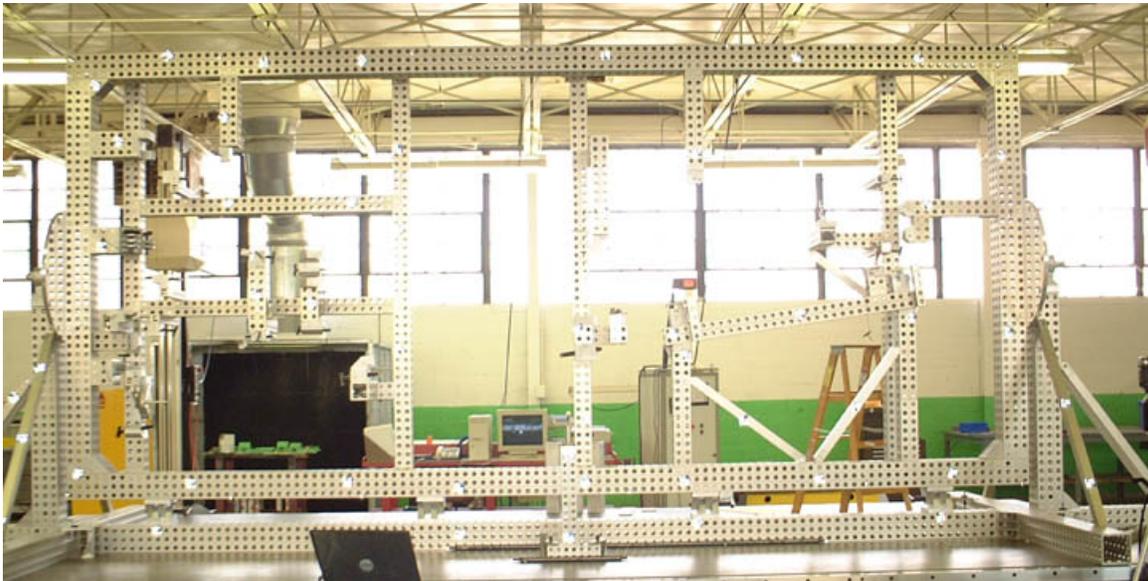




Paul W. Marino Gages Inc. V-STARS Demonstration

EXECUTIVE SUMMARY



- The fixture was completely inspected in less than four hours from start to finish.
- Interchangeable hand-held probes were used to measure the key pins and planes.
- Probed point accuracy was typically better than 0.025mm in XYZ.
- The Multi-camera system is portable and easily moved to overcome line of sight issues.
- Minimal disruption to production as acquisition is very fast.
- System can be used to complete off site inspection and verification of fixture.

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Introduction

The following report is a summary of the V-STARS work carried out at the Paul W. Marino Gages, Inc. facility in Warren, Michigan

One measurement was undertaken using the V-STARS metrology system.

The measurement involved the determination of the location of a number of details on a Tooling Fixture.



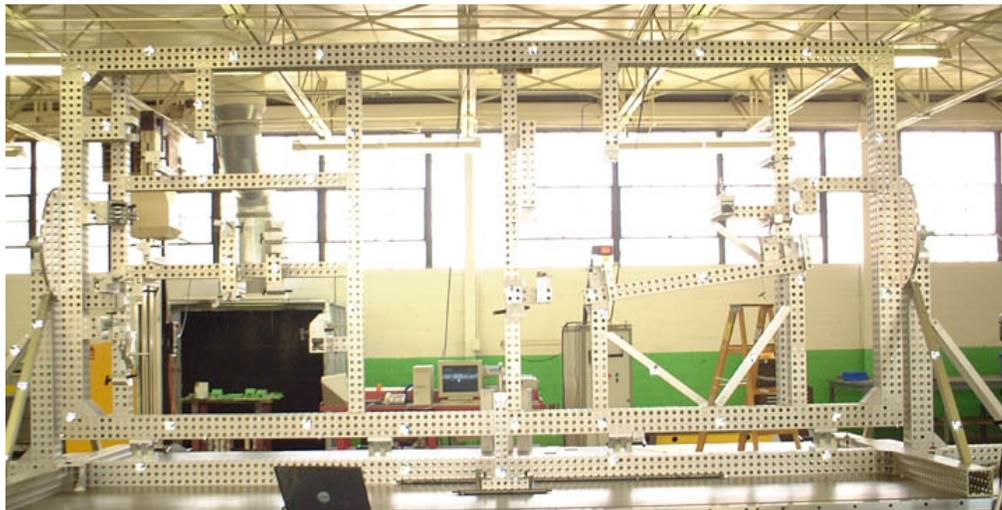
V-STARS with INCA camera.

The objective of the measurement is outline below in the requirements section.

Requirements

Tooling Fixture

1. Demonstrate camera use and object targeting.
2. Compute key circles, planes and other geometric information on Fixture Details.
3. Align fixture into its coordinate system using center points and a clocking location.
4. Compute deviations to supplied nominal data.
5. Compute geometric analysis of planes and lines on fixture details



Tooling Fixture Measured

Equipment Used

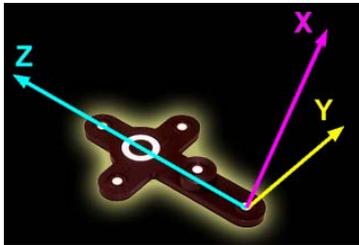
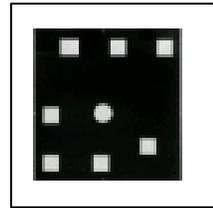
1. V-STARS S6 INCA Camera System
2. V-STARS M6 INCA Camera System
3. V-STARS Probes

Measurement Procedure

Targeting

In order to meet the measurement objectives outlined earlier it was necessary to target the object. 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. No suitable adapters were available so the datum points were probed.

To automate the measurement process it was necessary to add "coded" targets to the object. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photograph was taken. They also help tie the entire object into a uniform coordinate system. In the Multi Camera mode they are also used to determine the camera locations.



The initial coordinates system and approximate 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 resection 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.

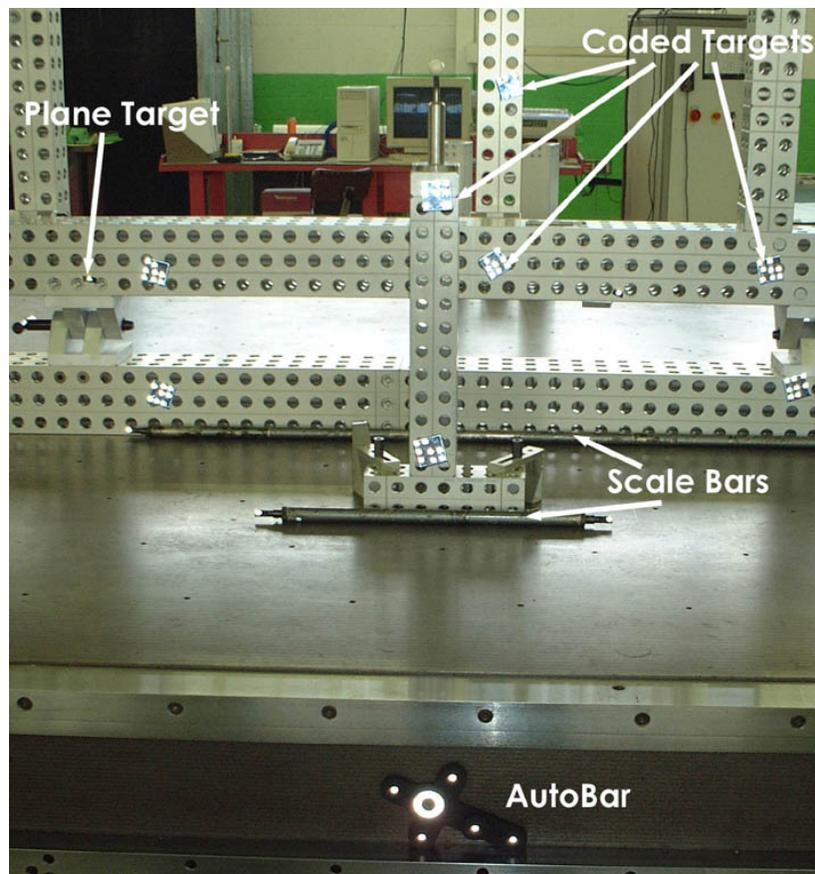
To scale a photogrammetric measurement, there must be at least one known distance. Normally this distance comes from a calibrated coded graphite scale bar or invar scale bar (Refer to adjacent image). Typically, multiple scales are used for redundancy. Two scale bars were used to complete each measurement.



Invar Scale Bar Kit

Scale bars made up of the same material as the Fixture are also popular as they have the same thermal expansion properties.

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



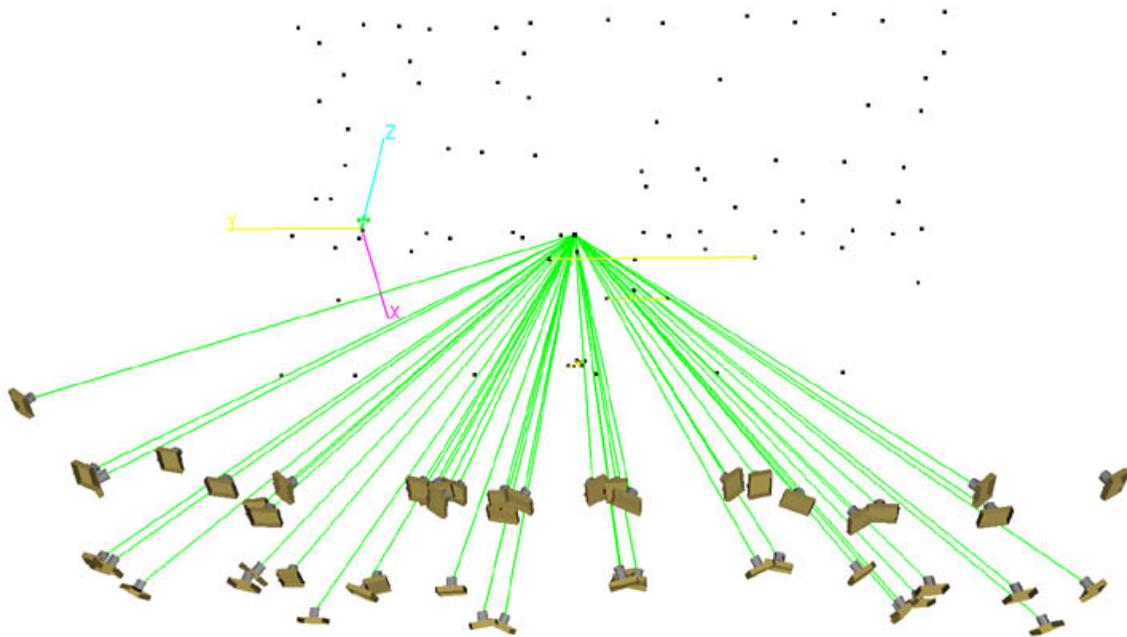
Targeting Used

1. AutoBar for initial coordinate system.
2. Coded targets to tie photography together.
3. Scale bars to scale the network.
4. Individual targets to define key clocking plane.

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 number of photos taken depends on the complexity of the measurement and accuracy requirements. In this measurement the photography was very straightforward.

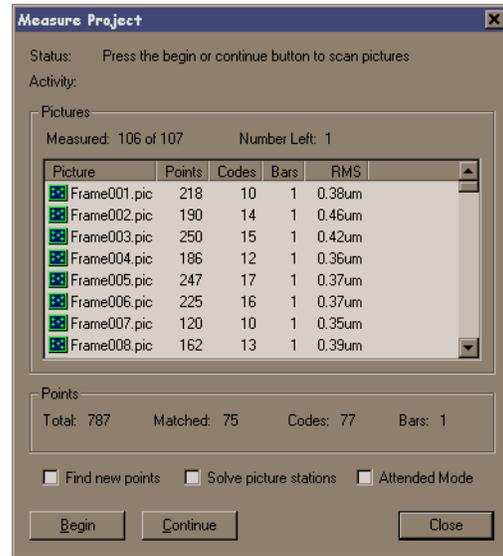
The geometry used to create the initial control for the measurement is illustrated in the image below. Also shown is an example of the rays of intersection to a point.



Processing

Once the photography has been completed the images are transferred to the system laptop. The images are stored on an IBM MicroDrive 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.



Typical AutoMeasure Dialog

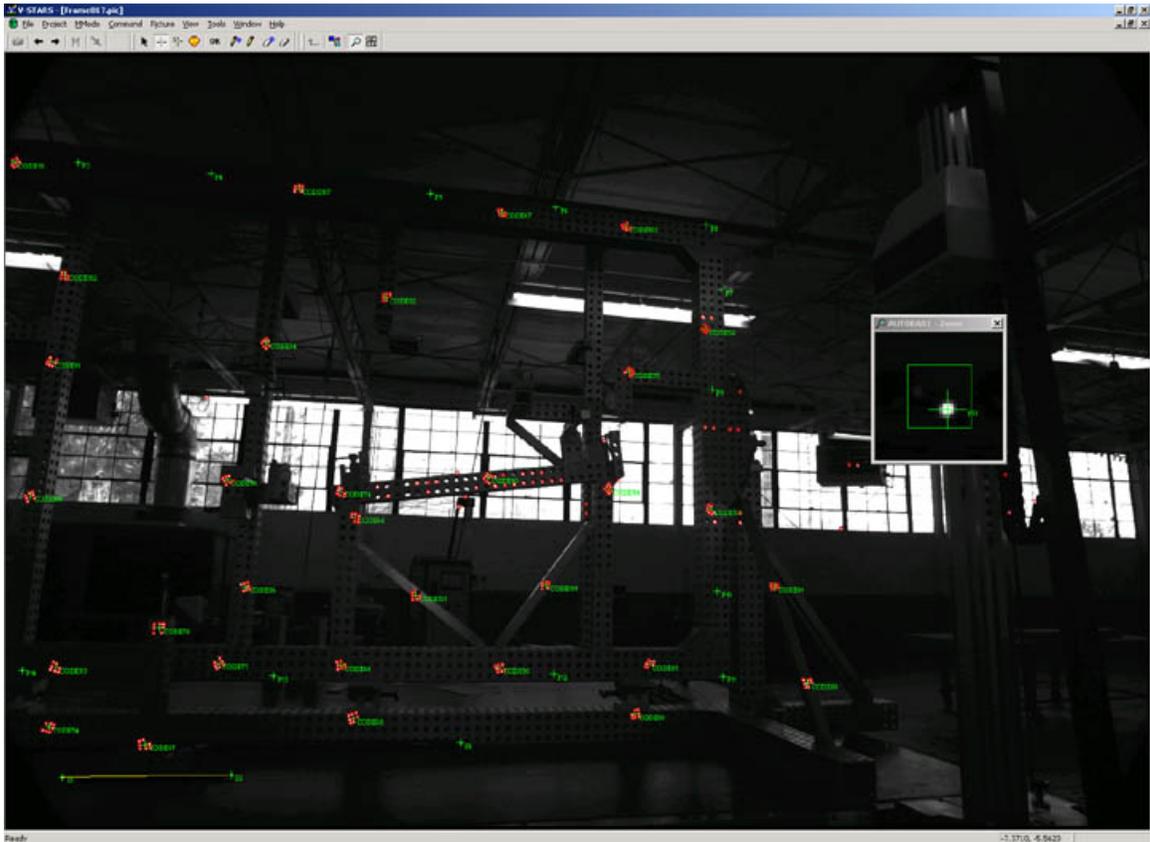
The AutoMeasure routine will assign random labels to the points it finds. These labels start with the key word "Target" followed by a number. If specific labeling is required the random labels can be easily changed to labels defined by the user. This is possible in both the picture view and the graphical 3D view.

Measurement Statistics

Initial Control Network

No. of photos	52
No. of points	86
Number of scale bars	2
Scale Agreement	0.025mm
Accuracy RMS X,Y,Z	X 0.011mm
	Y 0.011mm
	Z 0.021mm

Seen below is a typical measurement image.



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 ends.

At the conclusion of the AutoMeasure the 3D data is written to a file. A typical point listing from the 3D file is shown in the adjacent image

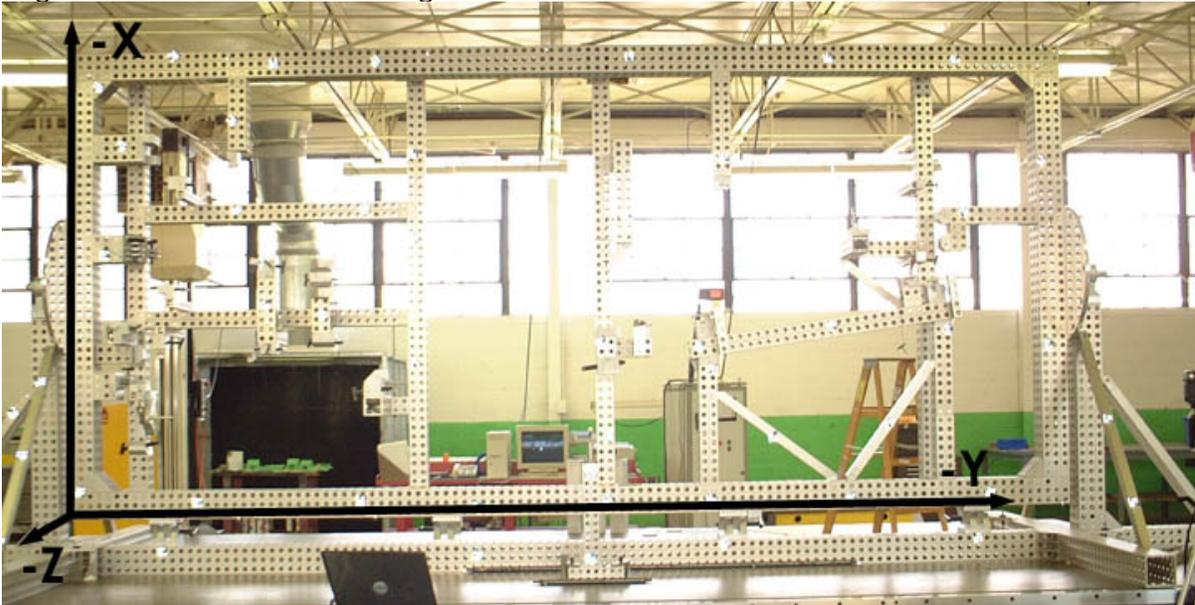
This point data can be analyzed within the V-STARS' SOLIDS module, easily exported to almost any CAD platform or other analysis program.

Point Label	X	Y	Z	Sigma X	Sigma Y	Sigma Z	Offset	Descr
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	0.0120	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	
SP1	-2.4124	0.0070	9.8901	0.0006	0.0002	0.0002	0.0000	
BS1	-2.3785	0.7996	-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	-6.4020	0.0002	0.0002	0.0002	0.0000	
CODE5	-1.8329	0.7115	-3.9801	0.0001	0.0001	0.0001	0.0000	
CODE6	-0.1947	-0.2348	-9.2510	0.0001	0.0001	0.0001	0.0000	
CODE7	-2.8924	-0.7821	2.8637	0.0001	0.0000	0.0001	0.0000	
CODE8	-12.2461	6.7397	-1.6250	0.0003	0.0001	0.0001	0.0000	
CODE9	-2.7518	4.0206	3.8968	0.0003	0.0003	0.0001	0.0000	
CODE10	0.3867	1.7769	-5.9284	0.0002	0.0001	0.0001	0.0000	
CODE11	-1.5466	4.0768	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	3.7495	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	5.0040	0.0002	0.0001	0.0001	0.0000	
CODE23	-13.6038	5.7645	4.1814	0.0003	0.0001	0.0001	0.0000	

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 measurement, the fixture was aligned using an axis alignment. The alignment is shown in the image below.



The fixture was also re-aligned using the feature data that was determined. This changed the alignment points as follows:

Point	ORIGINAL			AFTER ALIGNMENT			DIFFERENCES		
	X	Y	Z	X	Y	Z	Delta X	Delta Y	Delta Z
ORIGIN	0.000	0.000	-150.000	0.055	0.241	-150.140	-0.055	-0.241	0.140
AXIS	0.000	-5450.030	-150.000	0.095	-5449.789	-150.037	-0.095	-0.241	0.037
PLANE	2486.910	-14.489	-150.000	2486.965	-14.316	-150.262	-0.055	-0.173	0.262

The results of both these alignments to the nominal data is tabulated in the results spreadsheet.

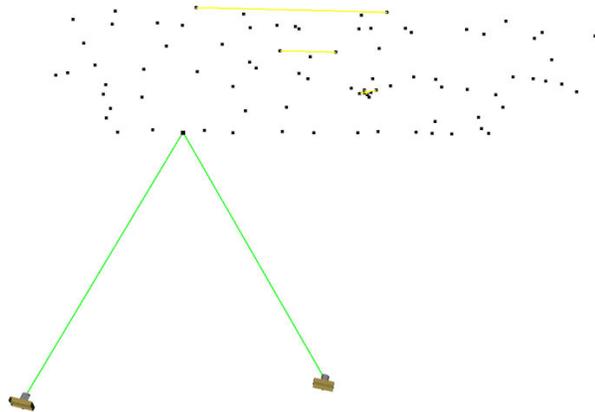
Point Probing – M-Mode

In order to establish the location of the key pins and planes 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. Sixteen different probes, each of which uses standard interchangeable CMM tips are available.



The probes themselves are interchangeable during a measurement. If the probe is changed, V-STARs automatically recognizes the new 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.

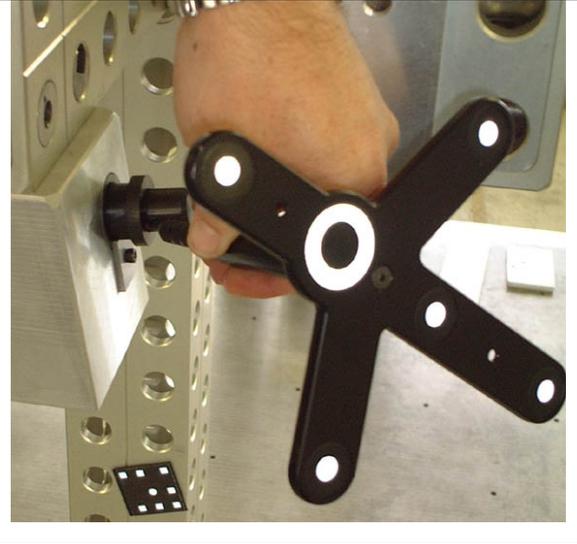
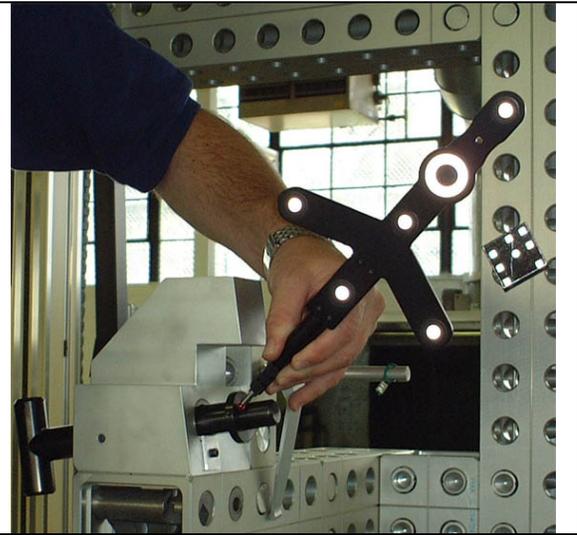
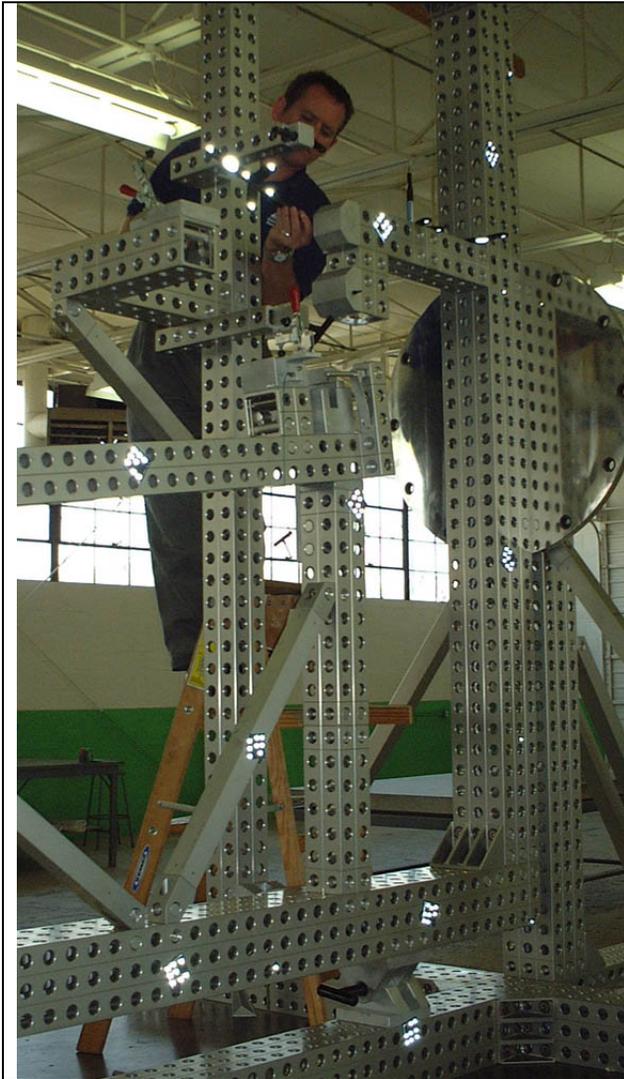
To work in M-Mode a coordinated reference frame is required. This reference frame is used to determine the location of the cameras after each flash. Fortunately no additional work is required to establish this reference as it was established during the initial single camera network.



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. Typical M-mode geometry is shown in the image above.

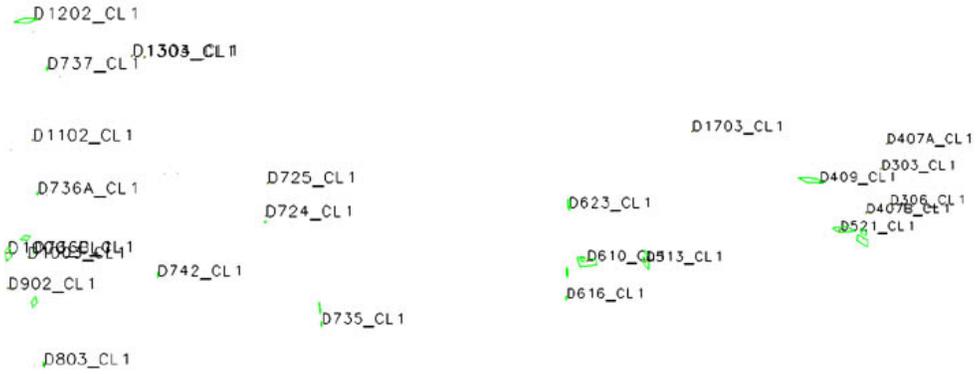
Once collection has been completed in a particular area, the cameras are simply relocated into the next measurement location. Re-establishment into the coordinate system is completed automatically.

The probing process is shown in the images below.

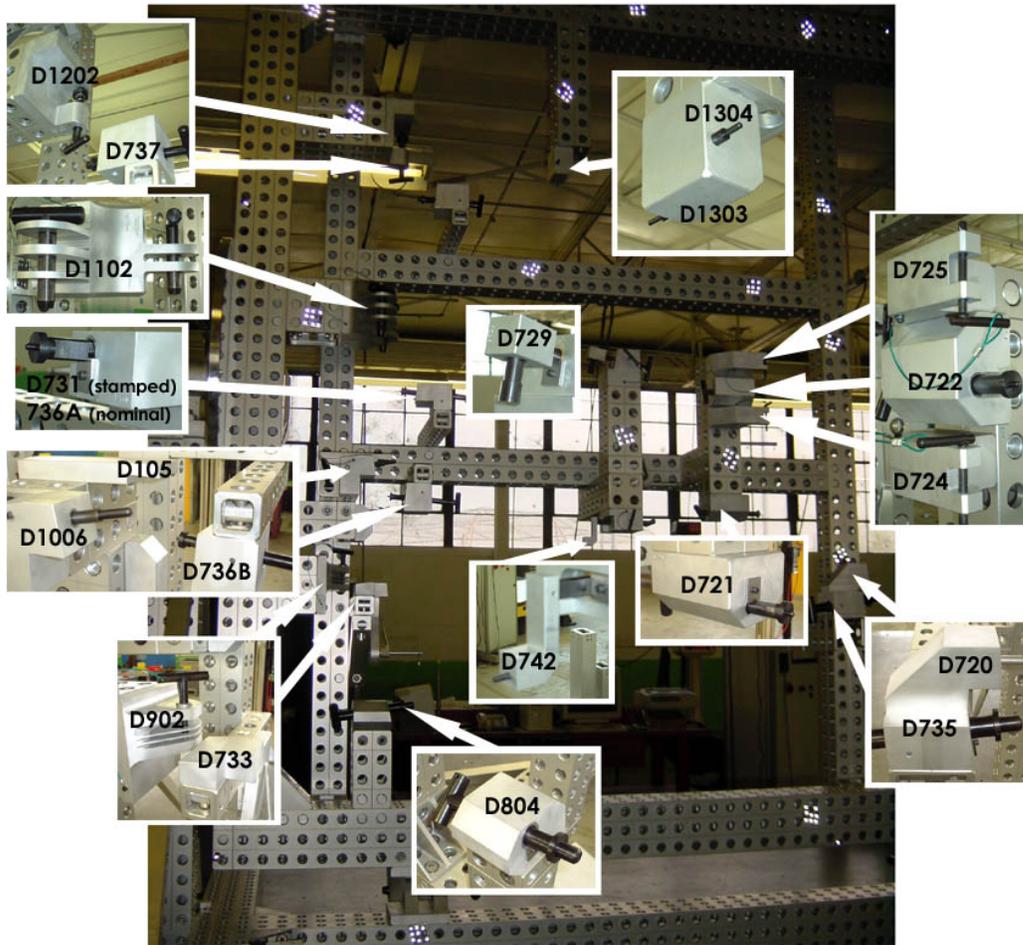


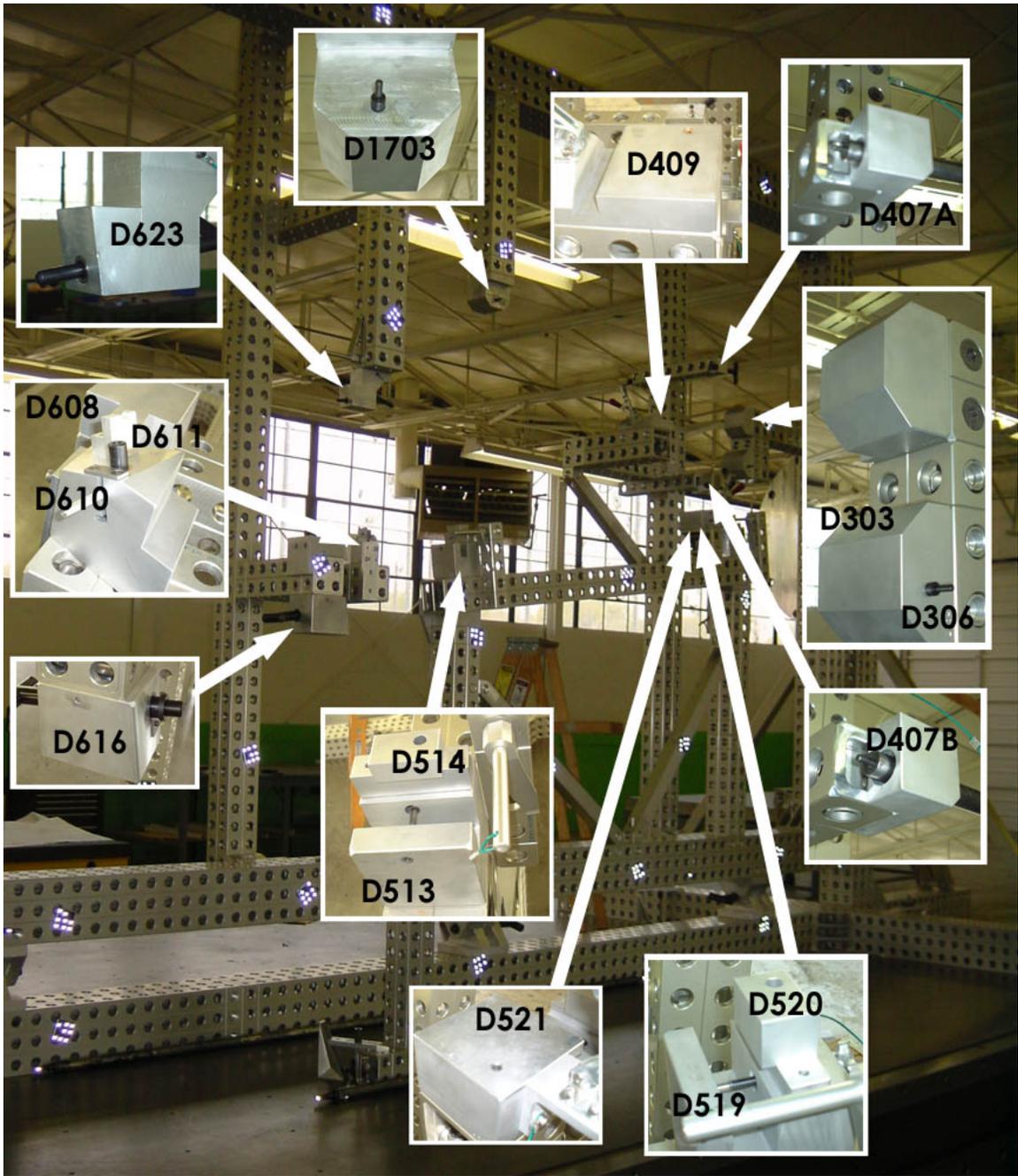
Numbering Guide

Individual points on the key planes and pins were named based on the supplied nominal file. This nominal file is shown below:



The following images show the locations of the features measured and their assigned label.





Analysis

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 written to the 3D 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 reports the results of the operation.

Similarly, best-fit lines, circles, cylinders, spheres, parabolas, 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.

These tools were used to compute the various pin centers, center lines and key planes.

Label	Residuals
+ CODE118	0.0017
+ NUGGET118_1	0.0004
+ NUGGET118_9	0.0001
+ NUGGET118_14	0.0011

Typical Plane Dialog

Results

The results of the measurement are summarized in the supplied spreadsheet.

Time Summary

Control Targeting	10 minutes
Control Photography	5 minutes
Control Processing	5 minutes
Point Probing	150 minutes
Analysis	50 minutes
Total	220 minutes

Concluding Remarks

The measurement undertaken has shown that V-STARS with the INCA S6/M6 system can be a very powerful measurement tool. The results of the measurement undertaken were very accurate and more importantly were produced quickly.

GSI would like to thank Paul W. Marino Gages, Inc. for welcoming us into their Warren facility. We will be happy to discuss the results of this report or any other aspect of the technology presented.