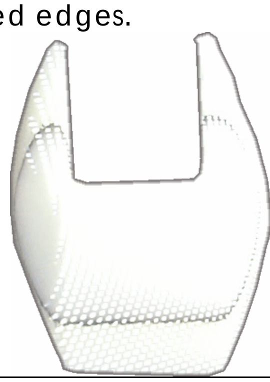
| Object | Description | Requirements | Equipment |
|---|---|---|---|
| GE F110 Frame | Approximately 40" diameter. Made up of 17 vanes.  | 1. Determine best-fit planes for key surfaces.<br>2. Determine centerline and radius of center circle.<br>3. Determine the location of 17 hole centerlines<br>4. Determine out circle radius and center point.<br>5. Determine best-fit planes through 17 vanes.<br>6. Compute angular fit between centerlines and vane planes.<br>7. Additional geometric analysis. | V-STARS/S |
| GKN Search light lay up mould | A small (15") lay up mould  | 1. Align to tooling holes<br>2. Measure edge of part, scribe lines, and other data.<br>3. Measure surface data<br>4. Compare to IGES model | V-STARS/S<br>V-STARS/M<br>PRO-SPOT |
| EH101 Foam inlet piece | A small 14" foam model with curved edges.  | 1. Measure surface data<br>2. Compare to IGES model | V-STARS/S<br>PRO-SPOT |

TABLE 1 – Measurement Summary

## Object 1 - Boeing Wing to Body Fairing Jig

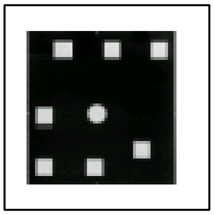
**Documentation:**
The following documentation is included in this report for this measurement.

- A report outlining methodology and results.
- Best-fit plane and line data.
- End Stop and additional data.

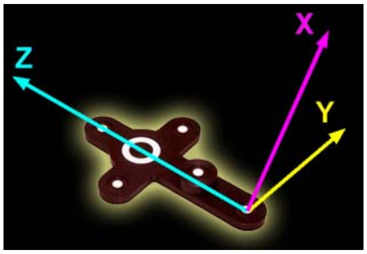
**Measurement Procedure:**

**Targeting:**

In order to meet the measurement objectives outlined earlier it was necessary to target the jig. 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 datums such as bushed holes or button datums, tooling targets are used. These come in a variety of shank and dot sizes. They are also available in variable orientations. For this measurement adapter sleeves were not available to adapt the 1" buttons to a tooling target. These buttons were measured using the V-STARS/M system and a hand-held probe. For a genuine periodic inspection program it would be advisable to have a collection of special targeting to adapt the buttons.



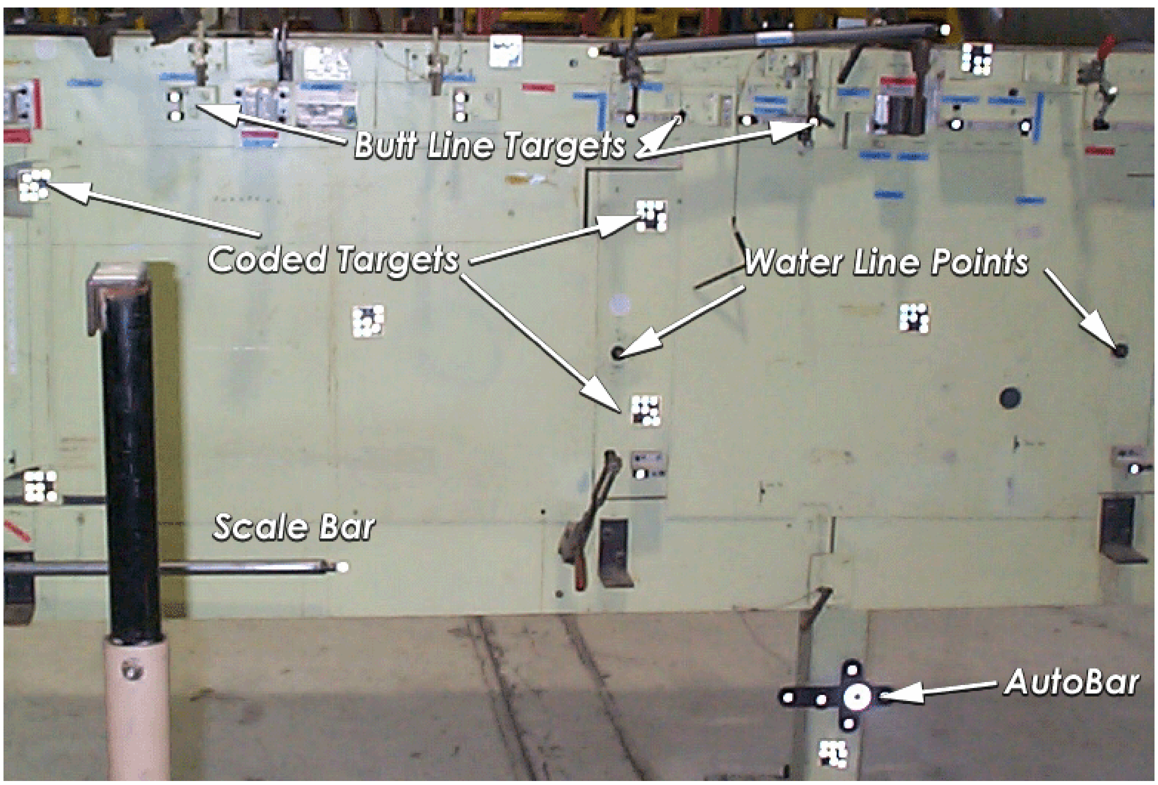
To automate the measurement process it was necessary to add "coded" targets to the jig. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photo was taken. They also help tie the entire object into a uniform coordinate system. The codes were placed along the length of the front and rear faces of the jig.




The initial coordinates 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 on the left shows both the AutoBar and its coordinate system

To scale a photogrammetric measurement, there must be at least one known distance. Normally this distance comes from a calibrated coded graphite scale bar or invar scale bar (Refer to adjacent image). Typically multiple scales are used for redundancy. Two scale bars were used to complete this measurement.

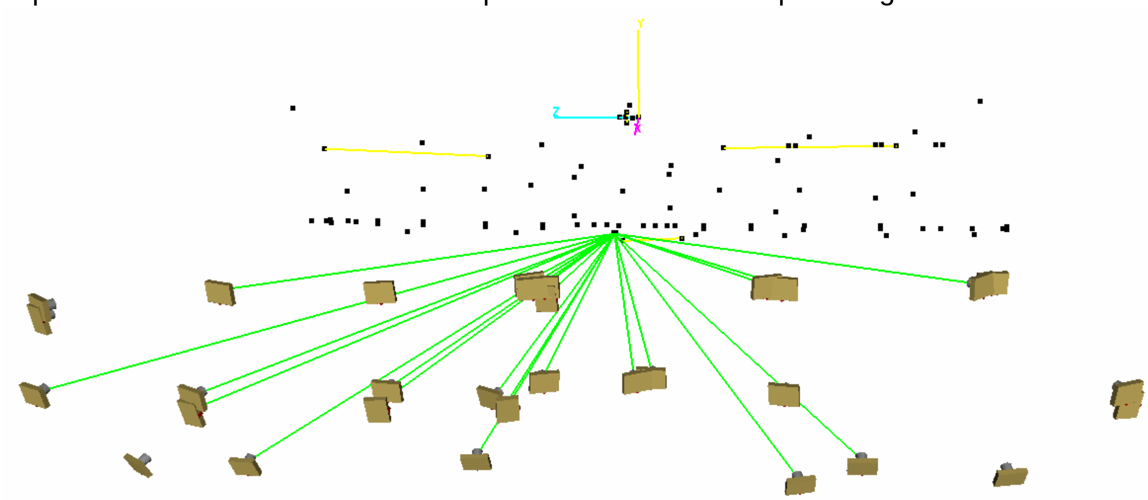
Some of the key targeting features are shown in the image below: -



**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. A total of 32 photographs were taken of the jig. The number of photos taken depends on the complexity of the measurement and accuracy requirements.

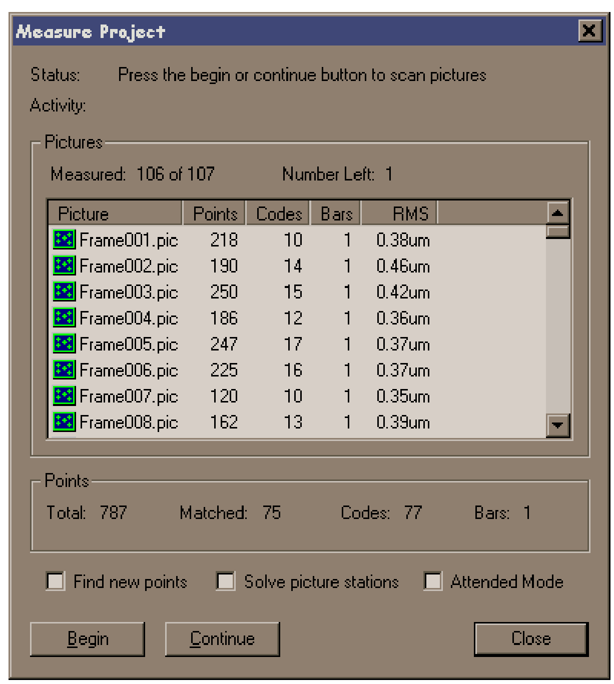
The photography for the jig was completed in approximately 2 minutes. Camera station locations for the measurement are shown in the diagram below. Also shown is a sample intersection pattern for a point. Each of the green lines represents an observation to that point from the corresponding camera station.



**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 labeling 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 necessary to re-label the points so that analysis could be simplified.

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

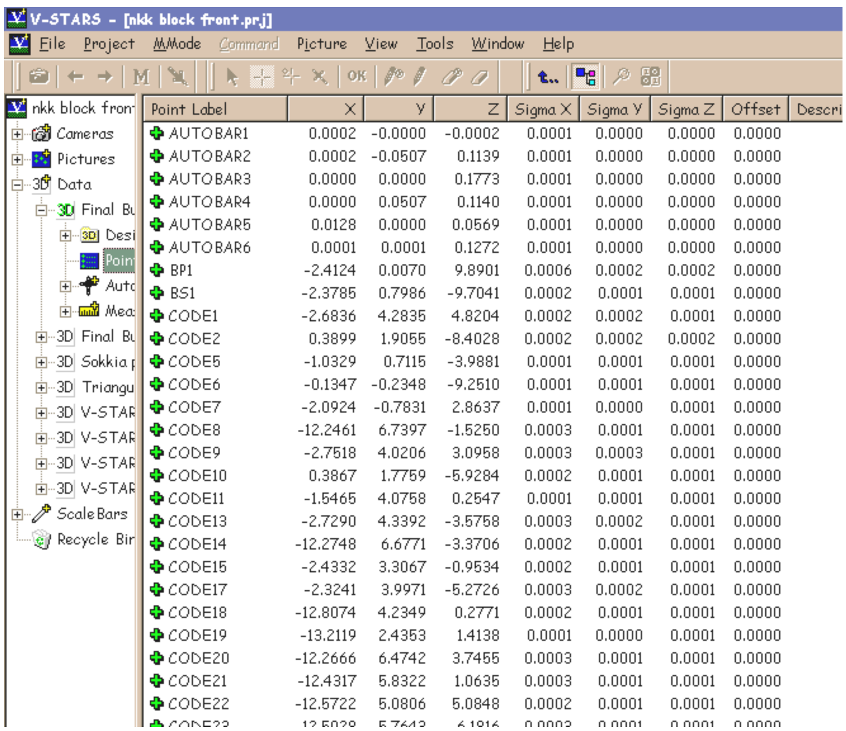

The green crosses represent points that have been located in this particular image. Note that the image appears a little dark and difficult to see. This is intentional as the best photogrammetric measurements are made on images that have dark backgrounds and bright targets. One of these targets is shown in the zoom window in the corner. If the scale bar is visible then a yellow line will be drawn between the two end points.

**Results:**

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

| | | |
|---|---|---|
| No. of photos | 32 | |
| No. of points | 86 | |
| No. of scales | 3 | |
| Scale Agreement | 0.0013" | |
| Accuracy RMS(") X,Y,Z | X | 0.0009 |
| | Y | 0.0004 |
| | Z | 0.0006 |

A typical point listing is shown below.

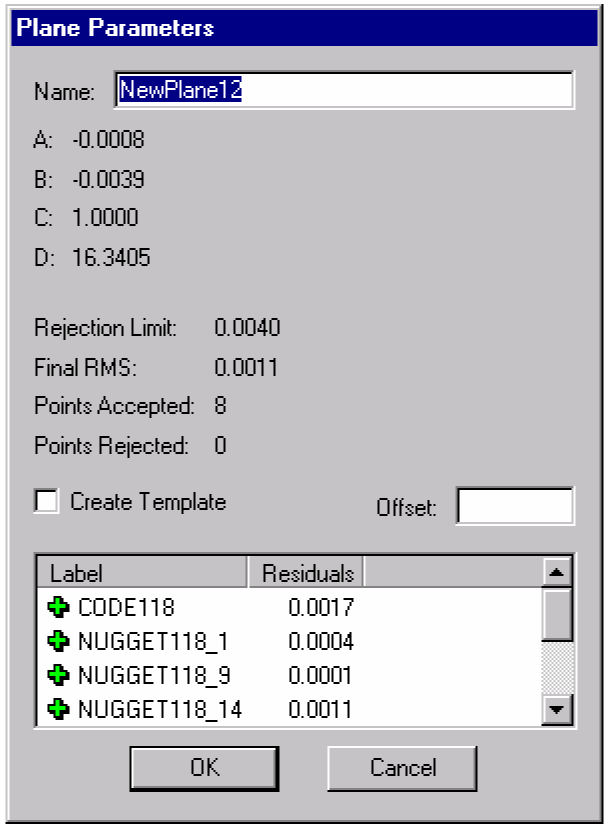



| Point Label | X | Y | Z | Sigma X | Sigma Y | Sigma Z | Offset | Descri |
|---|---|---|---|---|---|---|---|---|
| AUTOBAR1 | 0.0002 | -0.0000 | -0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR2 | 0.0002 | -0.0507 | 0.1139 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR3 | 0.0000 | 0.0000 | 0.1773 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR4 | 0.0000 | 0.0507 | 0.1140 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR5 | 0.0128 | 0.0000 | 0.0569 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR6 | 0.0001 | 0.0001 | 0.1272 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| BP1 | -2.4124 | 0.0070 | 9.8901 | 0.0006 | 0.0002 | 0.0002 | 0.0000 | |
| BS1 | -2.3785 | 0.7986 | -9.7041 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE1 | -2.6836 | 4.2835 | 4.8204 | 0.0002 | 0.0002 | 0.0001 | 0.0000 | |
| CODE2 | 0.3899 | 1.9055 | -8.4028 | 0.0002 | 0.0002 | 0.0002 | 0.0000 | |
| CODE5 | -1.0329 | 0.7115 | -3.9881 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE6 | -0.1347 | -0.2348 | -9.2510 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE7 | -2.0924 | -0.7831 | 2.8637 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | |
| CODE8 | -12.2461 | 6.7397 | -1.5250 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE9 | -2.7518 | 4.0206 | 3.0958 | 0.0003 | 0.0003 | 0.0001 | 0.0000 | |
| CODE10 | 0.3867 | 1.7759 | -5.9284 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE11 | -1.5465 | 4.0758 | 0.2547 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE13 | -2.7290 | 4.3392 | -3.5758 | 0.0003 | 0.0002 | 0.0001 | 0.0000 | |
| CODE14 | -12.2748 | 6.6771 | -3.3706 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE15 | -2.4332 | 3.3067 | -0.9534 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE17 | -2.3241 | 3.9971 | -5.2726 | 0.0003 | 0.0002 | 0.0001 | 0.0000 | |
| CODE18 | -12.8074 | 4.2349 | 0.2771 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE19 | -13.2119 | 2.4353 | 1.4138 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | |
| CODE20 | -12.2666 | 6.4742 | 3.7455 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE21 | -12.4317 | 5.8322 | 1.0635 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE22 | -12.5722 | 5.0806 | 5.0848 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |

This point data can be analyzed within the V-STARS' SOLIDS module, easily exported to almost any CAD platform or other analysis program. For this particular project, the analysis was completed in SOLIDS.

SOLIDS is the geometric analysis module of V-STARS. For example, consider a simple function like determining the distance between two points. Computing the point-to-point distance is as simple as highlighting the two points and pressing "d". The result appears on the screen and is also written to a report file.

Calculation of the Best-fit plane is also very simple. The plane points are highlighted and the “P” key is pressed. The plane dialog is shown in the adjacent image. The dialog gives you a few options and also reports the results of the operation.



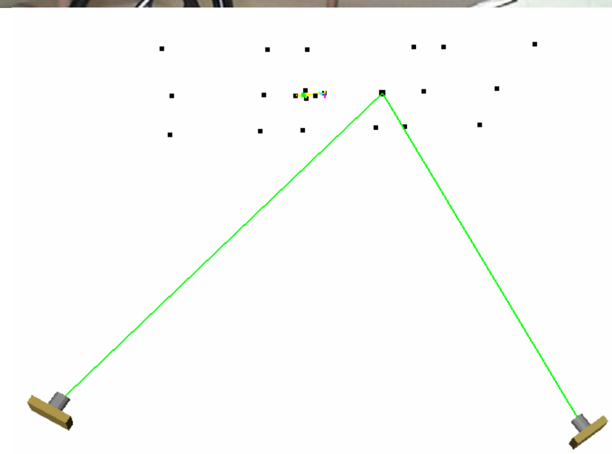

Similarly, best-fit lines, circles, spheres etc. can also be calculated. SOLIDS also has the ability to measure between objects. For example, by selecting a point and a plane the normal distance can be computed. This makes SOLIDS a very useful analysis tool.

**Point Probing – M Mode:**

In order to establish the button center point locations it was necessary to configure the system for use in M or Multi camera mode. In this mode two or more cameras are used 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. For this particular measurement datum button locations and pad plane points were required.

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 an image has been acquired the cameras are capable of determining their orientation relative to the object. This information is presented graphically so that the user can decide whether the positioning is suitable for the area of interest.

The set up that was used is shown below:



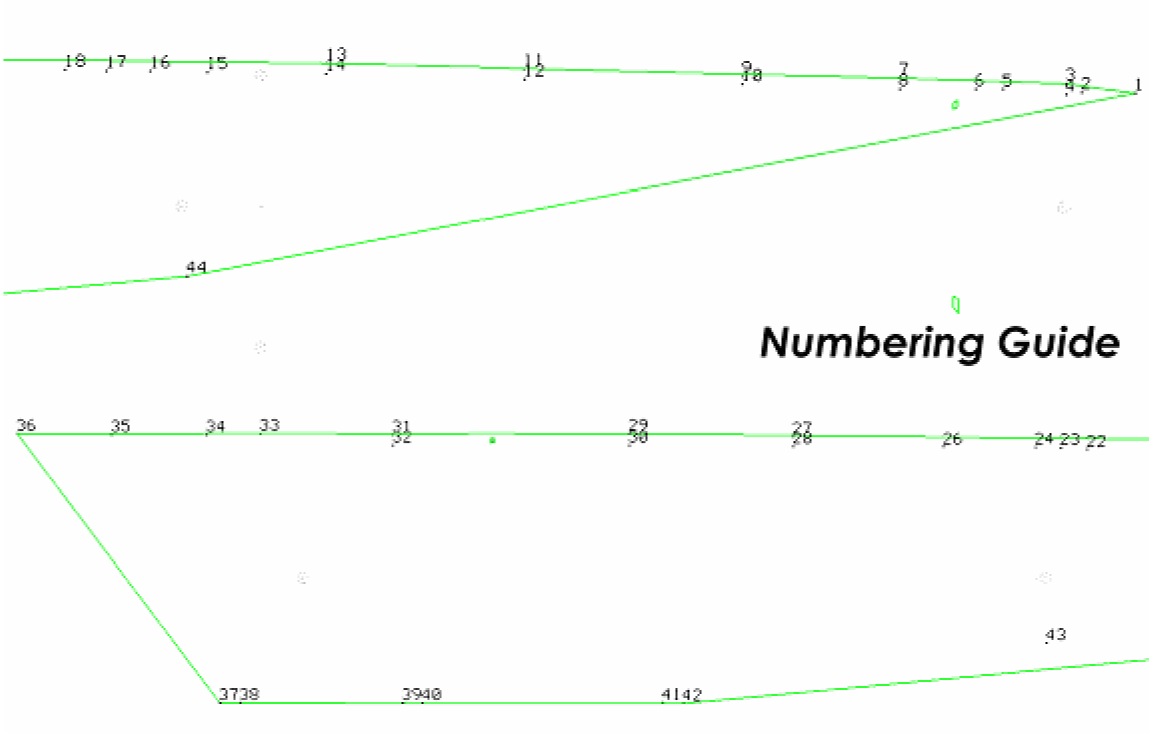
Measuring with the hand held probes is as simple as pointing the cameras roughly at the area of interest, placing the probe on the point of interest and pressing the hand held trigger. Each camera images the probe, determines the type of probe being used and sends this information to the system laptop. V-STARS then takes this data and computes the XYZ location of the probe tip. Up to 16 different probes are available. Each of these has a unique pattern of dots and is automatically identified by the system. The probes also have a variety of tips available. The probes typically come with a 3mm or 6mm ball tip. Scribe tips are also available.

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.

A total of six datum buttons were measured. Four of these were located along the Water Line. The remaining two buttons were in the Station direction. The buttons were measured by collecting six points around the circumference. These points were then used to create the center point.

**Numbering Guide:**

The numbering used on the jig is shown in the image below.

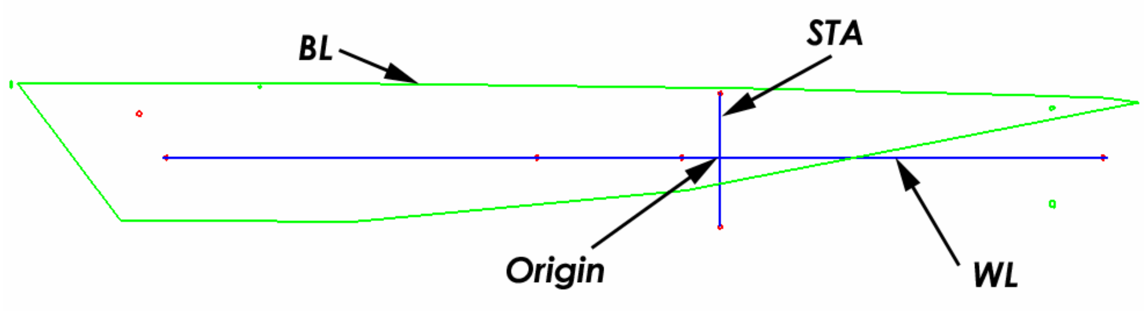



**Alignment:**

Typically one of the last tasks is alignment into the coordinate system of the object being measured. There are two basic types of alignment. The first is a simple Axis or 3-2-1 alignment. This alignment is based on three points – an origin, an axis point and a third point to define the plane in which the axis lies. The second type of alignment uses point correspondence from a known alignment (such as the CAD model) to transform the data into that coordinate system. This is a "best-fit" solution and is preferred as it involves greater redundancy.

For this particular project an axis alignment was completed. This was based on the derived Water Line and Station Lines and clocked through the Butt Line Plane. The Water Line and Station Line were intersected to form an Origin point. This Origin (BL = 57.78, WL = 100.00, STA = 1086), a second point on the Water Line and a third point on the Station line were used to create the Axis Alignment.

The graphical result of the alignment is shown below: -




**Analysis:**

The analysis competed is shown in the tables below.

*BL Data Based on Alignment*

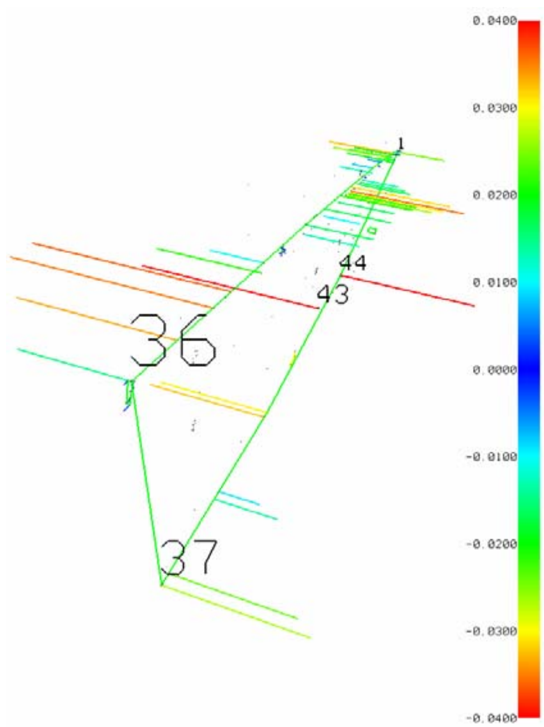
| PT | Actual | Nominal | Difference |
|---|---|---|---|
| 1 | 57.805 | 57.780 | 0.025 |
| 2 | 57.780 | 57.780 | 0.000 |
| 3 | 57.782 | 57.780 | 0.002 |
| 4 | 57.783 | 57.780 | 0.003 |
| 5 | 57.769 | 57.780 | -0.011 |
| 6 | 57.760 | 57.780 | -0.020 |
| 7 | 57.748 | 57.780 | -0.032 |
| 8 | 57.758 | 57.780 | -0.022 |
| 9 | 57.754 | 57.780 | -0.026 |
| 10 | 57.761 | 57.780 | -0.019 |
| 11 | 57.774 | 57.780 | -0.006 |
| 12 | 57.779 | 57.780 | -0.001 |
| 13 | 57.772 | 57.780 | -0.008 |
| 14 | 57.767 | 57.780 | -0.013 |
| 15 | 57.779 | 57.780 | -0.001 |
| 16 | 57.793 | 57.780 | 0.013 |
| 17 | 57.796 | 57.780 | 0.016 |
| 18 | 57.798 | 57.780 | 0.018 |
| 20 | 57.816 | 57.780 | 0.036 |
| 21 | 57.811 | 57.780 | 0.031 |
| 22 | 57.810 | 57.780 | 0.029 |
| 23 | 57.802 | 57.780 | 0.021 |

| PT | Actual | Nominal | Difference |
|---|---|---|---|
| 24 | 57.806 | 57.780 | 0.026 |
| 25 | 57.801 | 57.780 | 0.021 |
| 26 | 57.796 | 57.780 | 0.016 |
| 27 | 57.797 | 57.780 | 0.017 |
| 28 | 57.790 | 57.780 | 0.010 |
| 29 | 57.796 | 57.780 | 0.016 |
| 30 | 57.793 | 57.780 | 0.013 |
| 31 | 57.769 | 57.780 | -0.011 |
| 32 | 57.759 | 57.780 | -0.022 |
| 33 | 57.744 | 57.780 | -0.036 |
| 34 | 57.745 | 57.780 | -0.035 |
| 35 | 57.747 | 57.780 | -0.034 |
| 36 | 57.765 | 57.780 | -0.015 |
| 37 | 57.807 | 57.780 | 0.027 |
| 38 | 57.804 | 57.780 | 0.024 |
| 39 | 57.794 | 57.780 | 0.014 |
| 40 | 57.789 | 57.780 | 0.009 |
| 41 | 57.748 | 57.780 | -0.032 |
| 42 | 57.750 | 57.780 | -0.030 |
| 43 | 57.717 | 57.780 | **-0.063** |
| 44 | 57.830 | 57.780 | 0.050 |
| | **Deviation > 0.060"** | | |

*BL Data Based on Plane Fit*

**BL RMS = 0.024"**

| PT | Plane RMS(") | PT | Plane RMS(") |
|---|---|---|---|
| 1 | 0.025 | 24 | 0.026 |
| 2 | 0.000 | 25 | 0.021 |
| 3 | 0.002 | 26 | 0.016 |
| 4 | 0.003 | 27 | 0.017 |
| 5 | -0.011 | 28 | 0.010 |
| 6 | -0.020 | 29 | 0.016 |
| 7 | -0.032 | 30 | 0.013 |
| 8 | -0.022 | 31 | -0.011 |
| 9 | -0.026 | 32 | -0.022 |
| 10 | -0.019 | 33 | -0.036 |
| 11 | -0.006 | 34 | -0.035 |
| 12 | -0.001 | 35 | -0.034 |
| 13 | -0.008 | 36 | -0.015 |
| 14 | -0.013 | 37 | 0.027 |
| 15 | -0.001 | 38 | 0.024 |
| 16 | 0.013 | 39 | 0.014 |
| 17 | 0.016 | 40 | 0.009 |
| 18 | 0.018 | 41 | -0.032 |
| 20 | 0.036 | 42 | -0.030 |
| 21 | 0.031 | 43 | **-0.063** |
| 22 | 0.030 | 44 | 0.050 |
| 23 | 0.022 | **Deviation > 0.060"** | |




*End Stop Data Based on Plane Fit*

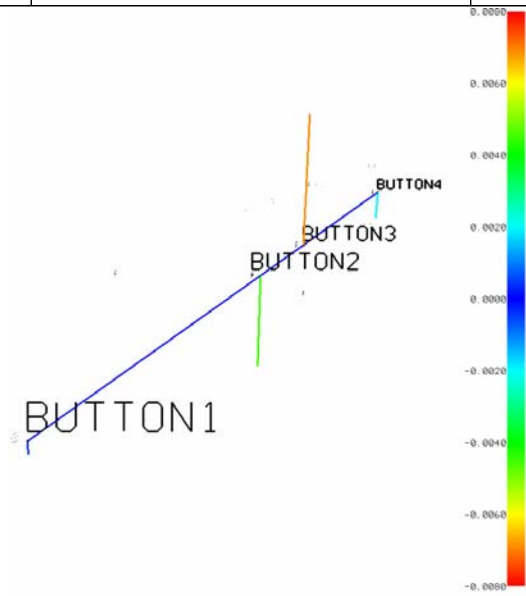
**End Stop RMS = 0.001"**

| Point | Plane RMS | STA |
|---|---|---|
| END1 | -0.001 | 918.760 |
| END2 | 0.001 | 918.770 |
| END3 | 0.002 | 918.766 |
| END4 | 0.001 | 918.773 |
| END5 | -0.002 | 918.771 |
| END6 | -0.001 | 918.755 |
| END7 | 0.001 | 918.760 |

*WL Data Based on Line Fit*

**WL Line RMS = 0.004"**

| Point | Line RMS | WL |
|---|---|---|
| Button 1 | 0.002 | 100 |
| Button 2 | 0.007 | 100.007 |
| Button 3 | 0.005 | 99.995 |
| Button 4 | 0.000 | 99.997 |




Deviations are based on button points projected to the BL Plane. Without projection the Water Line fit yields an accuracy RMS of 0.044".

**Time Summary:**
The following is an estimate of the time taken to complete the measurement.

| | |
|---|---|
| Targeting | 10 minutes |
| Photography | 2 minutes |
| Processing | 5 minutes |
| Probing* | 20 minutes |
| Alignment | 13 minutes |
| Analysis | 10 minutes |
| **Total** | **60 minutes** |

With the correct targeting and a better understanding of the measurement, the probing could be reduced to <40 minutes

## Object 2 – GE F110 Frame

**Documentation:**
The following documentation is included in this report for this measurement.

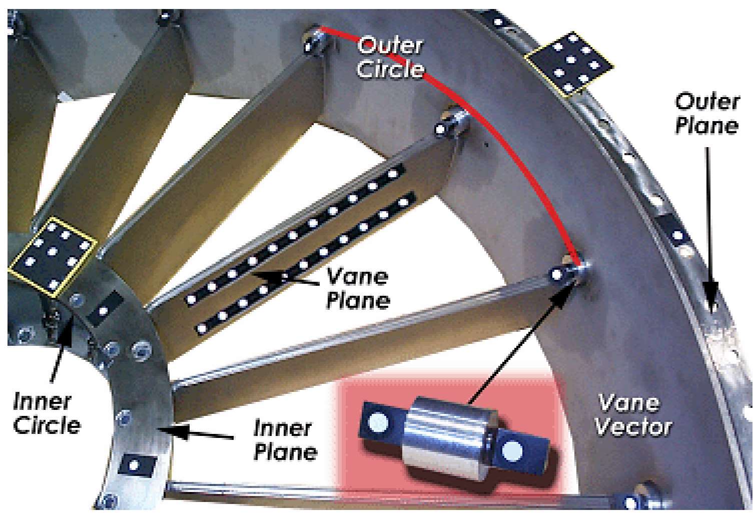
- A report outlining the results.
- Coordinate data for the measured component.
- Geometric analysis.

**Measurement Procedure:**

**Targeting:**

The following targeting was used

1. Approximately 20 targets on each of the 17 vanes.
2. Targets on the inner and outer planes.
3. Targets on the inner circle.
4. Vector targets in each of the 17 holes.
5. Coded targets.
6. AutoBar.
7. Two scale Bars.

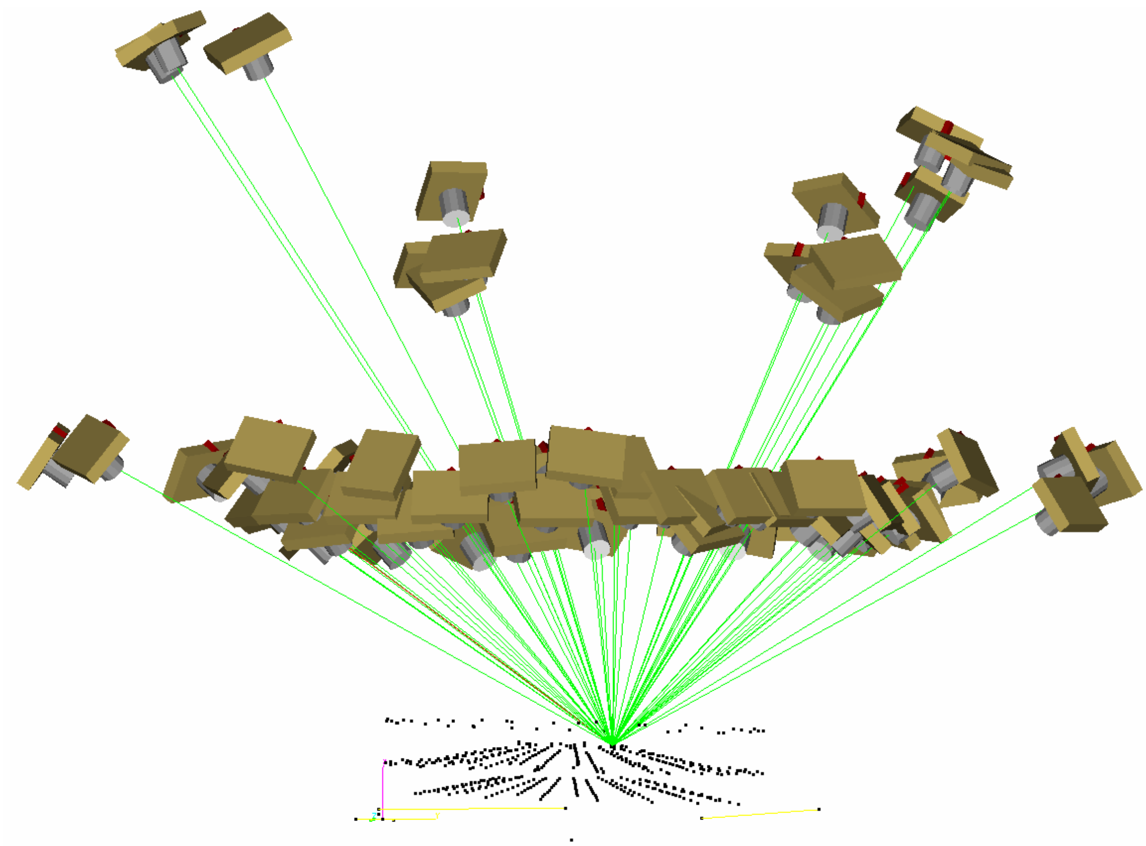



All of the necessary features could be targeted and therefore no probing was necessary.

**Photography:**

A total of 70 photographs were taken of the frame. The number of photos taken was high due to the steep angle to the points on the bottom of the vane. These points significantly complicated the measurement. The photography for the frame was completed in approximately 5 minutes.

Camera station locations for the measurement are shown in the diagram below. Also shown is a sample intersection pattern for a point.



**Processing:**

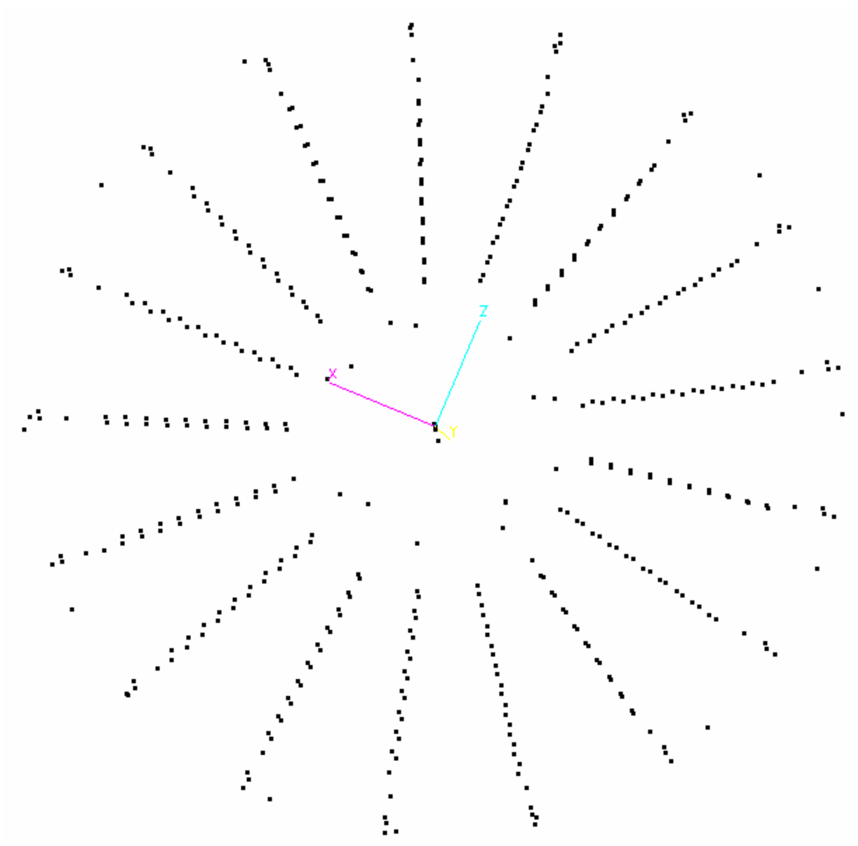
Seen below is an image taken as part of the jig measurement.

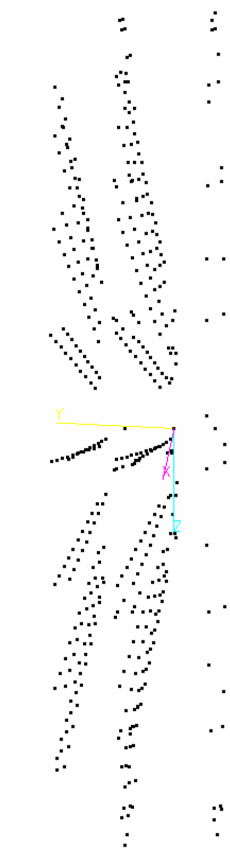
**Results:**

The following is a summary of the measurement statistics from the measurement of the frame

| | | |
|---|---|---|
| No. of photos | 70 | |
| No. of points | 467 | |
| No. of scales | 2 | |
| Scale Agreement | 0.0005" | |
| Accuracy RMS(") X,Y,Z | X | 0.0005 |
| | Y | 0.0005 |
| | Z | 0.0006 |

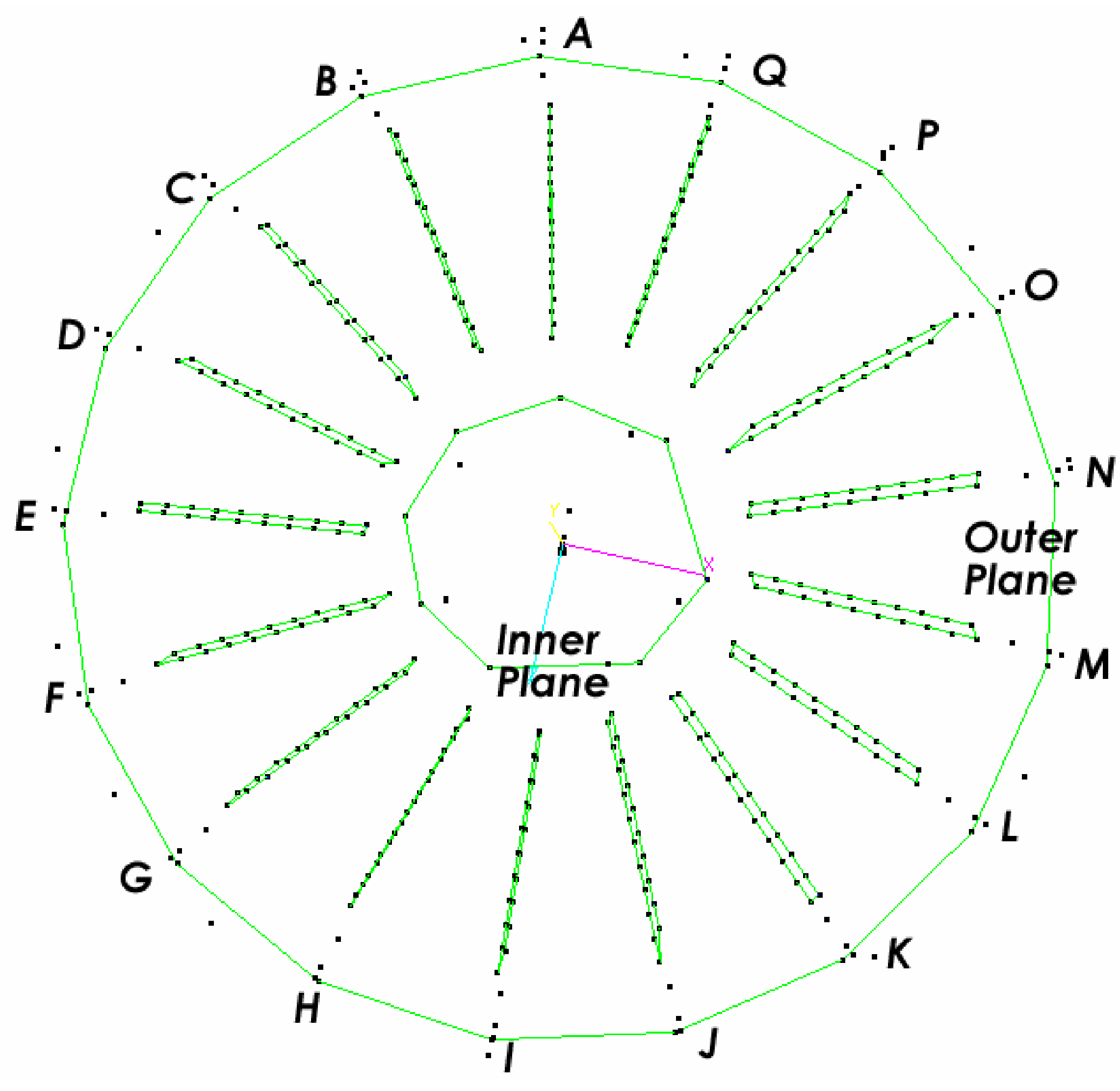
The point cloud is shown in the following images.



**Numbering Guide:**

The following numbering scheme was adopted. Each of the vanes was assigned a letter from A to Q respectively. Vector or surface data was then referenced against this letter.

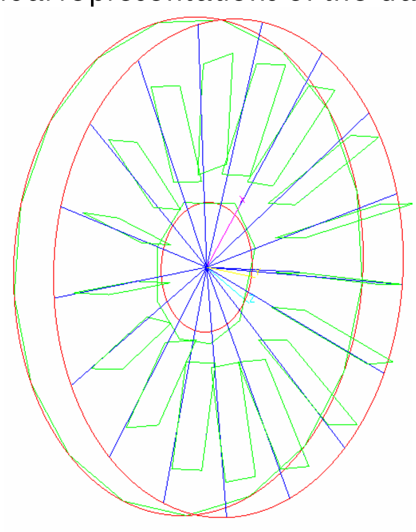


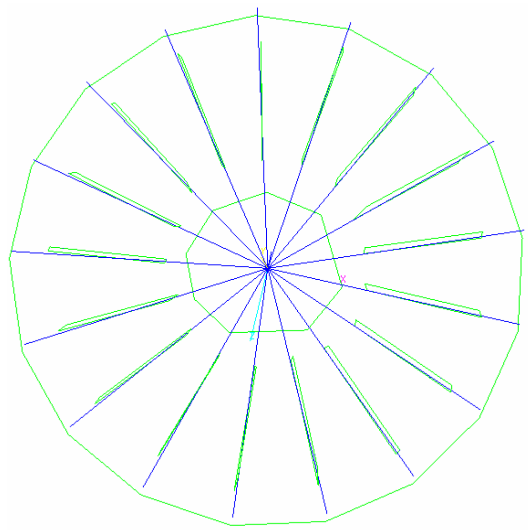

**Alignment:**

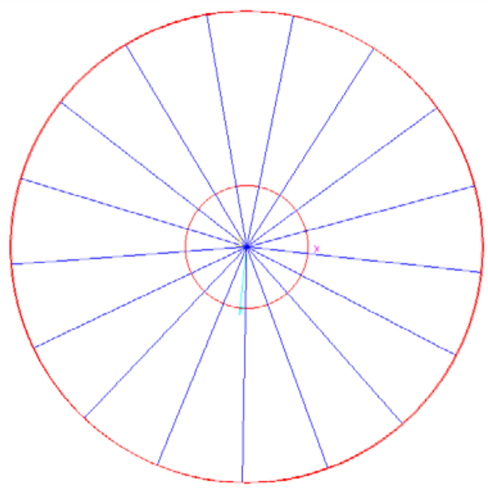
For the sake of simplicity an Axis alignment was carried out using the frame centerline and one of the reference planes.

**Analysis:**

The analysis competed is shown in the tables below.  Also shown below are some graphical representations of the data.



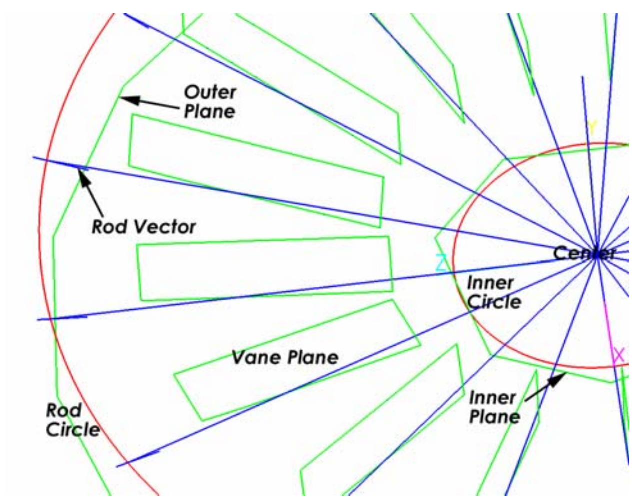




*Inner and Outer Planes*

| | RMS (") |
|---|---|
| Inner Plane | 0.0001 |
| Outer Plane | 0.0018 |
| Parallelism | 0.0023º |
| Inner - Outer Plane Distance | 1.962 |

This data indicates that the planes have a high level of flatness and parallelism.



*17 Vanes Planes Summary*

| VANE | RMS(") | Adjacent Plane Angle | Measured° | Theoretical° | Difference° |
|---|---|---|---|---|---|
| A | 0.0144 | Q to A | 21.1873 | 21.1765 | 0.0108 |
| B | 0.0128 | A to B | 21.2916 | 21.1765 | 0.1151 |
| C | 0.0113 | B to C | 21.0647 | 21.1765 | -0.1118 |
| D | 0.0154 | C to D | 21.2227 | 21.1765 | 0.0462 |
| E | 0.0119 | D to E | 21.0901 | 21.1765 | -0.0864 |
| F | 0.0145 | E to F | 21.1875 | 21.1765 | 0.0110 |
| G | 0.0131 | F to G | 21.2029 | 21.1765 | 0.0264 |
| H | 0.0147 | G to H | 21.1528 | 21.1765 | -0.0237 |
| I | 0.0121 | H to I | 21.1301 | 21.1765 | -0.0464 |
| J | 0.0133 | I to J | 21.2829 | 21.1765 | 0.1064 |
| K | 0.0160 | J to K | 21.1765 | 21.1765 | 0.0000 |
| L | 0.0113 | K to L | 21.0921 | 21.1765 | -0.0844 |
| M | 0.0144 | L to M | 21.3237 | 21.1765 | 0.1472 |
| N | 0.0108 | M to N | 21.1117 | 21.1765 | -0.0648 |
| O | 0.0120 | N to O | 21.0841 | 21.1765 | -0.0924 |
| P | 0.0134 | O to P | 21.2611 | 21.1765 | 0.0846 |
| Q | 0.0149 | P to Q | 21.0401 | 21.1765 | -0.1364 |
| A | 0.0144 | Q to A | 21.1873 | 21.1765 | 0.0108 |
| | | **SUM** | 359.9019 | 360 | |

*Inner Circle Summary*

| | |
|---|---|
| Radius | 5.0241" |
| Total RMS | 0.0003" |

*Vector Rod Data*

The 17 vectors rods were used to create a surface point for each of the holes in the frame. These points are reported in the table below. Also reported is the circle and plane fit for these points.

| | |
|---|---|
| Radius | 19.3268" |
| Total Circle RMS | 0.0025" |
| Total Plane RMS | 0.0027" |
| Distance from Rod Center to Frame Centerline | 0.0004" |

The plane and circle have higher RMS values than expected. More than likely this is due to the targeting adapter and the positioning of the target. The vector rod manufactured didn't have a lip to prevent it from slipping past the end of the plane.

| | | | | Deviations (") | |
|---|---|---|---|---|---|
| **Point Label** | **X** | **Y** | **Z** | **Circle** | **Plane** |
| A | -4.972 | 2.951 | -18.595 | 0.001 | 0.003 |
| B | -11.287 | 3.714 | -15.426 | 0.000 | 0.003 |
| C | -16.034 | 4.287 | -10.171 | -0.006 | 0.002 |
| D | -18.588 | 4.598 | -3.549 | 0.003 | 0.000 |
| E | -18.583 | 4.597 | 3.555 | -0.001 | 0.001 |
| F | -16.039 | 4.293 | 10.181 | 0.004 | -0.003 |
| G | -11.290 | 3.719 | 15.424 | 0.001 | -0.003 |
| H | -4.969 | 2.958 | 18.591 | -0.002 | -0.004 |
| I | 2.056 | 2.105 | 19.249 | 0.001 | 0.000 |
| J | 8.836 | 1.282 | 17.298 | -0.004 | 0.004 |
| K | 14.467 | 0.603 | 13.018 | 0.000 | 0.004 |
| L | 18.176 | 0.157 | 6.978 | -0.001 | 0.002 |
| M | 19.473 | 0.000 | 0.000 | 0.002 | 0.002 |
| N | 18.176 | 0.161 | -6.986 | 0.001 | -0.002 |
| O | 14.465 | 0.613 | -13.025 | 0.002 | -0.006 |
| P | 8.833 | 1.289 | -17.305 | -0.001 | -0.002 |
| Q | 2.047 | 2.106 | -19.247 | -0.002 | 0.000 |

*Vane to Reference Plane Angle*

| Vane | Angle° |
|---|---|
| A | 88.6190 |
| B | 88.6166 |
| C | 88.5503 |
| D | 88.3124 |
| E | 88.3910 |
| F | 88.4911 |
| G | 88.4005 |
| H | 88.4570 |
| I | 88.3770 |
| J | 88.7723 |
| K | 88.3932 |
| L | 88.5996 |
| M | 88.9438 |
| N | 88.9340 |
| O | 88.5340 |
| P | 88.6417 |
| Q | 88.4335 |

The pitch of the vane seems fairly consistent.  No theoretical value was available to compare the measured data to.

*Angle between rod lines*

| | |
|---|---|
| Q to A | 20.5567 |
| A to B | 21.0178 |
| B to C | 20.8649 |
| C to D | 21.1269 |
| D to E | 20.2966 |
| E to F | 21.0413 |
| F to G | 19.8774 |
| G to H | 21.2739 |
| H to I | 20.7580 |
| I to J | 20.6375 |
| J to K | 21.1384 |
| K to L | 20.4520 |
| L to M | 20.5305 |
| M to N | 21.1436 |
| N to O | 20.5350 |
| O to P | 20.8119 |
| P to Q | 20.6105 |
| Q to A | 20.5567 |
| **SUM** | **352.6729** |

*Angle between rod lines and adjacent vane*

| | |
|---|---|
| A | 0.5484 |
| B | 0.6768 |
| C | 0.8824 |
| D | **1.1644** |
| E | 0.8185 |
| F | **1.1220** |
| G | **0.2101** |
| H | 0.7860 |
| I | 0.8446 |
| J | 0.7123 |
| K | **1.0141** |
| L | 0.8333 |
| M | 0.5286 |
| N | 0.9746 |
| O | 0.7806 |
| P | 0.7968 |
| Q | 0.7396 |

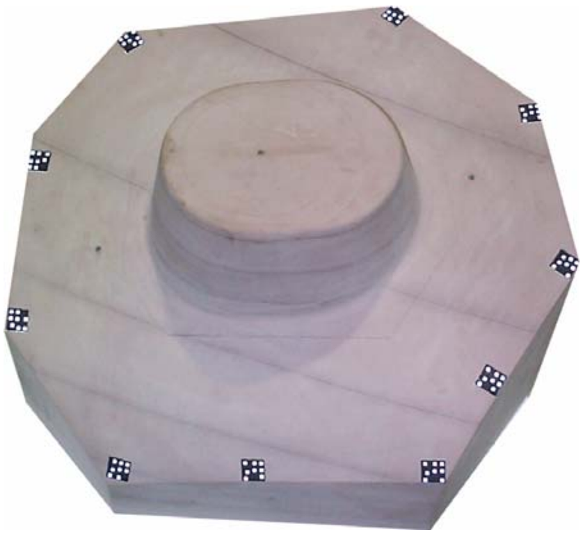
This data seems to indicate that there are vanes that have significant angular discrepancies. Vane F and G are the most severe. It is interesting to note that these are adjacent to one another.

**Time Summary**
The following is an estimate of the time taken to complete the measurement.

| | |
|---|---|
| Targeting | 30 minutes |
| Photography | 5 minutes |
| Processing | 10minutes |
| Analysis | 15 minutes |
| **Total** | **60 minutes** |

## Object 3 – GKN Search light lay up mould

The project was completed in three parts. The first part was to coordinate and align the work piece. In the second part the probe was used to probe the edge of part, scribe lines and other details. In the final part, PRO-SPOT was used to gather surface information.



**Documentation:**
The following documentation is included in this report for this measurement.

- A report outlining the results.
- Coordinate data for the measured component.
- Geometric analysis
- Comparison to IGES file


**Measurement Procedure:**

**Targeting:**

The following targeting was used

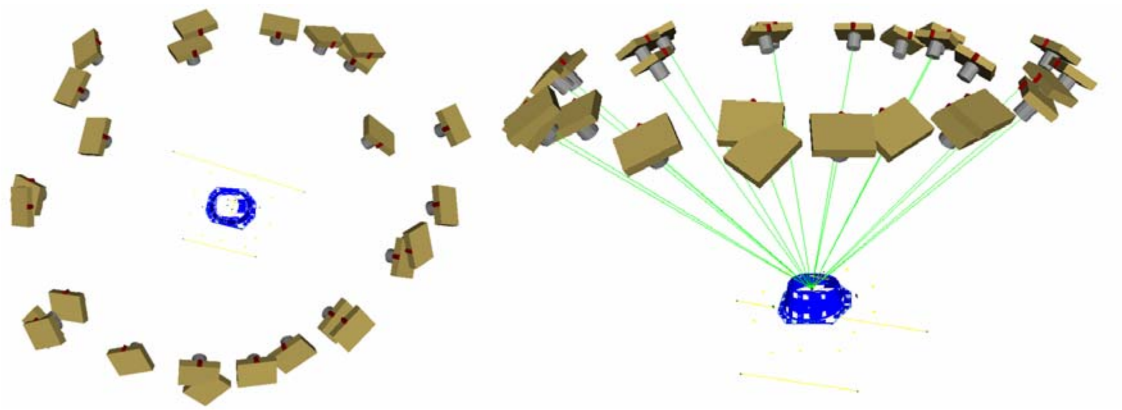
1. Projected targets from PRO-SPOT
2. Tooling targets
3. Coded targets around the edge
4. AutoBar
5. Two scale Bars.

It was necessary to probe the edge of part, a reference circle and four crosses using the hand-held probes.

**Photography – Part 1:**

A total of 26 photographs were taken of the mould. The photography for the piece was completed in approximately 5 minutes.

Camera station locations for the measurement are shown in the diagram below. Also shown is a sample intersection pattern for a point.



**Processing – Part 1:**
The processing consumed approximately five minutes.

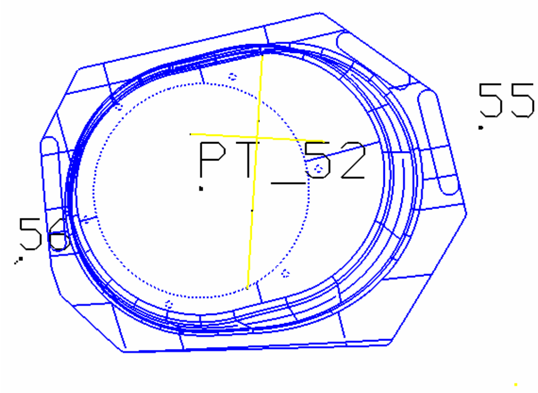
**Results – Part 1:**

The following is a summary of the measurement statistics from the first part of the mould measurement.

| | | |
|---|---|---|
| No of photos | 26 | |
| No of points | 30 | |
| No of scales | 2 | |
| Scale Agreement | 0.0007" | |
| Accuracy RMS(") X,Y,Z | X | 0.0005 |
| | Y | 0.0006 |
| | Z | 0.0005 |

**Numbering Guide – Part 1**

For the most part there was no defined numbering scheme. The only points assigned labels were the ones needed to complete the alignment to the design data. These are shown in the adjacent image.

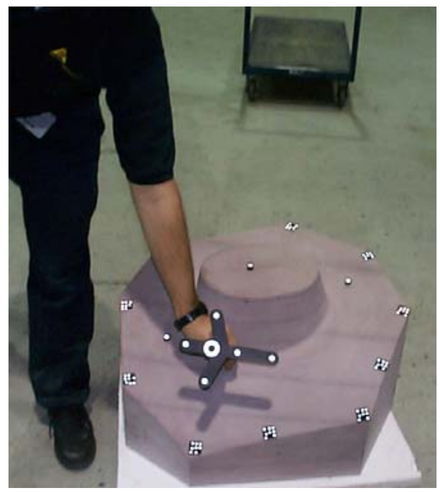


**Alignment:**

The alignment was a best-fit transformation to three tooling points. The results of the alignment are shown in the table below.

| Point | X | Y | Z | Total |
|---|---|---|---|---|
| 55 | 0.0037" | 0.0000" | 0.0013" | 0.0039" |
| 56 | -0.0048" | 0.0000" | -0.0006" | 0.0048" |
| PT_52 | 0.0011" | -0.0000" | -0.0007" | 0.0013" |

**Probing – Part 2:**

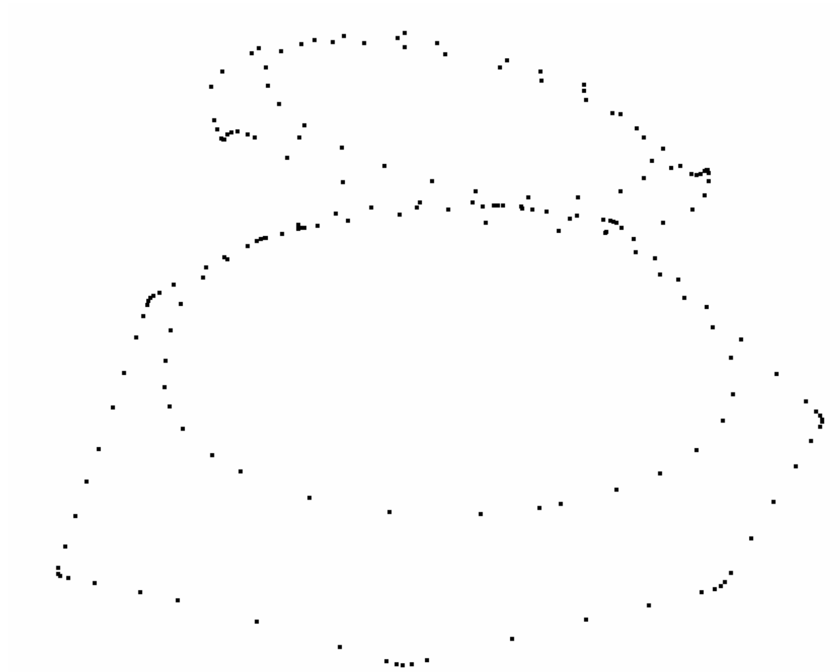


The following data was collected using the hand-held probes.

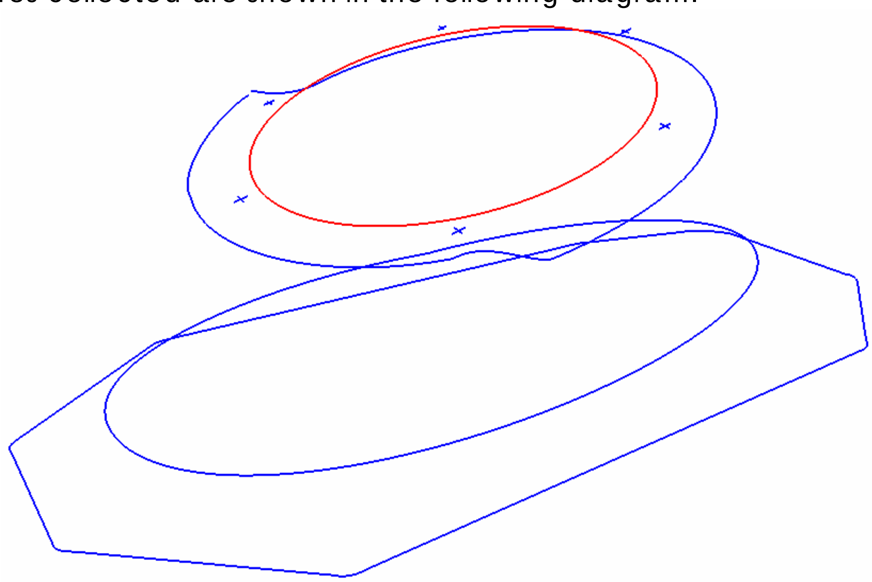
1. EOP.
2. Scribe lines.
3. Center circle.
4. Six crosses.

The cameras were set up as shown below.

A total of 180 points were collected with the probe. These are show in the point cloud below.

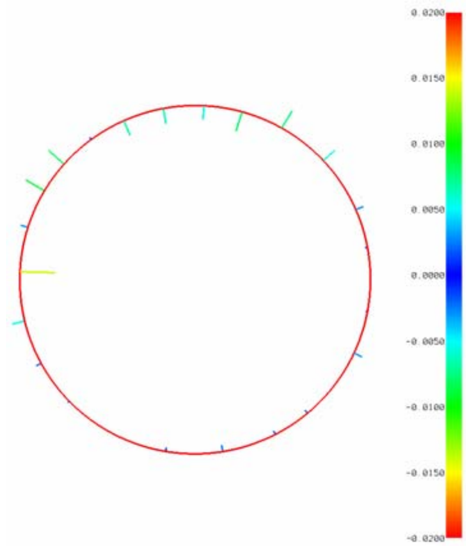


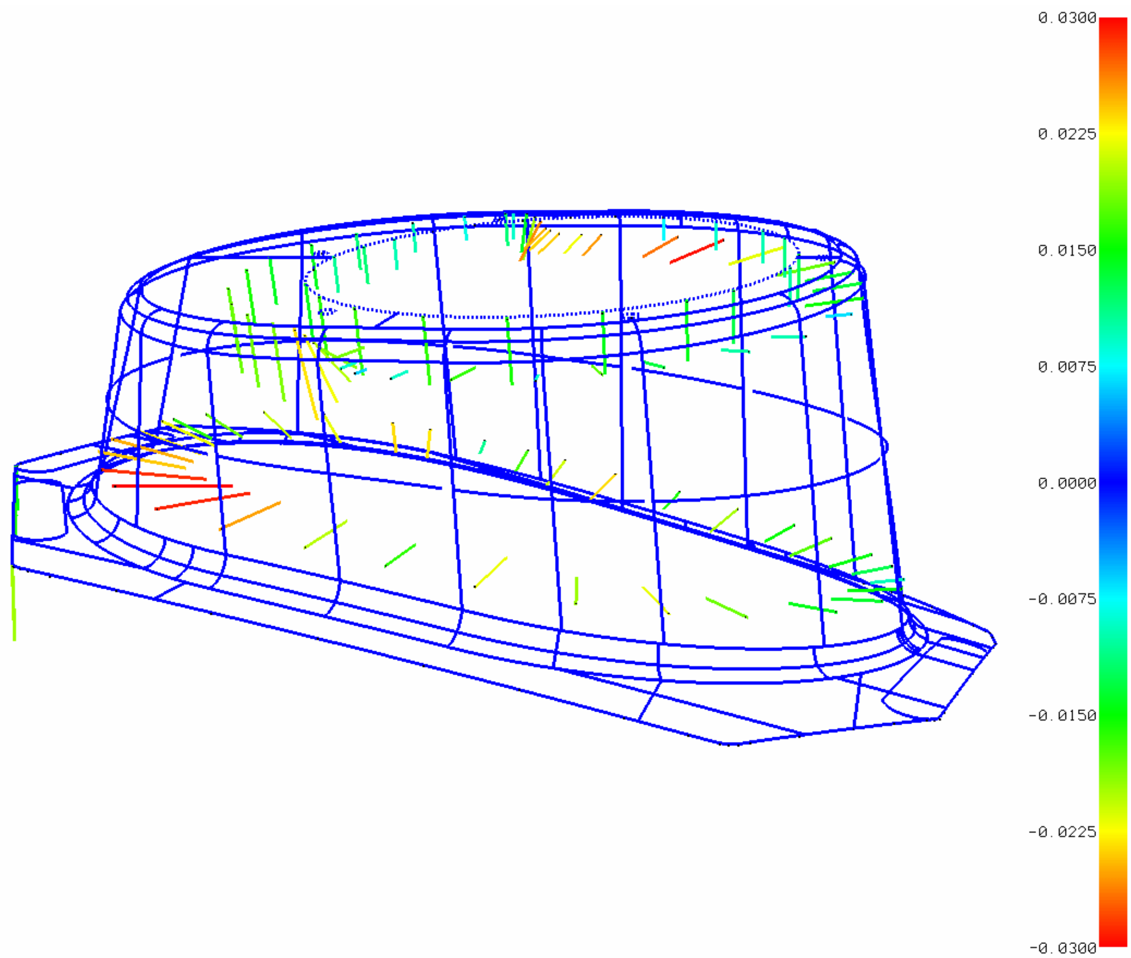
The features collected are shown in the following diagram.



The data collected was then compared to the IGES model. The circle was also computed.

Circle Radius = 3.271"
RMS = 0.0055"



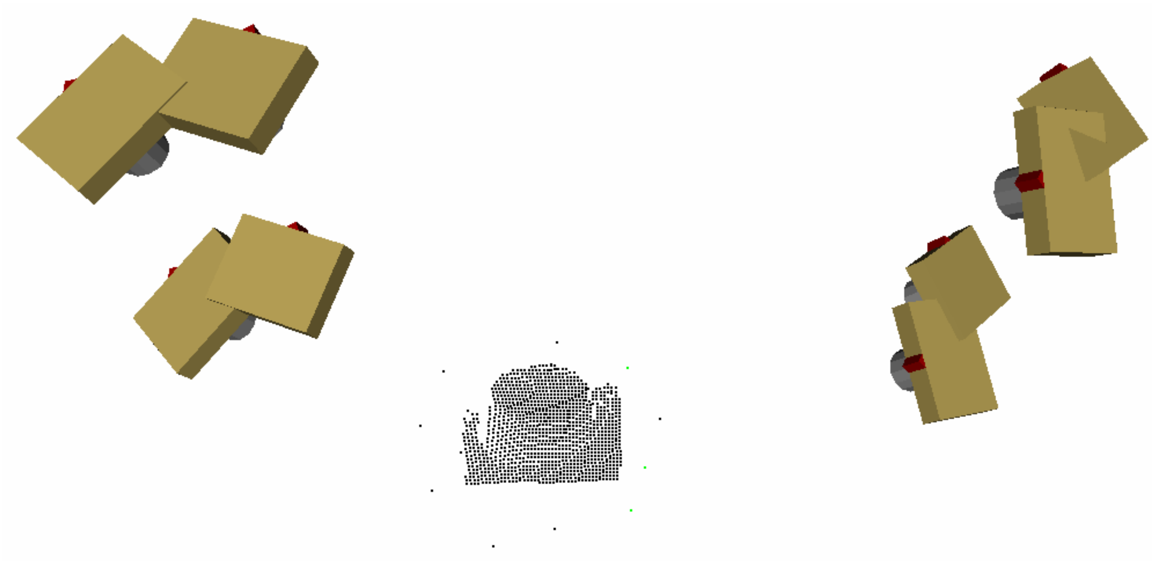



**Surface Measurement – Part 3**

The final part of the measurement involved the determination of surface points. The points were generated using the target projection system known as PRO-SPOT. A modeling light was used to focus and position the array of targets. Care was taken to ensure that the projected targets did not fall on any of the reference targets. To cover the component it was necessary to complete the measurement in four set-ups. These corresponded to each of the four sides of the piece. One of the set-ups is shown in the image below.

A total of eight photographs were taken at each of the four positions. The data sets were combined by using the coded targets placed around the periphery of the object.

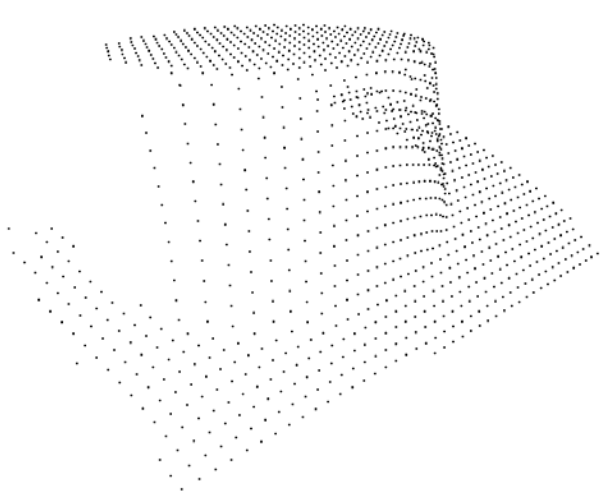
A typical camera network is shown in the image below:

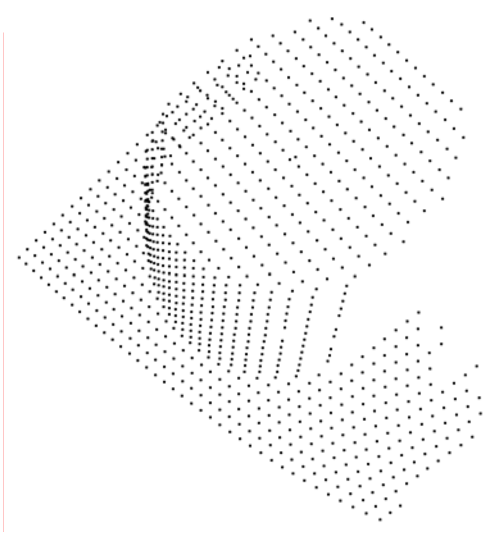


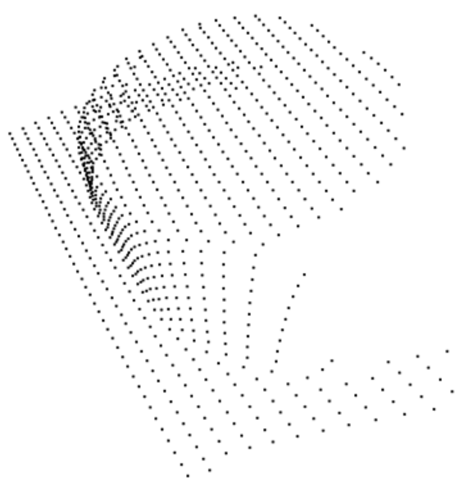
The results of the four networks are summarized in the following table

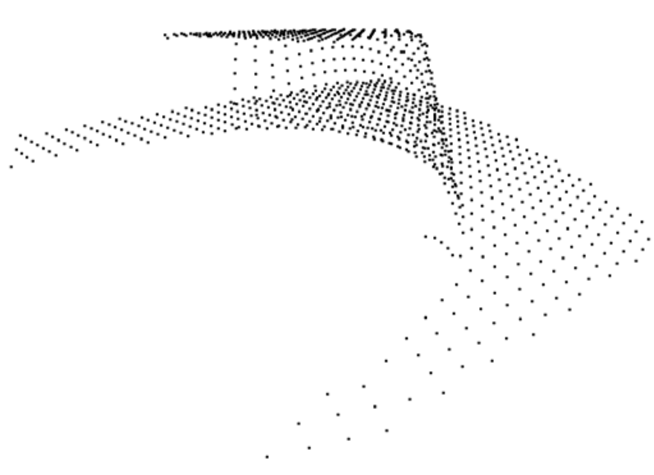
| Set-up | # of Points | X RMS | Y RMS | Z RMS |
|---|---|---|---|---|
| 1 | 1172 | 0.0002 | 0.0002 | 0.0003 |
| 2 | 979 | 0.0002 | 0.0003 | 0.0003 |
| 3 | 915 | 0.0002 | 0.0002 | 0.0002 |
| 4 | 1056 | 0.0001 | 0.0002 | 0.0002 |
| **Total** | **4122** | | | |

The individual models are shown in the images below.

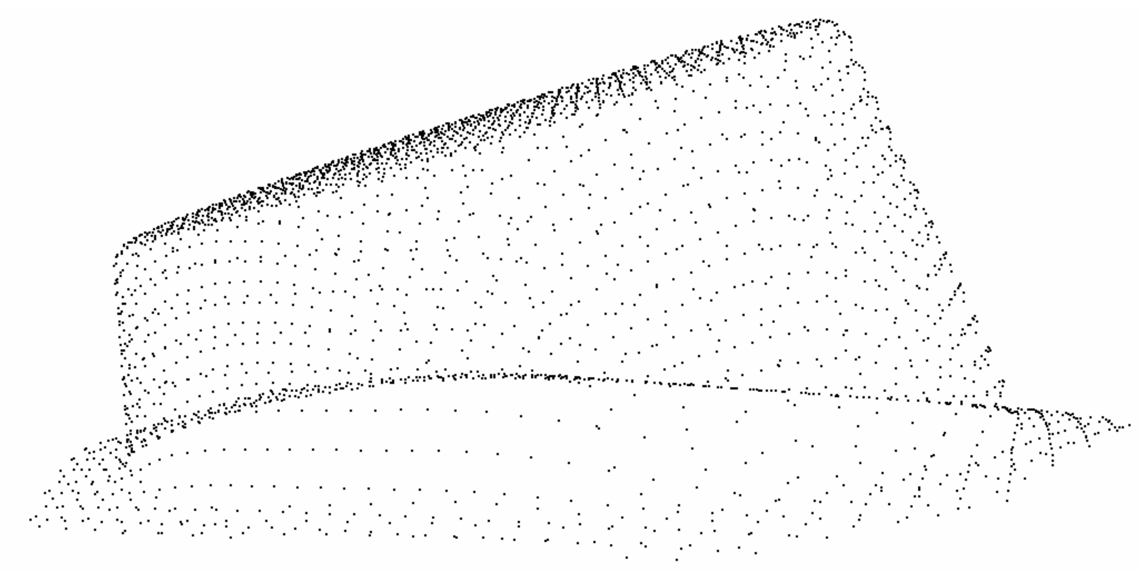


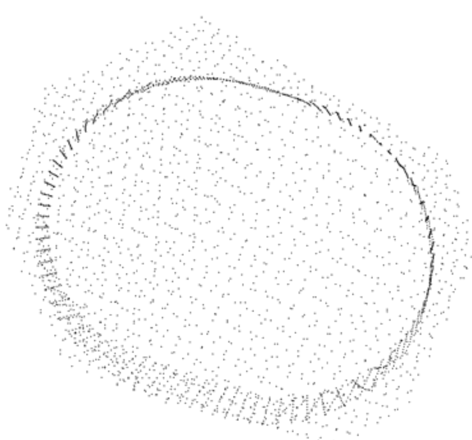


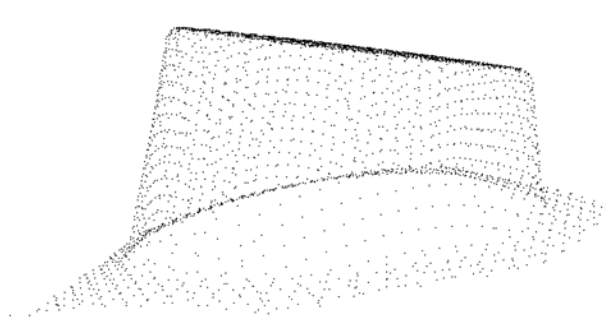




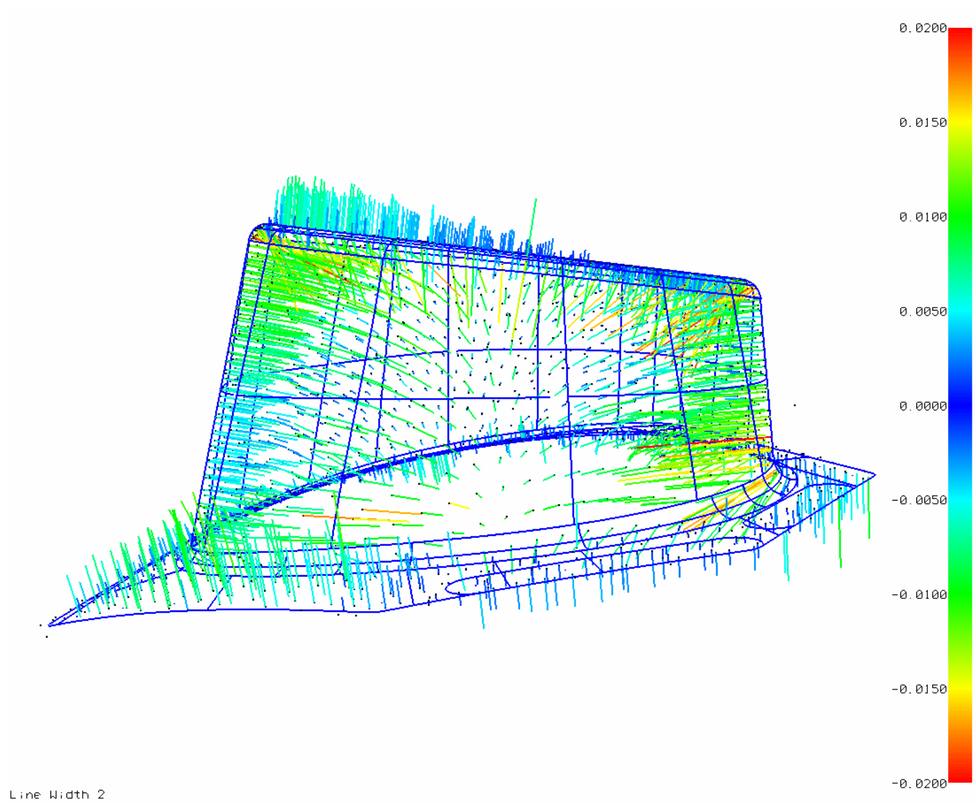
The combined model is shown below.

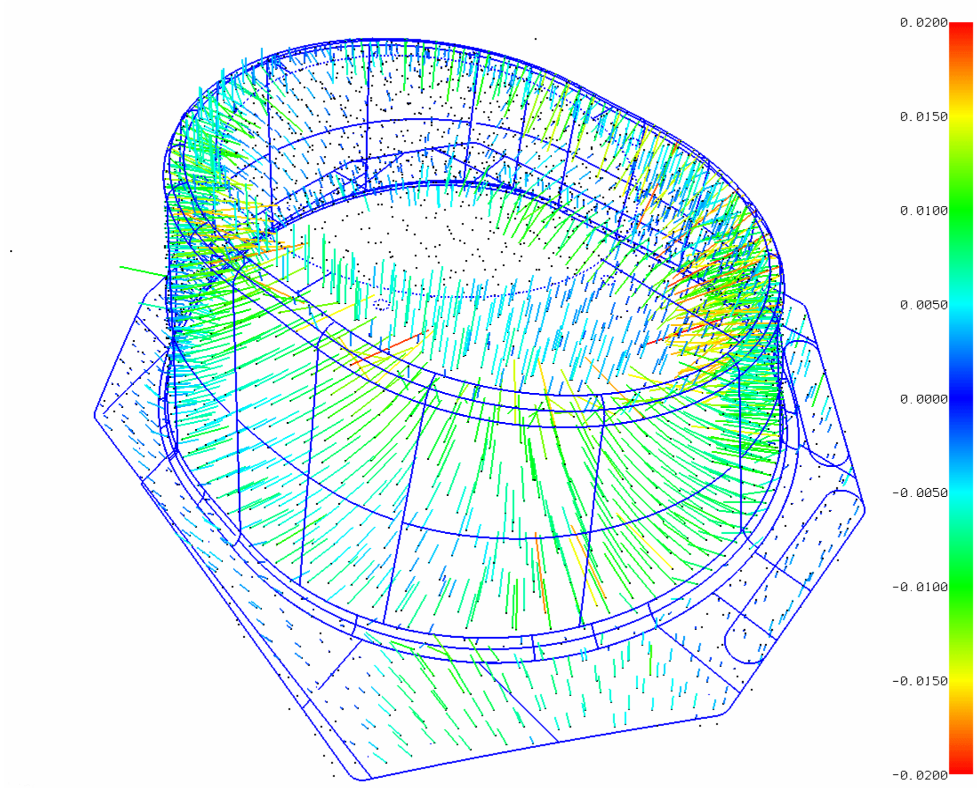


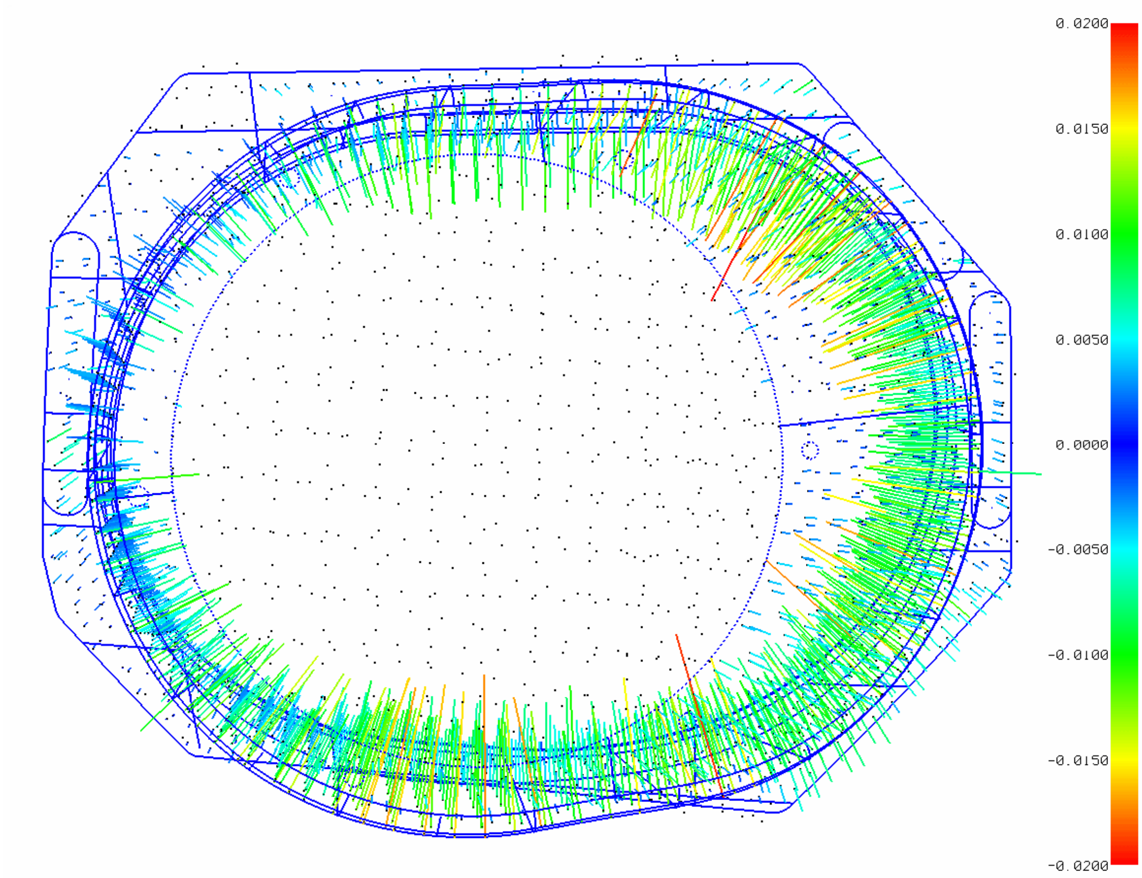




The final task was to measure the acquired surface data to the IGES model. This is shown below:






**Time Summary**

The following is an estimate of the time taken to complete the measurement.

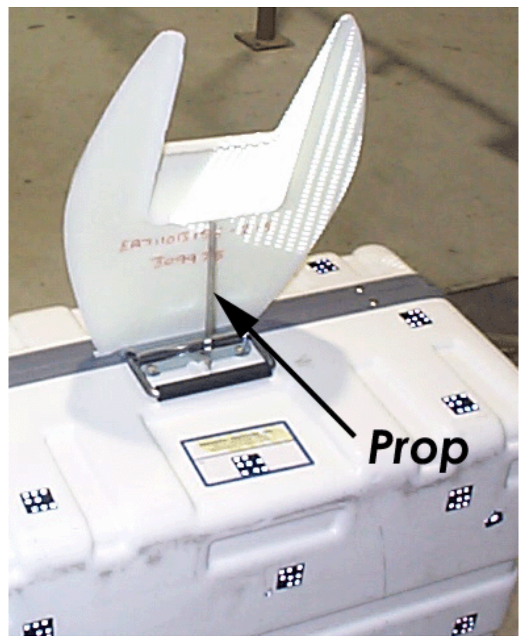
| | |
|---|---|
| Targeting | 2 minutes |
| Photography Part 1 | 3 minutes |
| Probing | 5 minutes |
| PRO-SPOT | 40 minutes (10 minutes per set-up) |
| Processing | 10 minutes |
| **Total** | **60 minutes** |

## Object 4 – EH101 Foam Inlet Piece

**Documentation:**
The following documentation is included in this report for this measurement.

- Coordinate data for the measured component.
- Comparison to IGES Model.

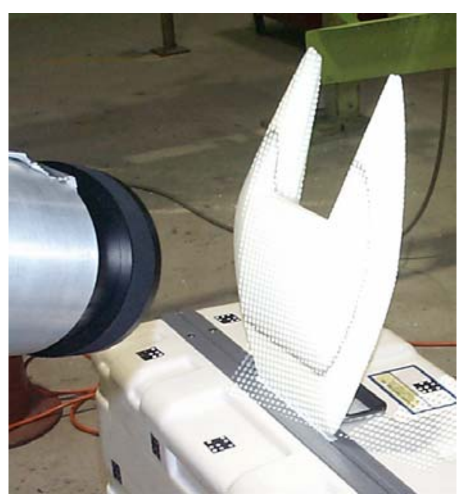
**Measurement Procedure:**




The following targeting was used
1. Projected targets from PRO-SPOT.
2. Coded targets around the case.
3. AutoBar.
4. Two scale Bars.

The measurement of this piece proved to be difficult due to its flimsy and porous nature. In order to capture the front and rear sides simultaneously it was necessary to prop the piece up as shown. This worked well apart from the fact that there were questions of the stability of the piece during the measurement.

In any case, it would be advisable to make future measurements in an enclosed room rather than on an open floor.



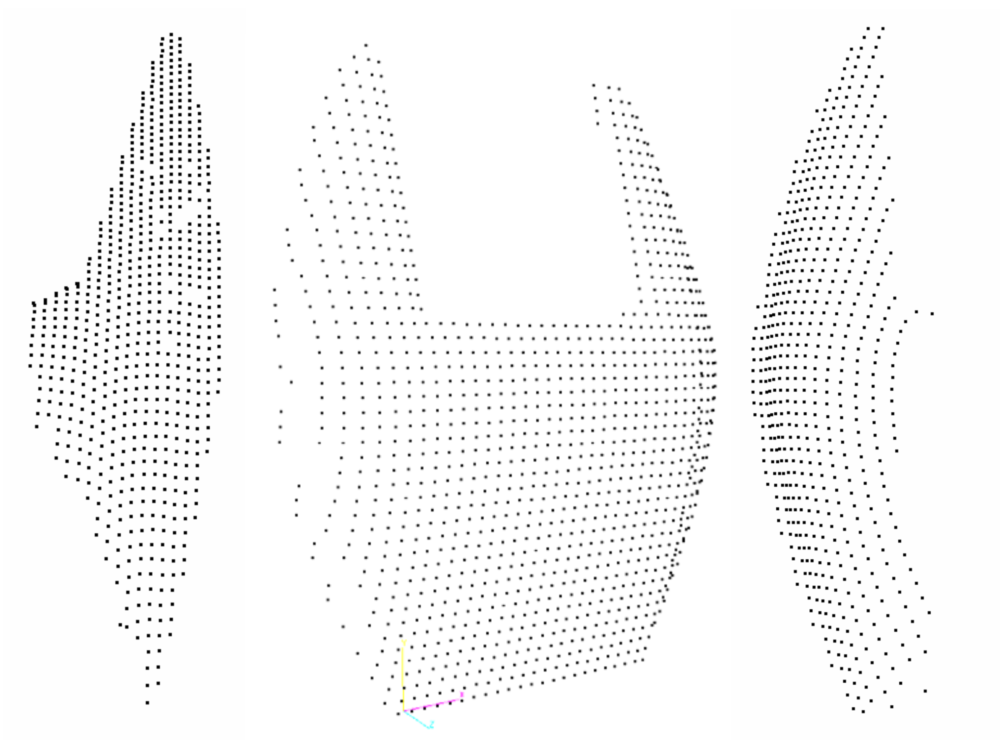
The measurement was completed in a very similar fashion to the GKN piece. In this instance due to the complex nature of the part it was covered in six set-ups.

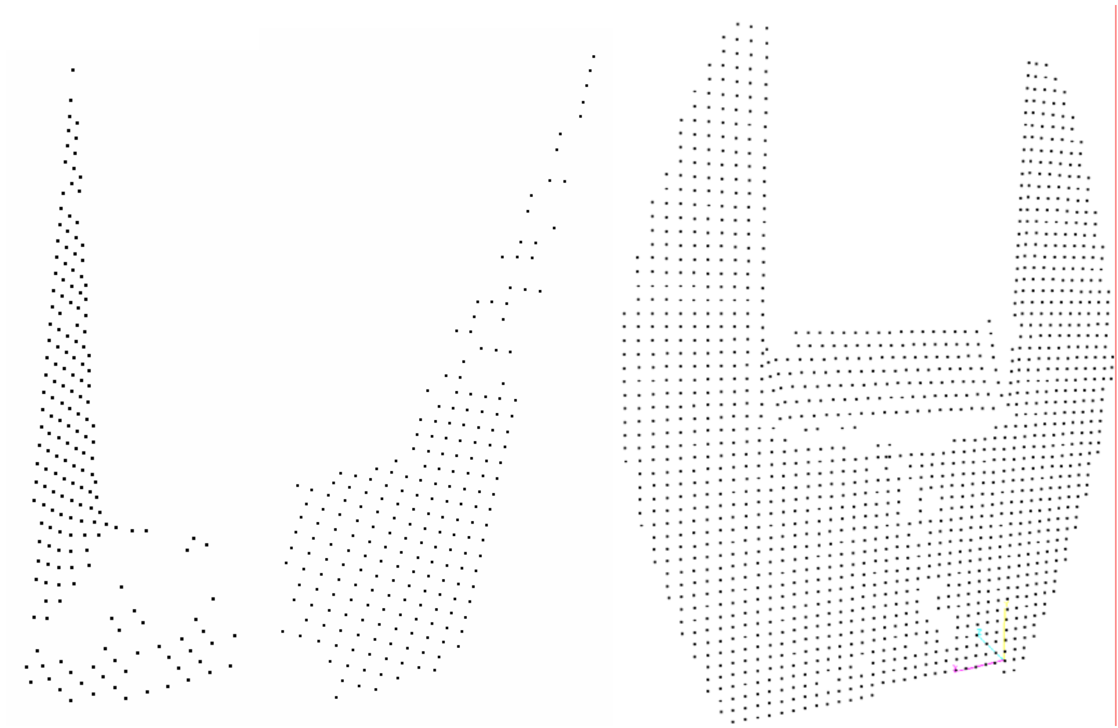
A sample of the target swath is shown here.

The results of the six networks are summarized in the following table

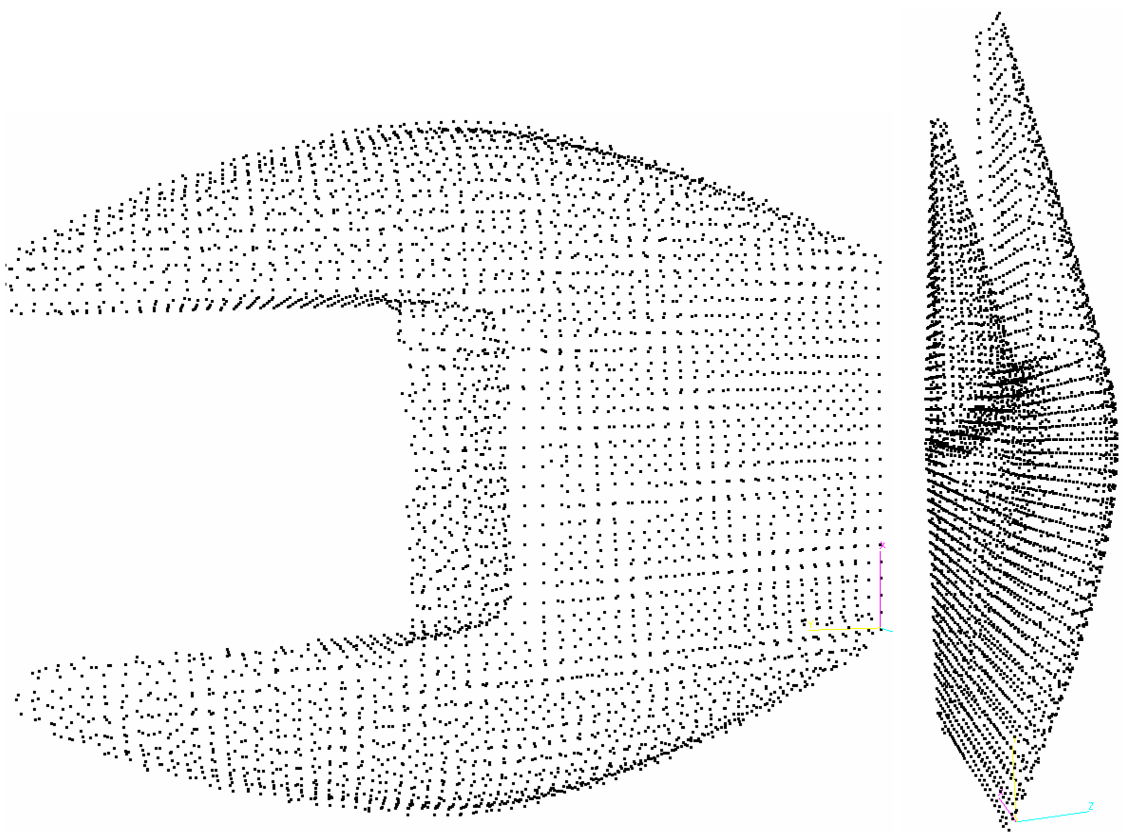
| Set-up | # of Points | X RMS(mm) | Y RMS(mm) | Z RMS(mm) |
|---|---|---|---|---|
| 1 | 1176 | 0.014 | 0.021 | 0.020 |
| 2 | 719 | 0.013 | 0.020 | 0.021 |
| 3 | 661 | 0.014 | 0.022 | 0.019 |
| 4 | 225 | 0.015 | 0.019 | 0.018 |
| 5 | 262 | 0.017 | 0.021 | 0.020 |
| 6 | 1607 | 0.014 | 0.020 | 0.021 |
| **Total** | **4650** | | | |

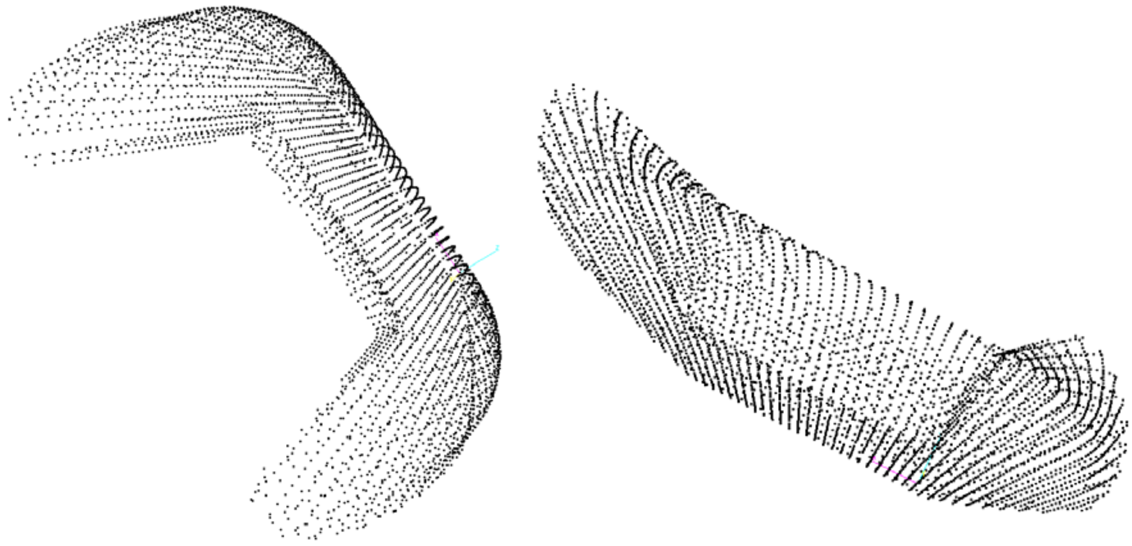
The six point clouds and the combined cloud are shown below.



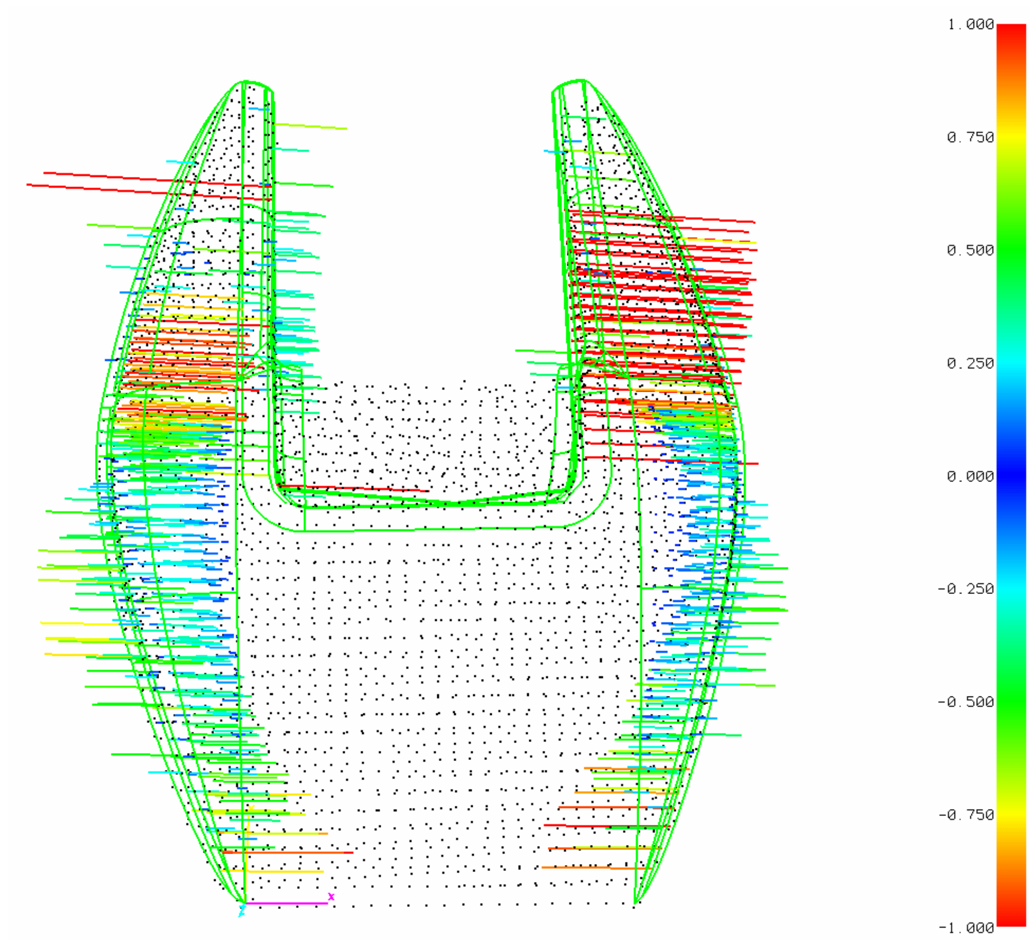


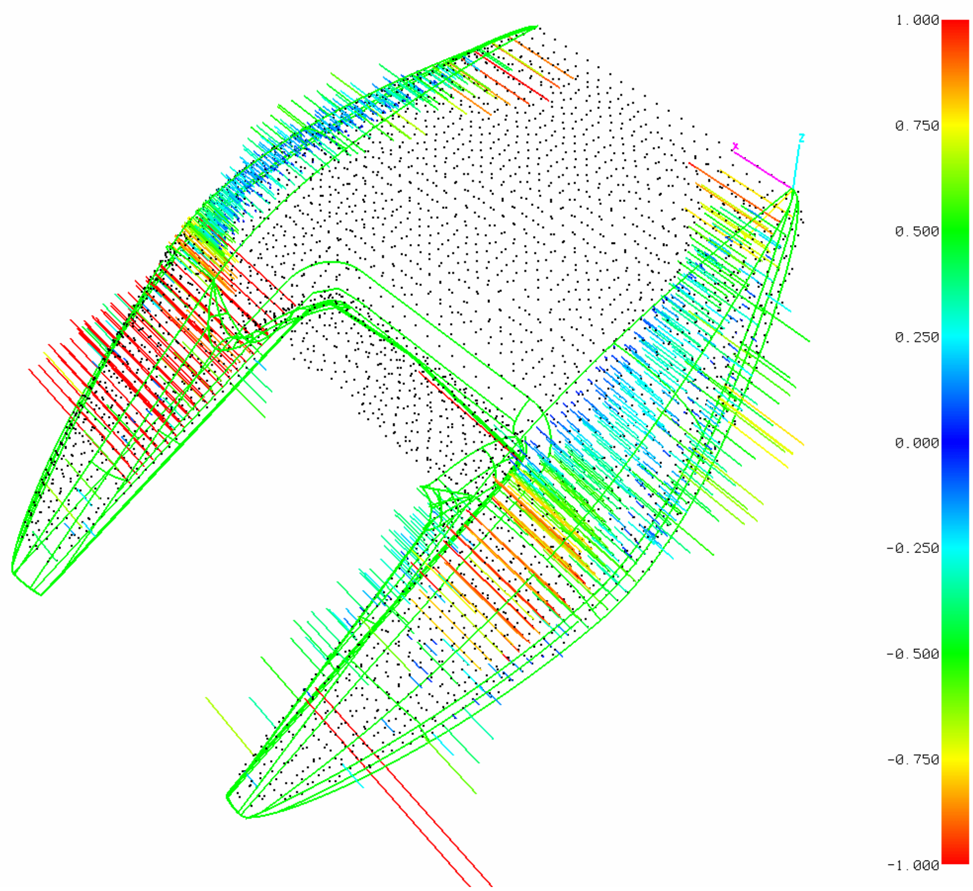
The combined model is seen below.





An axis alignment was completed in order to roughly align the points to the surface. Unfortunately no surface alignment was possible and the alignment had to be minimized manually by shifting the point cloud to minimize the surface deviations. The deviations are shown below.






**Time Summary**

The following is an estimate of the time taken to complete the measurement.

| | |
|---|---|
| Targeting | 2 minute |
| Photography Initial | 3 minutes |
| PRO-SPOT | 60 minutes (10 minutes per set-up) |
| Processing | 15 minutes |
| **Total** | **80 minutes** |

## PRO-SPOT 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*

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 measurements undertaken have shown that V-STARS and the PRO-SPOT target projector can be a very powerful measurement tools. The results of the measurements are very accurate and more importantly were produced quickly. The four object measured also demonstrate the measurement flexibility of V-STARS.