

## Report on demonstration of V-STARS for Northrop Grumman- Stuart, FL

### Introduction:

The following report is a summary of the V-STARS work carried out at the Northrop Grumman facility in Stuart, FL. As part of the demonstration one object was measured. The object measured was a 777 flap tool.

The primary objectives of the measurement were to determine the location of alignment points on the jig and to also check a number of other features and points.



This report summarizes the results of the measurements while also providing information on how V-STARS was used to meet the measurement requirements.

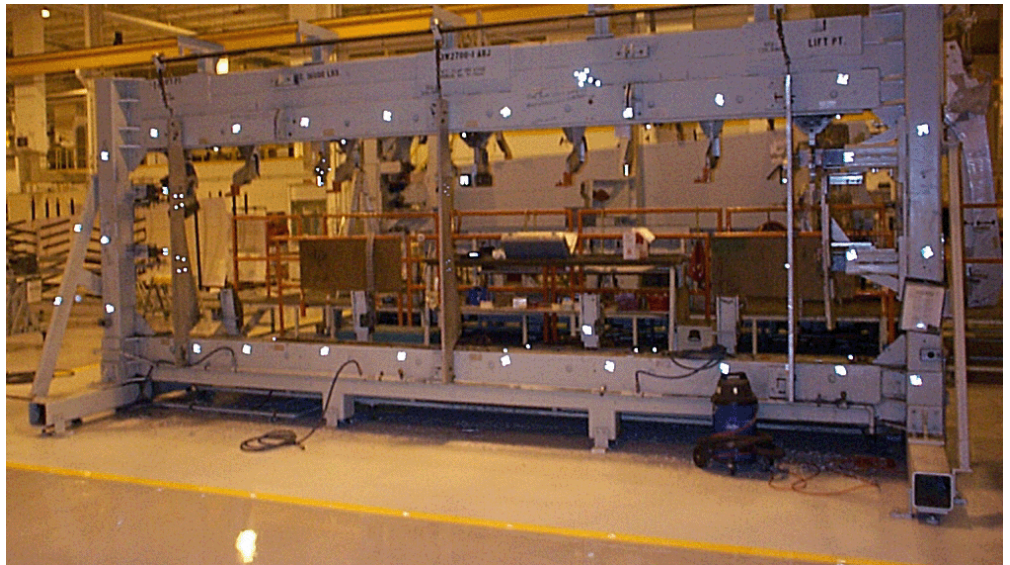
### Primary Measurement Requirements:

- Measure alignment points
- Align to aircraft coordinate system
- Check the location of slots, contour boards, station values and other features.

### Documentation:

The following documentation is included in this report.

- A report outlining methodology and results.
- XYZ data for the measured component.



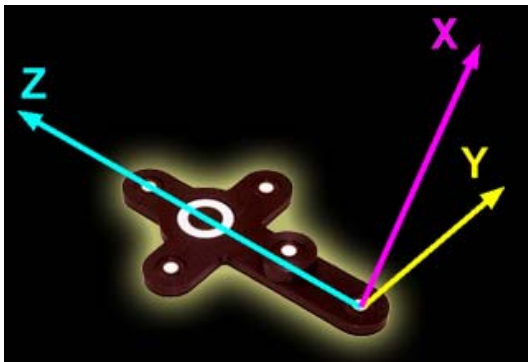
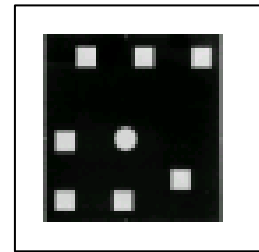
## Measurement Procedure:

### 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, 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 used to adapt the targets from the standard 0.250" to the 0.325" and 0.500" hole sizes.

Due to the variability of the features measured it was necessary to improvise on some of the targeting. For example, where no target was available at the correct offset a local plane was created and the point vectored to the correct offset. For a genuine period inspection program it would be advisable to have a collection of special targeting to meet the measurement objectives.

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

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. 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. As this was only a demonstration no scale distance was used in this measurement.



## 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. Due to the absence of the correct targeting and the need to measure points on both sides of the jig it was necessary to dramatically increase the number of images taken.

A total of 175 photographs were taken of the jig. The number of photos taken depends on the complexity of the measurement and accuracy requirements. With planning and correct targeting this number could probably be reduced to 100 photographs.

The photography for the jig was completed in approximately 20 minutes. Camera station locations for the measurement are shown in the adjacent diagram.

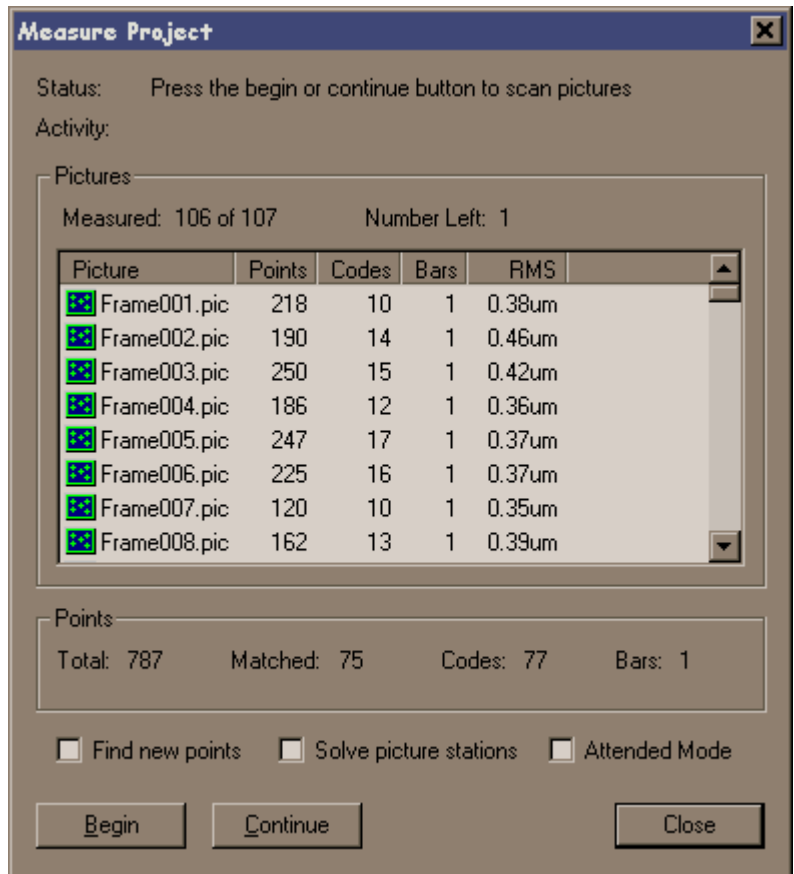


### Processing

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.

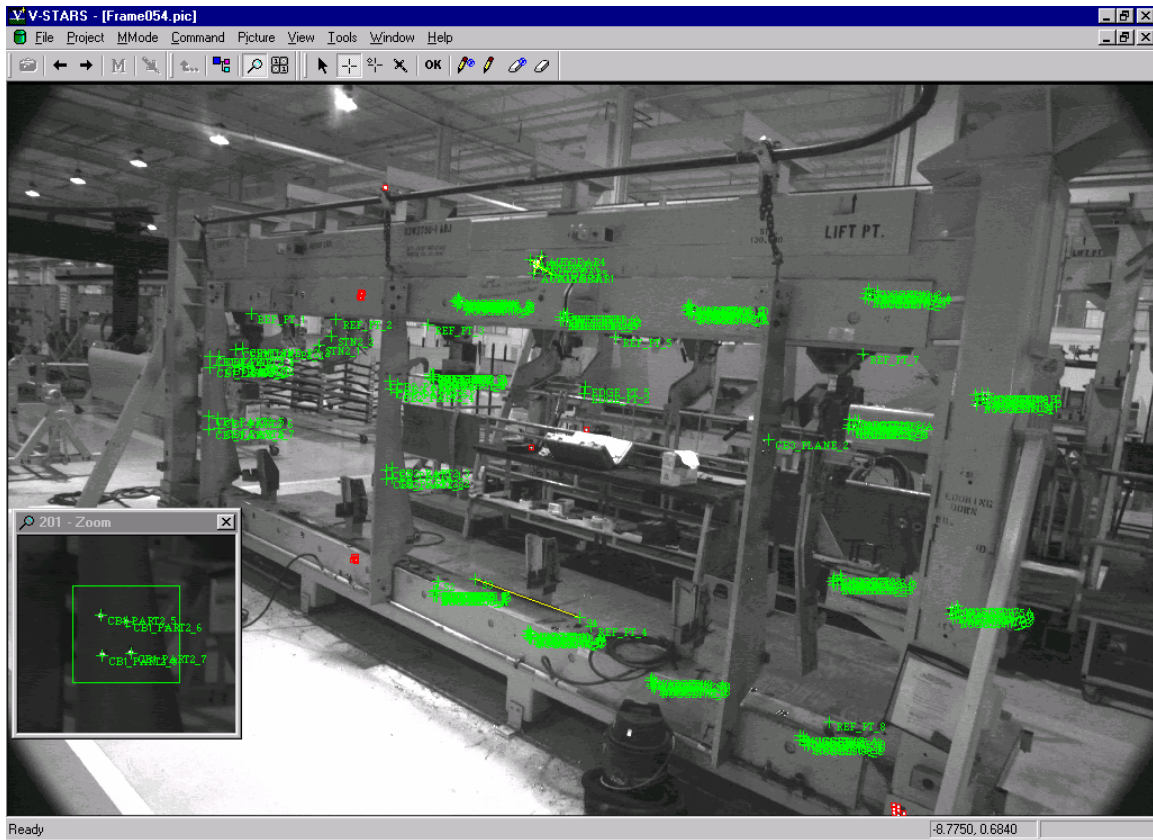
Almost all of the measurement process is automated. The images are processed and the coordinates extracted by the "AutoMeasure" command. A typical AutoMeasure dialog box is shown on the right. The AutoMeasure command will open each of the images, determine the camera location, find new target points 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 necessary to relabel 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    |   | 175     |
| No of points    |   | 790     |
| No of scales    |   | 4       |
| Scale Agreement |   | 0.0018" |
| RMS(") X,Y,Z    | X | 0.0007  |
|                 | Y | 0.0006  |
|                 | Z | 0.0006  |



A typical point listing is shown below.

| 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    | 0.0128   | 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 |       |
| CODE23      | 12.5028  | 5.7412  | 6.1816  | 0.0003  | 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.

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 images.

**Plane Parameters**

Name:

A: -0.0008  
 B: -0.0039  
 C: 1.0000  
 D: 16.3405

Rejection Limit: 0.0040  
 Final RMS: 0.0011  
 Points Accepted: 8  
 Points Rejected: 0

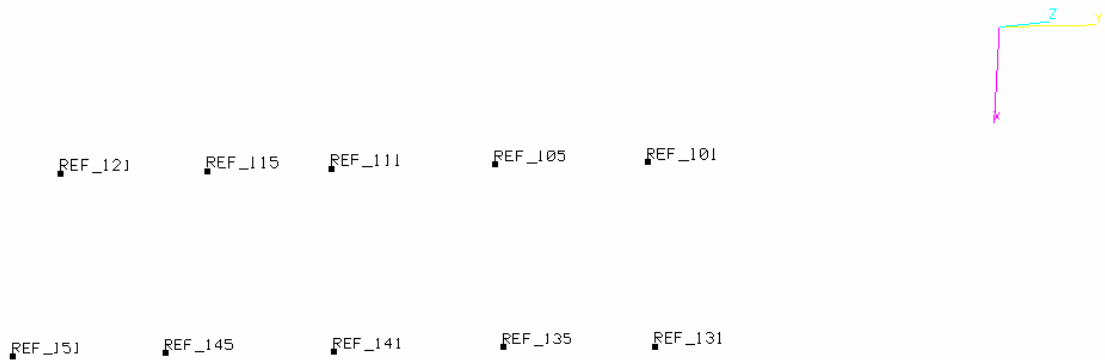
Create Template      Offset:

| Label        | Residuals |
|--------------|-----------|
| CODE118      | 0.0017    |
| NUGGET118_1  | 0.0004    |
| NUGGET118_9  | 0.0001    |
| NUGGET118_14 | 0.0011    |

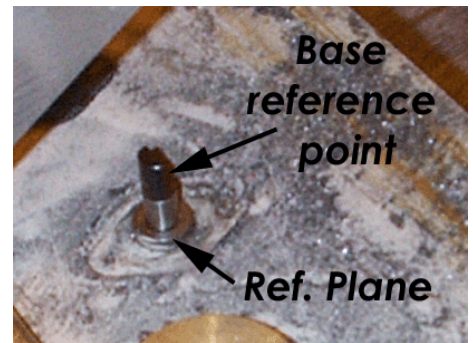
OK      Cancel

## Alignment:

A total of ten points were used to transfer the data from the arbitrary AutoBar coordinate system to that of the aircraft coordinate system. These are shown in the image below:



Prior to completing this transformation it was necessary to compute the equivalent point in the V-STARS data. As mentioned earlier this was due to the correct targets not being available at the time of the survey. For the reference points located at the top of the tool it was a matter of creating a vector point to the correct offset. For the reference points at the base of the tool it was necessary to create a reference plane and then vector a point to the 0.5" offset.



The results of the alignment are shown below.

| Label   | DX      | DY      | DZ      | Total  |
|---------|---------|---------|---------|--------|
| REF_115 | 0.0004  | -0.0141 | -0.0060 | 0.0153 |
| REF_101 | 0.0018  | 0.0013  | 0.0041  | 0.0047 |
| REF_105 | -0.0014 | -0.0041 | -0.0018 | 0.0047 |
| REF_111 | -0.0000 | 0.0083  | -0.0007 | 0.0083 |
| REF_121 | 0.0010  | -0.0068 | -0.0017 | 0.0071 |
| REF_131 | 0.0018  | -0.0035 | -0.0017 | 0.0043 |
| REF_135 | -0.0021 | -0.0052 | -0.0016 | 0.0058 |
| REF_141 | -0.0013 | 0.0044  | 0.0010  | 0.0047 |
| REF_145 | -0.0001 | 0.0016  | 0.0012  | 0.0020 |
| REF_151 | 0.0003  | 0.0040  | 0.0012  | 0.0041 |

RMS of Residuals  
X: 0.0013 Y: 0.0048 Z: 0.0019 Total: 0.0054

The point REF\_115 was rejected during the transformation. This is no doubt due to the high residual of the Y coordinate. The X and Z coordinates display very good agreement with the stamped data.





| Feature   | V-STARS |          |   | Nominal |          |   | Delta  |   |   | Description |
|-----------|---------|----------|---|---------|----------|---|--------|---|---|-------------|
|           | X       | Y        | Z | X       | Y        | Z | X      | Y | Z |             |
| LE_2_X    | 53.449  |          |   |         |          |   |        |   |   | Lead edge 2 |
| LE_2_X    | 53.447  |          |   |         |          |   |        |   |   | Lead edge 2 |
| LE_2_Y    |         | -175.980 |   |         | -176.000 |   | 0.020  |   |   | Lead edge 2 |
| LE_2_Y    |         | -175.959 |   |         | -176.000 |   | 0.041  |   |   | Lead edge 2 |
| LE_2_Y    |         | -175.976 |   |         | -176.000 |   | 0.024  |   |   | Lead edge 2 |
| LE_2_Y    |         | -175.947 |   |         | -176.000 |   | 0.053  |   |   | Lead edge 2 |
| LE_2_Y    |         | -175.966 |   |         | -176.000 |   | 0.034  |   |   | Lead edge 2 |
| CB = -228 |         | -227.998 |   |         | -228.000 |   | 0.002  |   |   | Con Board   |
| CB = -228 |         | -227.996 |   |         | -228.000 |   | 0.004  |   |   | Con Board   |
| CB = -228 |         | -227.998 |   |         | -228.000 |   | 0.002  |   |   | Con Board   |
| CB = -228 |         | -227.999 |   |         | -228.000 |   | 0.001  |   |   | Con Board   |
| CB = -228 |         | -228.001 |   |         | -228.000 |   | 0.000  |   |   | Con Board   |
| CB = -228 |         | -227.998 |   |         | -228.000 |   | 0.002  |   |   | Con Board   |
| CB = -228 |         | -228.000 |   |         | -228.000 |   | 0.000  |   |   | Con Board   |
| CB = -228 |         | -227.999 |   |         | -228.000 |   | 0.001  |   |   | Con Board   |
| 969       |         | -229.997 |   |         | -230.000 |   | 0.003  |   |   | Point       |
| 221       |         | -230.000 |   |         | -230.000 |   | 0.000  |   |   | Point       |
| STN2_1    |         | -277.917 |   |         | -278.000 |   | 0.083  |   |   | STN Point   |
| STN2_2    |         | -277.928 |   |         | -278.000 |   | 0.072  |   |   | STN Point   |
| STN2_3    |         | -277.891 |   |         | -278.000 |   | 0.110  |   |   | STN Point   |
| STN2_4    |         | -277.913 |   |         | -278.000 |   | 0.087  |   |   | STN Point   |
| STN2_5    |         | -277.924 |   |         | -278.000 |   | 0.076  |   |   | STN Point   |
| CB = -329 |         | -328.989 |   |         | -329.000 |   | 0.011  |   |   | Con Board   |
| CB = -329 |         | -328.997 |   |         | -329.000 |   | 0.003  |   |   | Con Board   |
| CB = -329 |         | -328.999 |   |         | -329.000 |   | 0.001  |   |   | Con Board   |
| CB = -329 |         | -328.996 |   |         | -329.000 |   | 0.004  |   |   | Con Board   |
| CB = -329 |         | -328.999 |   |         | -329.000 |   | 0.001  |   |   | Con Board   |
| CB = -329 |         | -328.997 |   |         | -329.000 |   | 0.003  |   |   | Con Board   |
| CB = -329 |         | -329.005 |   |         | -329.000 |   | -0.005 |   |   | Con Board   |
| CB = -329 |         | -329.000 |   |         | -329.000 |   | 0.000  |   |   | Con Board   |
| CB = -329 |         | -329.000 |   |         | -329.000 |   | 0.000  |   |   | Con Board   |
| CB = -329 |         | -329.002 |   |         | -329.000 |   | -0.002 |   |   | Con Board   |
| CB = -329 |         | -328.999 |   |         | -329.000 |   | 0.001  |   |   | Con Board   |
| CB = -328 |         | -327.998 |   |         | -328.000 |   | 0.002  |   |   | Con Board   |
| CB = -328 |         | -327.993 |   |         | -328.000 |   | 0.007  |   |   | Con Board   |
| CB = -328 |         | -327.997 |   |         | -328.000 |   | 0.003  |   |   | Con Board   |
| CB = -328 |         | -327.992 |   |         | -328.000 |   | 0.008  |   |   | Con Board   |
| CB = -328 |         | -327.994 |   |         | -328.000 |   | 0.006  |   |   | Con Board   |
| CB = -328 |         | -327.988 |   |         | -328.000 |   | 0.012  |   |   | Con Board   |
| CB = -328 |         | -327.988 |   |         | -328.000 |   | 0.012  |   |   | Con Board   |
| CB = -328 |         | -327.992 |   |         | -328.000 |   | 0.008  |   |   | Con Board   |

| Feature   | V-STARS |          |       | Nominal |          |       | Delta  |   |       | Description   |
|-----------|---------|----------|-------|---------|----------|-------|--------|---|-------|---------------|
|           | X       | Y        | Z     | X       | Y        | Z     | X      | Y | Z     |               |
| CB = -328 | 100.006 | -328.231 |       | 100.000 |          | 0.006 |        |   |       | CB Tool Point |
| CB = -328 | 100.825 | -329.003 |       |         | -329.000 |       | -0.003 |   |       | CB Tool Point |
| 511       |         | -340.984 |       |         | -340.985 |       | 0.002  |   |       | Point         |
| 525       |         | -338.884 |       |         | -338.520 |       | -0.364 |   |       | Point         |
| 523       | 53.704  | -338.520 | 1.211 | 53.701  | -338.520 | 1.200 | 0.003  |   | 0.011 | Centerline    |

### Concluding Remarks:

The measurement of this piece has demonstrated that V-STARS can be a very powerful measurement tool for objects such as jigs and other production tooling. 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.

GSI would like to thank Northrop Grumman for welcoming us into their facility. We will be happy to discuss the results of this report or any other aspect of the technology presented.