DIGITAL IMAGE PHOTOGRAMMETRY

FINAL REPORT

GULF COAST REGION MARITIME TECHNOLOGY CENTER

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by

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ABSTRACT

A problem in modular shipbuilding is the lack of a reliable and quick method of obtaining and utilizing dimensional control in 3D . Photogrammetry has been successfully used as a tool for this application, but because of the large number of systematic errors associated with film-based cameras only very large shipyards have attempted this. Recently, developments in Charge Coupled Device (CCD) imaging arrays for cameras have allowed some success in applying photogrammetric techniques *without film* in dimensional control. The software and hardware configurations have been expensive and complicated. Digital camera systems and computers were purchased and programmed to tie existing *inexpensive* software packages with Geometric Dilution of Control (GDOP) error propagation analysis originally designed for topographic mapping into a tool for production shipyard fabrication dimensional control.

Five separate digital photogrammetry applications were initiated (the first three were at Avondale Shipyards) consisting of:

1.) Shell Bolster Model. Photographs were taken of a scale model at Avondale and checked at the University of New Orleans (UNO). Images were imported to the Desktop Mapping System (**DMS**®) mensuration software. Photogrammetric analysis was performed using **PC GIANT**© software. The GDOP error analysis results appeared good, but initial reaction by Avondale personnel indicated that discrepancies existed. It was discovered that the discrepancies were due to the poor identification of the pin-prick targets utilized.

2.) Double Hull Mid-body Tanker Section. Plans were made to use the digital camera system in providing dimensional control after an existing ship stern was cut for later mating to a new mid-body section and bow. Results appear promising. Large (1¼-inch diameter) “day glow” targets were used in daylight at a distance of approximately 88 feet with complete success.

3.) Plate Shop / Factory. There was concern at Avondale Shipyards with their numerically-controlled flame cutting tables with respect to differential movement of large steel plates (1-inch thick x 20ft x 60ft) being cut. The remote control three-camera system was ideally suited for such an investigation to determine how much movement exists and when and where it occurs. Three cameras were set up and exposures were shot at 10-minute intervals for 2 hours; the period required to cut the subject steel plate. The results were inconclusive because of camera exposures of the target points. The electronic flashes were quite adequate for the distances (less than 200 feet), but the orientation of the target points (flat retro-reflective tape stickers) were at too shallow an angle to permit sufficient light to return to all of the cameras. Initial results of target design research can be improved upon by using magnets and ball-bearings painted with various retro-reflective materials.

4.) "As Built" Industrial Site. Wink Engineering collaborated with us with respect to an industrial "As Built" experiment which demonstrated ¼ - inch accuracy easily achieved over 30 feet. Retro-reflective targets (Scotchlite® tape) were used indoors with a electronic flash. The GDOP indicates that 30 feet is not a limiting size.

5.) Tugboat Hull Offsets. Collaborative efforts were facilitated through the assistance of A.K. Suda & Associates, Inc. for a project to determine "as built" hull offsets of a tugboat inside of a dry dock. The project was a success with only one-half day of field work. Retro-reflective targets (Scotchlite® tape) were used in daylight with a electronic flash. Accuracy achieved was 1/3 - inch accuracy in the X-Y plane (more or less parallel to the deck) and ¼ - inch accuracy in the Z component (vertical) for a vessel over 100 feet long.

The UNO results demonstrated that existing *inexpensive* topographic mapping software with GDOP error propagation analysis can be used with high-resolution CCD cameras for shipbuilding and industrial "3D As-Built" applications. It is recommended that work continue for target design, software to easily connect applications, and to develop a training package to facilitate technology transfer of inexpensive terrestrial photogrammetry software & techniques to the U.S. Shipbuilding Industry.

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INTRODUCTION

A major difficulty in the shipbuilding industry is the lack of a reliable and quick method of obtaining three-dimensional measurements of complex parts during fabrication and fitting to other parts. Photogrammetry has been successfully used as a tool for this application, but because of the large number of systematic errors associated with film-based cameras, only very large shipyards have attempted this because of the complexity of the film-based problem. The requirements have been for expensive and exotic photogrammetric instruments, expensive proprietary special-purpose software packages, heavy training requirements for a multi-disciplinary staff, etc. Furthermore, film-based photogrammetric systems have tended to be on the slow end of the spectrum of dimensional-control systems. For quick turn-around time for results back to the workers in the shipyard, film-based photogrammetry has not been effective.

Recently, developments in Charge Coupled Device (CCD) imaging arrays for cameras have allowed some success in applying photogrammetric techniques *without film* in dimensional control. Previously classified technology for high-resolution CCD arrays has become available on the open market, but the existing film-based software has still been quite expensive. Digital camera systems (Kodak DCS 460) and computers were purchased and configured to tie existing *inexpensive* software packages with Geometric Dilution of Precision (GDOP) error propagation originally designed for topographic mapping into a tool for production shipyard fabrication dimensional control. The availability of GDOP is a **critical** distinction for photogrammetric software. Most photogrammetry packages, both in the public domain (free) as well as commercial, have only rudimentary indicators of adjustment quality (errors) and commonly give only root-mean-square (rms) values for the fit of object space control. **PC GIANT©** performs an error propagation analysis of the geometric dilution of precision for every point in the adjustment *including the unknown points being solved.* The presentation of the GDOP results in the form of eigenvectors/eigenvalues allows the shipyard analyst to inspect the accuracy of each and every individual point identified for fitting. Graphical screen plots of positional errors presented as ellipses are an easy check to verify consistency of results; blunders and large errors become instantly evident. GDOP allows for a constant and consistent quality check for accuracy control.

The Kodak DCS 460 cameras are the most expensive component of the system developed. Presently, the DCS 460 costs approximately $29,000 each, plus an additional $10,000 to include all the requisite accessories (multiple lenses, radio remote-control, tripod, case, etc.). This total is equivalent to the price of a luxury sedan automobile in 1996. The reliability of the three cameras has been flawless except for one faulty battery that was replaced within 24 hours. The cameras seem to be completely acceptable for heavy day-to-day use in a shipyard environment.

However, the software will probably cost *less than $3,000* per seat.

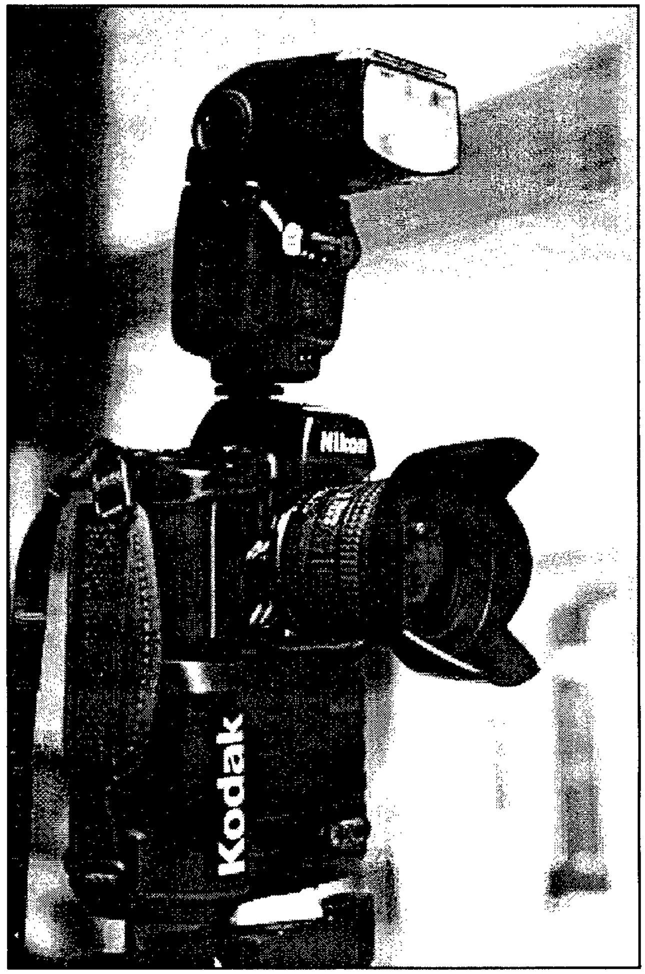


Figure 1 Kodak DCS 460 Camera

OBJECTIVE

The shipyard system will be capable of being used in production demonstrations as well as serving as a model configuration of components easily assembled by individual shipyards throughout the United States. The primary objective is to provide a demonstrable system that consists of standard (state-of-the-art) hardware components, standard (state-of-the-art) software components, and a minimum of customizing. Nothing in this research is especially new in concept except that technology has progressed in PC-based image processing, PC-based photogrammetry and digital camera design to the extent that old ideas that were extremely difficult to implement - are now <u>well</u> within reach of any shipyard in need of reliable, high-volume dimensional control. The system is intended to demonstrate that a single technician (with one or two helpers) can provide near real-time 3D dimensional control in a production shipyard environment. By minimizing the use of "dry dock" time, the competitiveness of U.S. shipyards will be enhanced with the most advanced CCD cameras available for unclassified applications.

SCOPE

The system is intended to be used in as many different application areas as possible that are pertinent to the U.S. shipbuilding industry within the time constraints of the project (1 year). Critical components to this scope were:

1. Research current work & present results of that research.
2. Purchase & acquire hardware/software.
3. Integrate complete system to operational status.
4. Collaborate with industry partners for possible projects.
5. Produce results.

METHOD OF PROCEDURE (METHODOLOGY)

The accuracies stated herein are as reported by the photogrammetric solution through the rigorous least squares adjustment of observed parameters and the computation of the geometric dilution of precision (GDOP). A variance-covariance matrix for each set of parameters is determined from the inverse of the normal equation. This is then multiplied by the estimate of variance of unit weight. The standard deviation for each element is the square root of the diagonal terms of that matrix.

The Variance of Unit Weight (σ_o^2) may be estimated by the equation:

$$\sigma_o^2 = \frac{\Sigma(v_i\ w_i\ v_i)}{(n - u)}$$

where

v_i	is the residual of the i^{th} observation
w_i	is the weight
n	is the number of observations
u	is the number of 'unknowns' or 'solvable parameters'
(n-u)	is the degrees of freedom

In the photogrammetric problem <u>the number (n) of observations</u> is equal to the number of plate components; one for x and one for y, or two times the number of image points measured. Add to this the number of measurements for object space coordinates , one for each of the known components (X,Y,Z). Depending on the external source of information, camera station position (X_c,Y_c,Z_c) and orientation elements azimuth, elevation, swing (α,h,s) as well; they can be added to the number of observations as six times the number of camera stations. Although these are considered as solvable parameters, they can also be treated as weighted observations if sufficient information is available.

The unknowns or solvable parameters (u) are the object space control positions. For each unique point in the adjustment, three unknowns are counted. Camera station position (X_c,Y_c,Z_c) and orientation elements (α,h,s) are commonly considered 'unknowns', giving rise to additional numbers of unknowns equal to six times the number of camera stations.

To summarize, let:

v = the output residual for each observation.

w = input weight which may be thought of as $1/\sigma^2$ for each observation.

(Note that 'weight' is the reciprocal of sigma squared.)

n = total number of observations.

m = 2 * number of plate measurements.

c = 1 for each object space component.

s = 6 * number of camera stations.

Factor 6 represents the camera parameters: the position coordinates (X_c,Y_c,Z_c) and orientation elements (α,h,s). These parameters are always treated as unknowns; however, depending on the external source of information, these may also be treated as weighted observations contributing to the number of direct weighted observation equations. When the weights of the direct observations are small, the camera parameters may be treated as completely free and no contribution is then made to the direct weighted observations.

p = 3 * number of points (X_G,Y_G,Z_G). Note: one, two or three of these components may have also been counted as observations under 'c'.

Again simplistically, the estimate of variance of unit weight is defined as the summation of the input weights ($1/\sigma^2$) multiplied by the output residuals squared (v^2). *If all is perfect,*

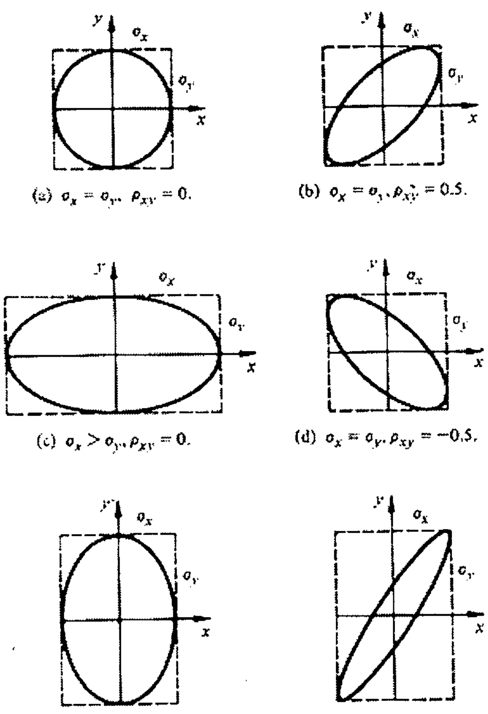
$$\frac{\Sigma v^2}{\sigma^2} = (n - u)$$

for all observations. This summation, when divided by the <u>degrees of freedom</u> (the number of observations minus the number of parameters) results in a value close to 1.00.

For a two-dimensional case, we consider the bivariate normal distribution then for random error components only:

$$\left(\frac{x}{\sigma_x}\right) - 2\varrho\left(\frac{x}{\sigma_x}\right)\left(\frac{y}{\sigma_y}\right) + \left(\frac{y}{\sigma_y}\right)^2 = (1 - \varrho^2)\, c^2$$

This represents a family of error ellipses centered on the origin of the X,Y coordinate system. When c = 1, this is the *standard error ellipse.* The size, shape and orientation of the standard error ellipse are governed by the distribution parameters σ_x, σ_y, and ϱ.



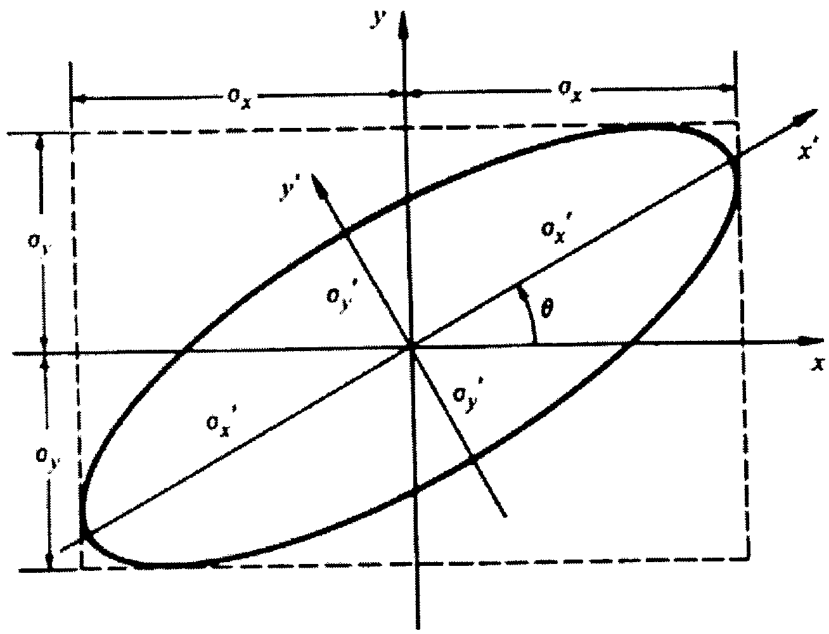
(a) $\sigma_x = \sigma_y, \rho_{xy} = 0.$ (b) $\sigma_x = \sigma_y, \rho_{xy} = 0.5.$

(c) $\sigma_x > \sigma_y, \rho_{xy} = 0.$ (d) $\sigma_x = \sigma_y, \rho_{xy} = -0.5.$

(e) $\sigma_x < \sigma_y, \rho_{xy} = 0.$ (f) $\sigma_x < \sigma_y, \rho_{xy} = 0.9.$

Six examples illustrating the effects of different combinations of error distribution parameters are shown in the figures to the left. Note that these figures represent the various effects of a *bias* as the result of the least squares adjustment of random error. What we desire is a result equivalent to ellipse (a) - no bias such that the error figure is equal in all directions - a circle. The further we depart from a circle, the less desirable the result in that **a significant bias is displayed.** Ellipse (f), then, is the <u>least desirable</u> for a position determination. The Shipbuilder is given a quality check tool that on the surface can be viewed as a subjective criterion. In fact, the choice of the appropriate math model for the photogrammetric adjustment offers a solid mathematical foundation for the graphical review of "goodness of fit". In surveying, we acknowledge that all measurements are made with some degree of error. With an error propagation of the geometric dilution of precision (GDOP) in a 3D analytical photogrammetric adjustment of observations, we obtain a realistic estimate of the reliability of our measurements. There is less reliance on "experience" and a greater assurance of an objective estimator of the quality of the observations, quality of dimensions and quality of the fabrication accuracy control.

A typical standard error ellipse in the X-Y plane is shown below.



Since c = 1, the imaginary box (broken line) that encloses the ellipse has half-dimensions σ_x and σ_y. In general, the principal axes of the ellipse, x' and y' do not coincide with the coordinate axes X and Y; the major axis of the ellipse, x' makes an angle θ with the X-axis. A positional error is expressed in the x,y coordinate system by random vector [X',Y']. The orthogonal (rotational) transformation which relates the two vectors is

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} ,$$

where θ is the angle of rotation.

Now the covariance matrices for random vectors

$$\begin{bmatrix} X \\ Y \end{bmatrix} , \begin{bmatrix} X' \\ Y' \end{bmatrix}$$

are

$$\begin{bmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{bmatrix} , \begin{bmatrix} \sigma_{\acute{x}}^2 & 0 \\ 0 & \sigma_{\acute{y}}^2 \end{bmatrix} ,$$

respectively. The off-diagonal terms in the covariance matrix for $\begin{bmatrix} X' \\ Y' \end{bmatrix}$ are zero because X' and Y' are uncorrelated (x' and y' are the principal axes of the ellipse).

Applying the general law of propagation of variances and covariances to the vector relationship given above, we get:

$$\begin{bmatrix} \sigma_{\acute{x}}^2 & 0 \\ 0 & \sigma_{\acute{y}}^2 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} .$$

Multiplying the matrices and equating corresponding elements we obtain

$$\sigma_{\acute{x}}^2 = \sigma_x^2 \cos^2\theta + 2\sigma_{xy}\sin\theta\cos\theta + \sigma_y^2\sin^2\theta$$

$$\sigma_{\acute{y}}^2 = \sigma_x^2 \sin^2\theta - 2\sigma_{xy}\sin\theta\cos\theta + \sigma_y^2\cos^2\theta$$

$$0 = (\sigma_y^2 - \sigma_x^2)\sin\theta\cos\theta + \sigma_{xy}(\cos^2\theta - \sin^2\theta) .$$

Substituting (1/2) sin 2θ for sinθ cosθ, and cos 2θ for ($\cos^2\theta - \sin^2\theta$), we obtain

$$\frac{1}{2}(\sigma_y^2 - \sigma_x^2)\sin 2\theta + \sigma_{xy}\cos 2\theta = 0$$

from which we get

$$\tan 2\theta = \frac{2\sigma_{xy}}{\sigma_x^2 - \sigma_y^2} .$$

The quadrant of 2θ is determined in the usual way from the signs of the numerator $2\theta_{xy}$ and denominator ($\sigma_x^2 - \sigma_y^2$). Eliminating θ results in the following expressions for the variances of X' and Y':

$$\sigma_{\acute{x}}^2 = \frac{\sigma_x^2 + \sigma_y^2}{2} + \left[\frac{(\sigma_x^2 - \sigma_y^2)^2}{4} + \sigma_{xy}^2\right]^{\frac{1}{2}}$$

$$\sigma_{\acute{y}}^2 = \frac{\sigma_x^2 + \sigma_y^2}{2} - \left[\frac{(\sigma_x^2 - \sigma_y^2)^2}{4} + \sigma_{xy}^2\right]^{\frac{1}{2}} .$$

The standard deviations $\sigma_{x'}$ and $\sigma_{y'}$ are the ***semimajor axis*** and ***semiminor axis***, respectively, of the standard error ellipse.

It can be demonstrated that the variances $\sigma^2_{x'}$ and $\sigma^2_{y'}$ are the ***eigenvalues*** of the covariance matrix of the random vector $\begin{bmatrix} X \\ Y \end{bmatrix}$.

For the three-dimensional case as provided by **PC GIANT©**, the eigenvectors are provided in the form of a 3X3 matrix of direction cosines for each point and the eigenvalues are provided for each component ($\sigma_{x'}, \sigma_{y'}, \sigma_{z'}$). Graphics software provides 2-D views for the X-Y plane, X-Z plane and the Y-Z plane.

DISCUSSION OF RESULTS

Research results of the industry survey indicated the following equipment used by shipyards:

EQUIPMENT	SHIPYARD
THEODOLITE	AVONDALE NORFOLK NAVAL SHIPYARD NEWPORT NEWS BATH IRON WORKS, CORP.
TRANSIT	NEWPORT NEWS BATH IRON WORKS, CORP.
LEVEL	NEWPORT NEWS
OPTICAL MICROMETER	BATH IRON WORKS, CORP.
ACMAN	INGALLS NASSCO
LASER INTERFEROMETER	AVONDALE NEWPORT NEWS NASSCO
TOTAL STATION	NEWPORT NEWS
DIGITAL PHOTOGRAMMETRY	NORFOLK NAVAL SHIPYARD NEWPORT NEWS BATH IRON WORKS, CORP.
HARDCOPY PHOTOGRAMMETRY	NORFOLK NAVAL SHIPYARD NEWPORT NEWS BATH IRON WORKS, CORP.

Active participation with Avondale Shipyards commenced the last week of the third Quarter. Three (3) separate Digital Photogrammetry applications have been initiated at the request of Avondale, consisting of:

<u>Shell Bolster Model.</u>

Photographs were taken of a scale model at Avondale and checked at UNO. Photos were overexposed (photographer error), and the model was later delivered to UNO for a second photography session. The exposures were correctly done the second time, with good geometry and good tonal range (Figure 2). Images were imported to the Desktop Mapping System (DMS®) software, and the majority of the point selection was done by Mr. Shannon Doliese, Director of Accuracy Control at Avondale Shipyards. Photogrammetric analysis was later performed by the Principal Investigator and Dr. Michael E. Pittman, Consultant. The analysis results appeared good, but initial reaction by Avondale personnel indicated that discrepancies existed.

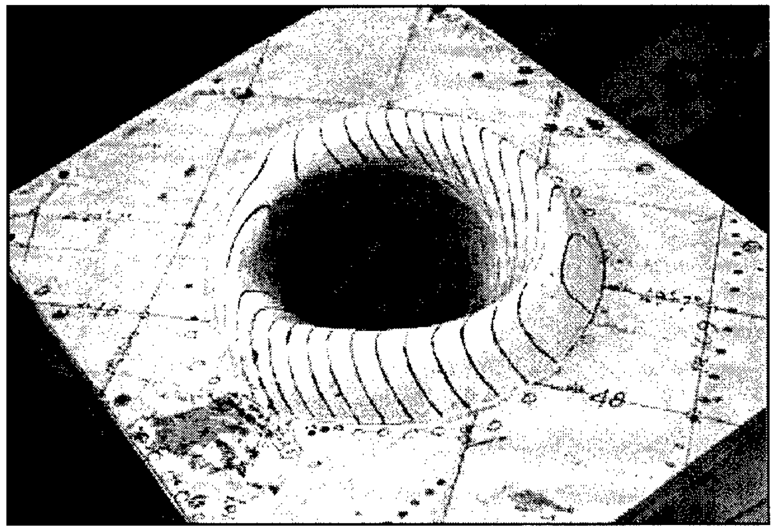


Figure 2 Shell Bolster Model

The actual targets were holes made in the surface of the model by a drafting compass needle. The sizes of the holes varied under magnification, the material around many of the holes were craterous (Figure 3), and when the results of the photogrammetric analysis were perused, the

Figure 3 Example of Marked Points

units were expressed at full scale. We believe that whatever discrepancies do exist are due to the difficulty in the identification of the photogrammetric targets available. The preparation of the model *was intended* for mechanical 3D digitization which was used with acceptable results. Although a different method of marking targets might be used in the future for such models, the use of digital photogrammetry is probably inappropriate when mechanical 3D digitizers are accessible.

Double Hull Mid-Body Tanker Section. Informational photographs were taken of a mid-body section under fabrication at Avondale Shipyards (Figure 4).

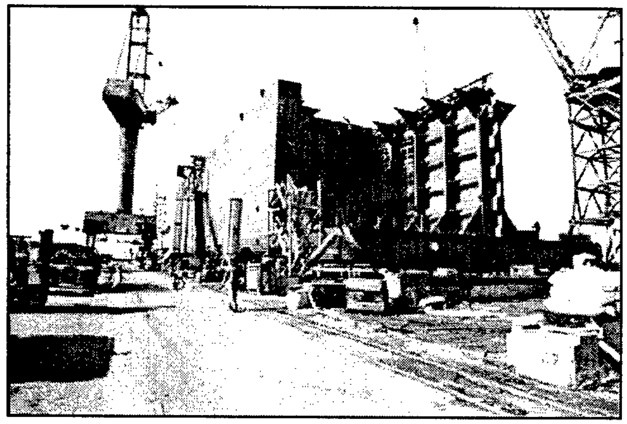


Figure 4 Double Hull Mid-Body Section

Plans have been made to use the digital camera system in providing dimensional control after an existing ship is cut for later mating to the new mid-body section. As of the end of the period of funded research for this project, the existing ship stern has just been photographed in the dry dock at Avondale Shipyards (Figure 5). Tests were made for target visibility with excellent results. Camera distance was about 88 feet from the mating surface of the stern section, and a 28mm wide-angle lens was used. This particular focal length of lens was chosen because of the physical constraints imposed by the size of the interior of the dry dock. Targets were Avery Color Coding Labels (1¼″ Round). The beige ship color required "Red Glow" (Avery 05497-2020RG) for contrast.

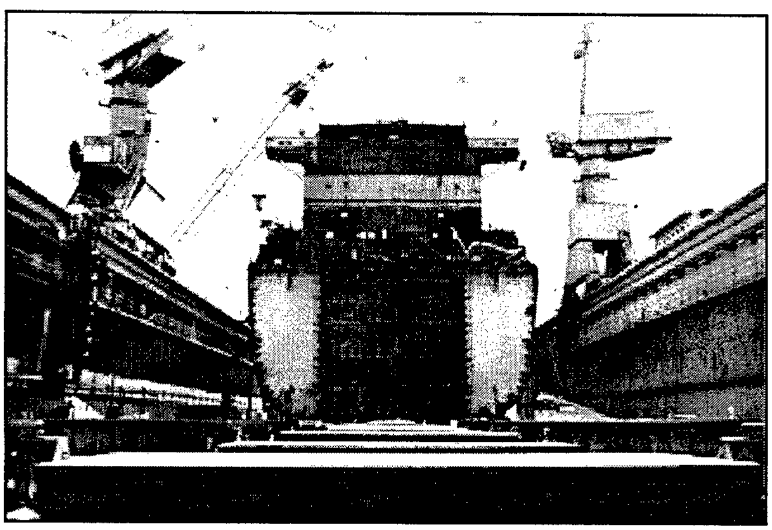


Figure 5 Stern Section in Dry Dock - General View

A return trip was made to the dry dock and Avondale Shipyards made a cherry picker available for the photography session (Figure 6). Avondale personnel placed the "Red Glow" target stickers (one hour) at the locations where coordinates were desired by the Accuracy Control Section. Photos were taken at nine locations with 100% overlap such that practically every control point and unknown point ("pass point") appeared in each of the nine convergent photos (one hour). Resulting accuracies were X= ±0.016 inches, Y= ±0.433 inches, Z= ±0.014 inches (four hours for analysis) and were deemed acceptable (Appendix A).

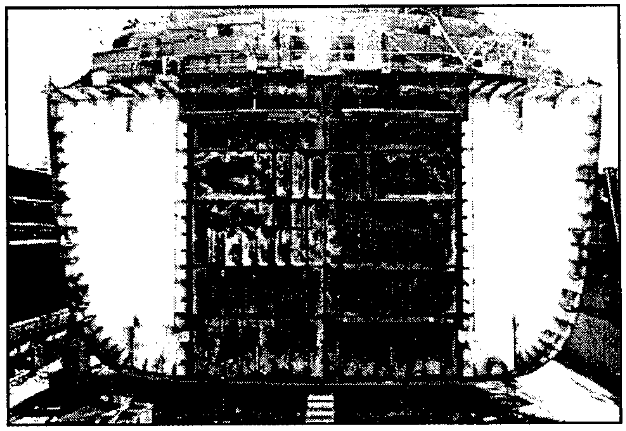


Figure 6 Stern Section - Survey Photo

Plate Shop / Factory. There is some concern at Avondale Shipyards with the numerically-controlled flame cutting tables with respect to differential movement of large steel plates (1 inch thick x 20 ft x 60 ft) being cut. Sometimes these steel plates move during cutting, othertimes they don't. These plates may move a lot or a little during cutting, then move back to where they were. The three-camera system with simultaneous remote control is ideally suited for such an investigation to determine how much movement exists and when & where it occurs. A visit to the Plate Shop / Factory was made and control was established by Avondale Accuracy Control Department. Three cameras were set up, and 3 simultaneous exposures were shot at 10-minute intervals for 2 hours, the period required to cut the subject steel plate (Figure 7). The results were inconclusive because of camera exposures of the target points. The Nikon "SB-26" electronic flash units were quite adequate for the distances (less than 200 feet), but the

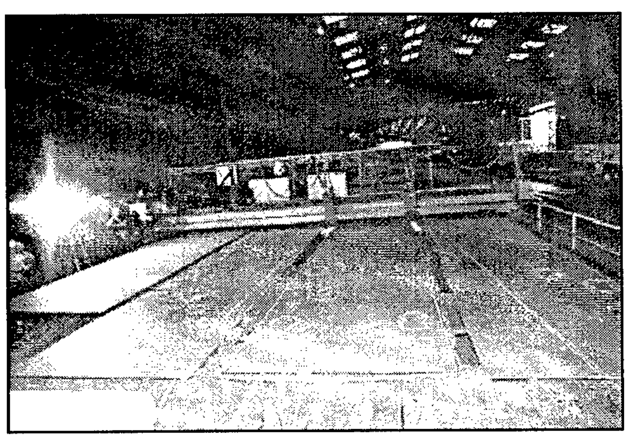


Figure 7 Plate Shop / Factory

orientation of the target points (flat retro-reflective tape stickers) were at too shallow an angle to permit sufficient light to return to the camera. (Stickers that were oriented perpendicular to the camera & strobe lights showed up with spectacular light returns at distances exceeding 200 feet.) Experiments were initiated to develop retro-reflector targets that would be adequate for such distances and for any angle of incidence. Initial results of target design research can be improved upon by using magnets and ball-bearings painted with various retro-reflective materials (Figure 8).

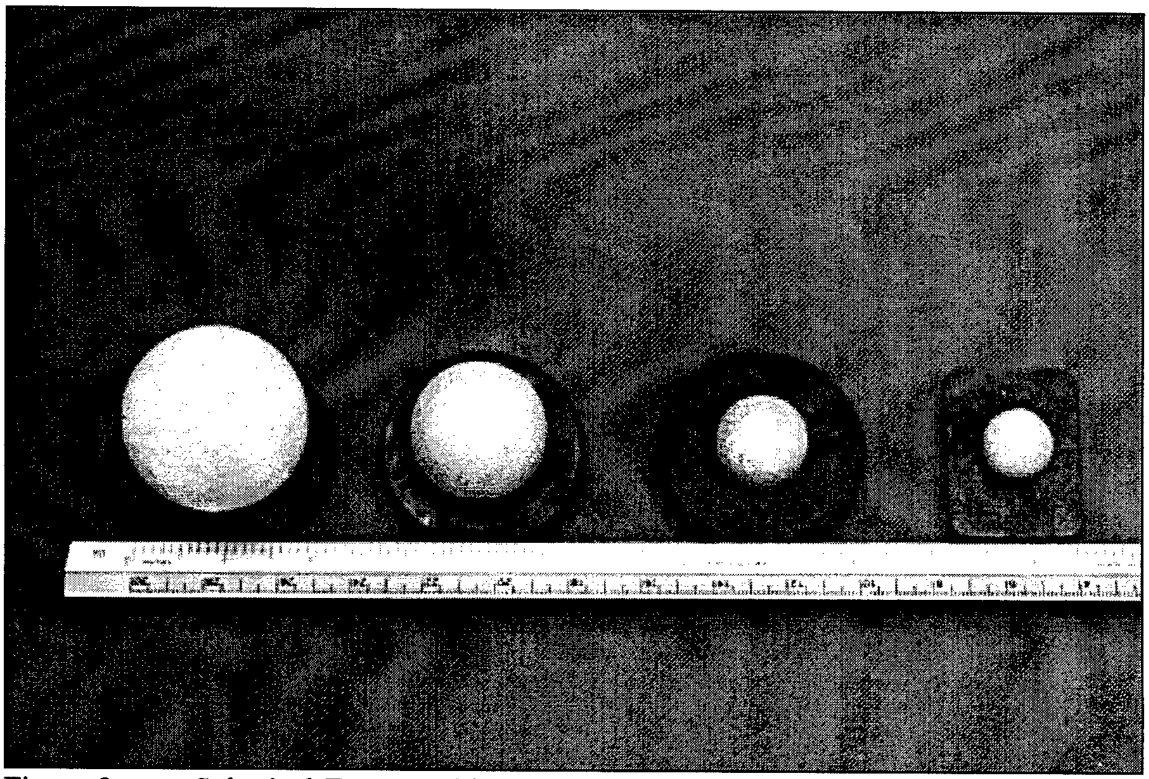


Figure 8 Spherical Targets with Magnets

Initially, ball bearings were painted with 3M Scotchlite™ "7216 White Reflective Liquid". The quality of the targets was considered poor because of the viscous nature of the liquid coating. On recommendation from a professional sign painter's store the targets were then painted with Zinsser® Bulls Eye 1-2-3 white primer. In an attempt to replicate the aluminum layer of Scotchlite™ reflective tape, the targets were then spray painted with a splattered aluminum paint. The targets were then spray painted with 3M Photo Mount™ spray adhesive and coated with spherical glass beads. The resultant targets appear promising.

In addition to the three projects initiated with the collaboration with Avondale, two additional projects were completed with potential for shipbuilding applications: one in collaboration with Wink, Inc. (industrial or "as built'), the other with A.K. Suda, Inc. (ship repair hull offsets).

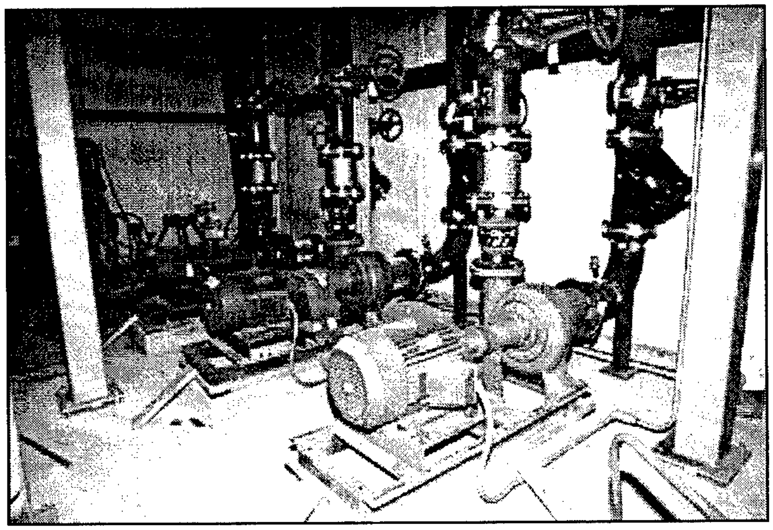


Figure 9 Industrial Site Demonstration

Industrial "As-Built 3D CAD Model." An industrial facility under construction was chosen for a pilot project, and was targeted and surveyed (two hours) by two Wink surveyors (Figure 9). The target points were flat retro-reflective tape stickers (circular) with rectangular tabs attached for ID notes (one hour) (Figure 10). The Wink control consisted of approximately 12 points surveyed to an accuracy of better than 1/16 inch in X-Y-Z. The photogrammetric solution included 19 photographs with 2 different focal length lenses. Results were satisfactory and were generally within the requisite accuracy of ¼ inch in X-Y-Z. The computed coordinates were delivered in the form of a final report. The photogrammetric solution took 16 hours. Retro-fitting new equipment into an existing engine room is an obvious application of this easily-implemented technique. The site survey requires only the technician and the camera.

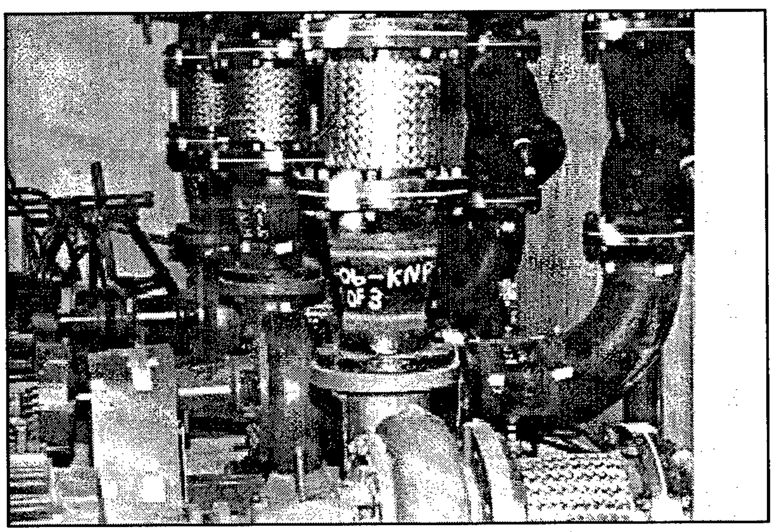


Figure 10 Industrial Site - Target Resolutions

5.) <u>"As-Built" Tugboat Hull Offsets.</u> A.K. Suda, Inc., *Consulting Naval Architects,* needed to determine the "as-built" dimensions of an existing tugboat (M/V J.K. McLean) in order to compute the stability characteristics of the vessel. Desired overall accuracy was ± ½ inch for all three components (X-Y-Z), and speed of measurement was a major concern in order to ***minimize the charges for dry dock rental time*** (Figure 11).

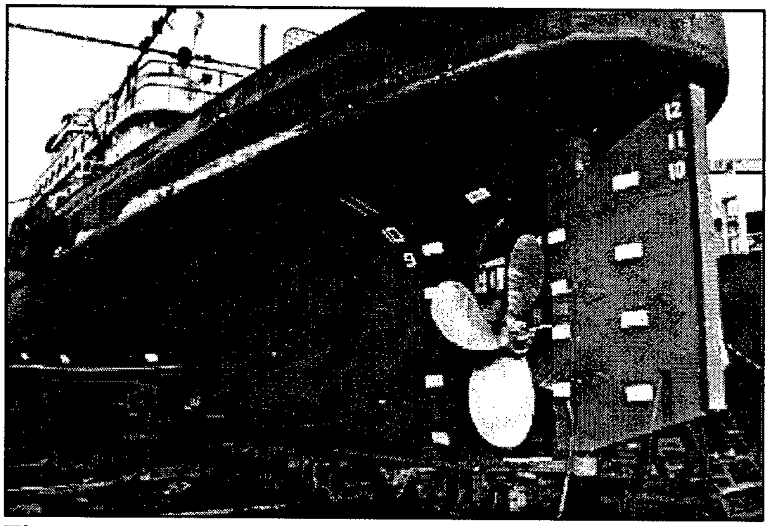


Figure 11 M/V J.K. McLean (tugboat)

The vessel was available at 12:30 pm, and three men started targeting the bulkhead locations with 13/32 inch diameter Scotchlite™ reflective tape. The targeting operation took a total of 4½ hours. Four object space control points were surveyed with the aid of a 100 foot steel tape and an automatic level. The X-Y-Z control was completed in 15 minutes. A total of 52 photographs were taken with electronic flash in 15 minutes. Total dry dock time was 5 hours. Of the 52 photos taken, 26 were actually used in the photogrammetric analysis. Photogrammetric analysis time totalled 48 hours because of two blunders - one blunder in the reduction of the object space control points (approximately one foot), one blunder because of duplicate point identifications assigned during the measurement phase. Thirty seven hours were wasted because of human error; actual productive work *would have taken* about 12 hours *if* there were no blunders. Final accuracy was ±0.33 inches in X (lengthwise along the keel), ±0.0.35 inches in Y (width offsets perpendicular to the keel) and ±0.20 inches in Z (vertical). Note that the blunders were made in the office and were corrected in the office.

CONCLUSIONS

Digital Image Photogrammetry is a system that is reliable and easily implemented with "off-the-shelf" equipment and inexpensive topographic mapping software. Higher accuracies can be obtained by modeling more sources of systematic error such as lens distortion. Greater functionality can be obtained from the system by customizing the topographic mapping software to a more specific shipbuilding context; specifically with respect to units of measurement and reference conventions. A phototriangulation software package that computes the error propagation of the Geometric Dilution of Precision is a necessity for reliable production Quality Checks.

RECOMMENDATIONS

The Digital Image Photogrammetry system should be promoted as a 'Low-Cost' investment to change current methodology in dimensional control.

Software should be developed that will easily adapt inexpensive topographic software applications to industrial applications in use in shipyard production environments.

A documented series of "successes" with industrial collaborators should serve as instructional material useful in spreading the gospel of easy, low-cost dimensional control using digital image photogrammetry.

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APPENDIX A

Stern Section of Double-Hull Tanker

PC GIANT© Solution Output

PC-Giant (c)Copyright 1990-1994

05/16/96   16:44:26.33

GPA Associates
UNO Box 1200
New Orleans, LA 70148
(504) 286-1200

AHLK Stern - AVONDALE SHIPYARDS, INC.

Object Space Reference System is Rectangular (Close-Range)

Rotation angles are Terrestrial Object-to-Photo

Complete Triangulation process is requested

Error Propagation is requested

[Eigenvector/Eigenvalue output]

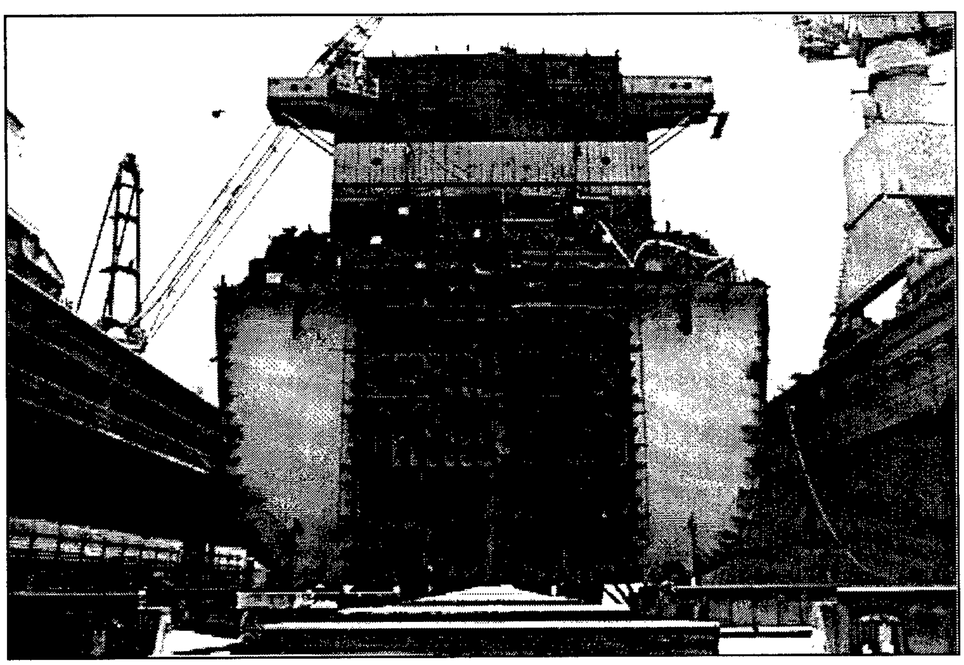
Unit Variance will be based on constrained camera parameters

All Image Residuals will be listed

Triangulated Object Coordinates will be saved

Adjusted Camera Station Parameters will be saved

Images are in millimeters. Object space is in feet



FRAME 1ft_bot

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm

CAMERA STATION PARAMETERS

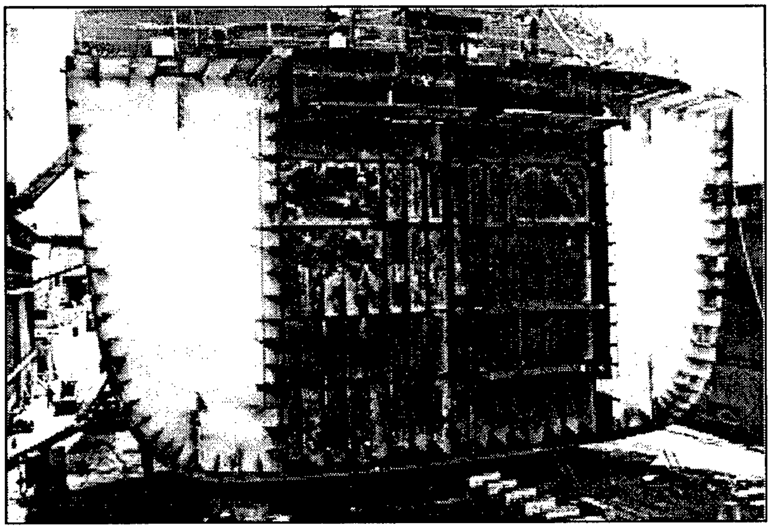
P O S I T I O N		Std. Dev.	A T T I T U D E (Terrestrial->Ph)		Std. Dev.
X =	-45.8370 ft	10.0000 ft	Azim. =	22 48 40.4270	01 00 00.0000
Y =	-88.8940 ft	10.0000 ft	Elev. =	09 37 33.5650	01 00 00.0000
Z =	7.2940 ft	10.0000 ft	Swing =	- 01 59 53.6020	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
31	-5.4810	-5.1510	32	-7.2370	-2.8060
33	-7.1980	0.3850	34	-7.1570	3.5010
35	-7.0850	6.9400	25	-10.9280	7.7080
21	-9.0260	-5.1290	22	-9.9060	-2.8110
23	-10.4720	0.5040	10	2.4860	-6.8020
11	2.4080	-5.0560	51	10.8130	-4.4220
52	11.1470	-2.6870	53	11.2720	-0.2960
54	11.2670	2.0410	43	9.3980	-0.2120
42	9.6450	-2.6980			

FRAME 1ft_mid

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

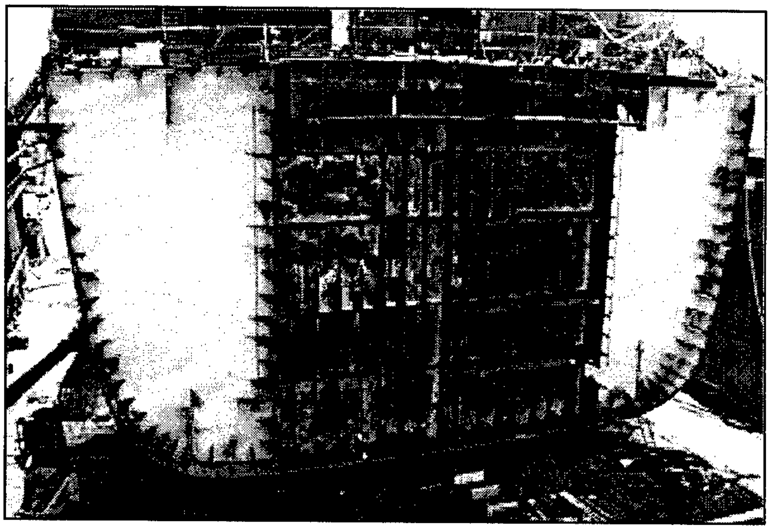
P O S I T I O N		Std. Dev.	A T T I T U D E (Terrestrial->Ph)		Std. Dev.
X =	-41.2960 ft	10.0000 ft	Azim. =	20 03 27.0900	01 00 00.0000
Y =	-91.3140 ft	10.0000 ft	Elev. =	00 46 42.5660	01 00 00.0000
Z =	22.6930 ft	10.0000 ft	Swing =	- 01 37 30.0630	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
31	-5.5840	-5.5080	32	-7.3810	-3.3280
33	-7.4450	-0.1560	34	-7.5110	3.0670
35	-7.5710	6.7480	25	-11.6630	7.0610
21	-9.0470	-5.6670	22	-10.0080	-3.4810
23	-10.7320	-0.2280	24	-11.2650	3.1040
10	2.2930	-6.6980	11	2.2510	-5.0210
41	8.6650	-4.2400	42	9.7550	-2.2770
43	9.6730	0.2500	44	9.5900	2.7980
55	12.5500	5.6030	52	11.3340	-2.1790
53	11.6310	0.2830	54	11.8000	2.7540

FRAME 1ft_top

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

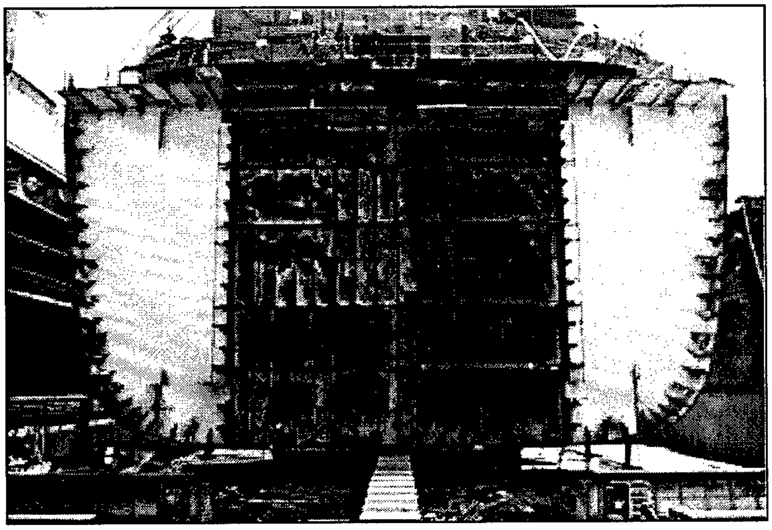
POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	-40.0240 ft	10.0000 ft	Azim. =	20 21 54.5760	01 00 00.0000
Y =	-87.7250 ft	10.0000 ft	Elev. =	- 11 24 37.7720	01 00 00.0000
Z =	42.0950 ft	10.0000 ft	Swing =	00 18 05.5000	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
10	1.8730	-6.0740	11	1.9120	-4.5260
31	-5.8000	-5.3200	32	-7.6190	-3.3490
33	-7.7640	-0.2450	34	-7.9060	3.0570
21	-9.2120	-5.6160	22	-10.2470	-3.6110
23	-11.1360	-0.4660	24	-11.8710	2.9400
25	-12.5440	6.8990	42	9.5540	-1.5970
43	9.7380	0.8890	44	9.9350	3.4910
41	8.2870	-3.5220	52	11.1320	-1.4400
53	11.7240	1.0000	54	12.2060	3.5380

FRAME cen_bot

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

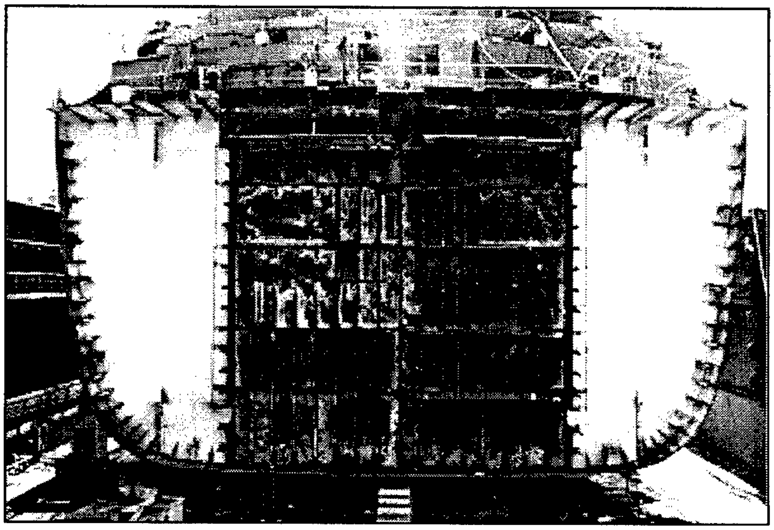
POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	0.0790 ft	10.0000 ft	Azim. =	359 18 51.1420	01 00 00.0000
Y =	-104.0160 ft	10.0000 ft	Elev. =	08 32 20.2960	01 00 00.0000
Z =	7.9370 ft	10.0000 ft	Swing =	- 00 04 57.9490	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
11	0.3330	-4.7540	31	-7.1690	-4.5640
32	-8.5600	-2.5600	33	-8.4410	0.1050
34	-8.3180	2.7470	35	-8.1890	5.6860
25	-11.6470	5.8350	21	-10.0380	-4.4460
22	-10.6500	-2.5630	23	-10.9990	0.0970
24	-11.1960	2.7190	41	7.8600	-4.5340
42	9.2510	-2.5090	43	9.1190	0.1770
44	8.9750	2.8140	45	8.8180	5.7630
55	12.3060	5.9520	51	10.7580	-4.4220
52	11.3720	-2.4960	53	11.7140	0.1810
54	11.8900	2.8160			

FRAME cen_mid

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

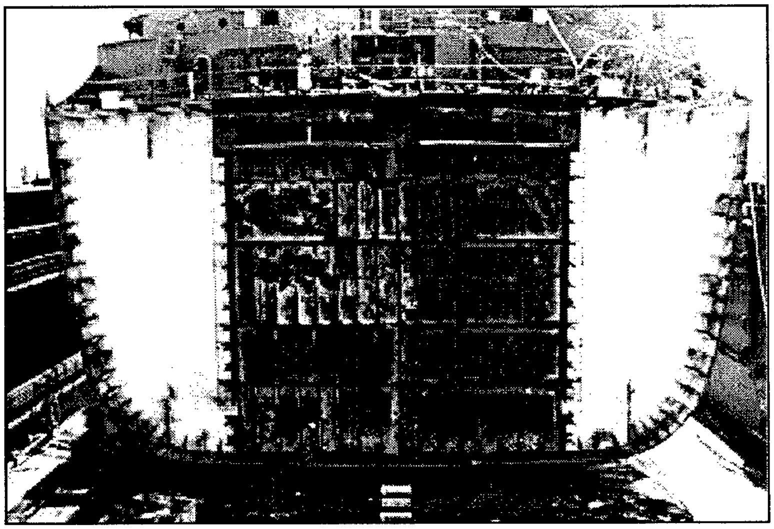
POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	0.3390 ft	10.0000 ft	Azim. =	359 04 49.9800	01 00 00.0000
Y =	-103.6610 ft	10.0000 ft	Elev. =	01 39 11.9560	01 00 00.0000
Z =	23.3170 ft	10.0000 ft	Swing =	00 18 59.7010	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
11	0.3400	-5.5330	31	-7.1210	-5.2680
32	-8.5610	-3.2600	33	-8.5230	-0.5580
34	-8.4790	2.1800	35	-8.4230	5.3090
21	-9.9710	-5.1200	22	-10.6550	-3.2450
23	-11.1100	-0.5410	24	-11.4130	2.1780
25	-12.0350	5.3360	41	7.8330	-5.3790
42	9.3250	-3.3800	43	9.3130	-0.6530
44	9.2930	2.1010	45	9.2630	5.2510
51	10.7420	-5.2930	52	11.4620	-3.3910
53	11.9580	-0.6700	54	12.2900	2.0780
55	12.9260	5.2640			

FRAME cen_top

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

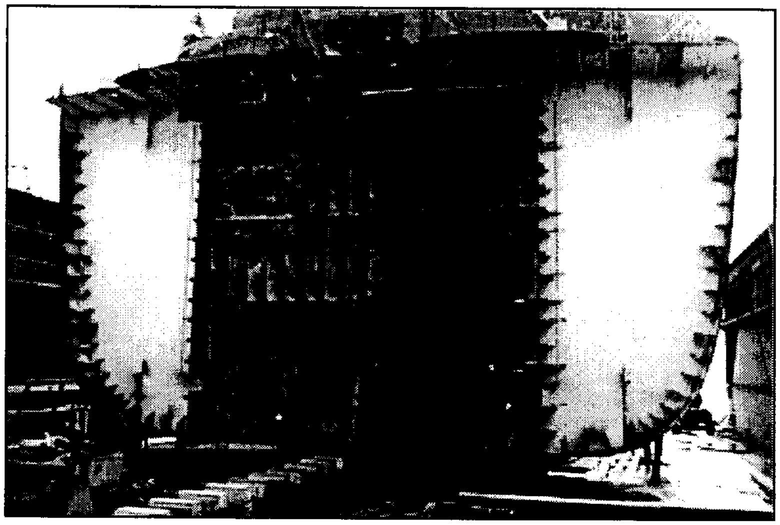
POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	0.2820 ft	10.0000 ft	Azim. =	359 11 24.0670	01 00 00.0000
Y =	-103.6540 ft	10.0000 ft	Elev. =	- 06 32 33.9820	01 00 00.0000
Z =	37.6500 ft	10.0000 ft	Swing =	- 00 25 26.8810	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
11	0.3620	-5.1690	31	-6.8810	-4.9950
32	-8.3720	-3.1140	33	-8.4870	-0.4910
34	-8.5950	2.2330	35	-8.7320	5.4450
21	-9.6420	-4.8890	22	-10.4270	-3.1190
23	-11.0550	-0.5050	24	-11.5550	2.2080
25	-12.4080	5.2730	41	7.6160	-4.9440
42	9.1160	-3.0350	43	9.1970	-0.3920
44	9.2680	2.3450	52	11.2050	-3.0200
53	11.8130	-0.3880	54	12.2780	2.3510
55	13.0850	5.4690	51	10.4280	-4.8470

FRAME rht_bot

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

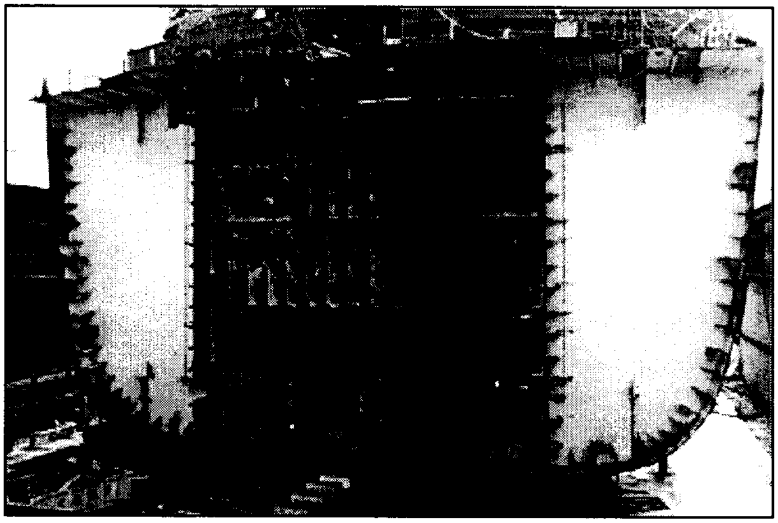
POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	30.5290 ft	10.0000 ft	Azim. =	344 09 39.7560	01 00 00.0000
Y =	-94.6690 ft	10.0000 ft	Elev. =	07 16 20.1220	01 00 00.0000
Z =	10.2950 ft	10.0000 ft	Swing =	01 04 00.4480	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
10	-1.1300	-6.5520	11	-1.0950	-4.8070
31	-8.0350	-4.3960	32	-9.1830	-2.4260
33	-9.0330	0.1520	34	-8.8750	2.7160
35	-8.7170	5.6000	21	-10.4490	-4.2110
22	-10.9210	-2.4150	23	-11.1570	0.1050
24	-11.2670	2.5940	25	-11.8910	5.5050
41	7.0040	-4.8300	42	8.7140	-2.5550
43	8.6470	0.5320	44	8.5660	3.5650
45	8.4780	6.9600	51	10.4740	-4.7770
52	11.3020	-2.5650	53	11.8190	0.5890
54	12.1480	3.7230	55	12.4410	7.4800

FRAME rht_mid

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

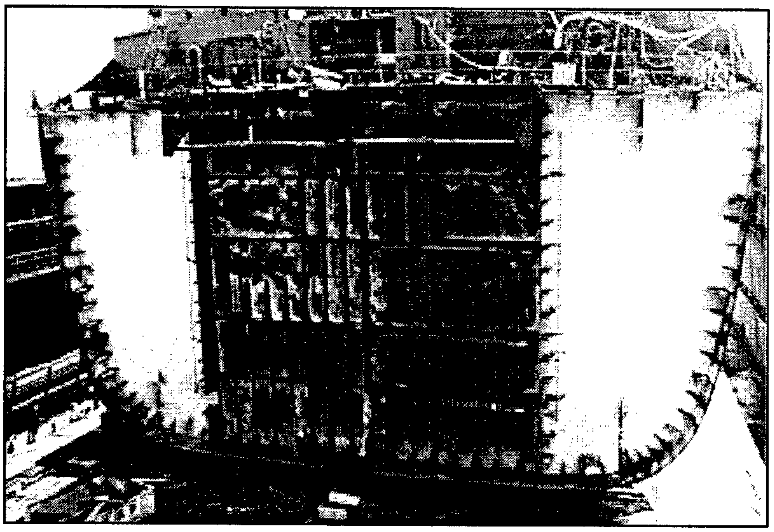
P O S I T I O N		Std. Dev.	A T T I T U D E (Terrestrial->Ph)		Std. Dev.
X =	30.2710 ft	10.0000 ft	Azim. =	343 38 25.6440	01 00 00.0000
Y =	-92.5230 ft	10.0000 ft	Elev. =	00 30 11.2300	01 00 00.0000
Z =	22.9930 ft	10.0000 ft	Swing =	00 05 56.3430	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
10	-0.8600	-6.8910	11	-0.8620	-5.1620
31	-7.8410	-4.5810	32	-9.1010	-2.5800
33	-9.0980	0.0570	34	-9.0870	2.7380
35	-9.0720	5.8130	21	-10.2690	-4.3460
22	-10.8520	-2.5300	23	-11.2530	0.0530
24	-11.5290	2.6460	25	-12.3950	5.6330
41	7.3410	-5.3630	42	9.1230	-3.1100
43	9.1170	0.0910	44	9.0980	3.3240
45	9.0630	7.0170	51	10.8780	-5.4020
52	11.7930	-3.1790	53	12.4370	0.0870
54	12.8910	3.4200	55	13.3620	7.3790

FRAME rht_top

PRINCIPAL DISTANCE = -28.0000 mm
Std. Dev. of X = 0.0060 mm
Std. Dev. of Y = 0.0060 mm



CAMERA STATION PARAMETERS

POSITION		Std. Dev.	ATTITUDE (Terrestrial->Ph)		Std. Dev.
X =	30.0370 ft	10.0000 ft	Azim. =	343 43 23.4760	01 00 00.0000
Y =	-93.0700 ft	10.0000 ft	Elev. =	- 09 23 10.0310	01 00 00.0000
Z =	41.4230 ft	10.0000 ft	Swing =	- 01 19 45.1580	01 00 00.0000

PLATE COORDINATES in millimeters

ID	X	Y	ID	X	Y
10	-0.5700	-6.7870	11	-0.6200	-5.2330
31	-7.3350	-4.5170	32	-8.6920	-2.6250
33	-8.8880	-0.1110	34	-9.0880	2.5240
21	-9.6840	-4.2350	22	-10.4000	-2.5270
23	-11.0240	-0.0500	24	-11.5380	2.5140
25	-12.6920	5.3670	41	7.1640	-5.6310
42	8.9110	-3.6270	43	8.9930	-0.6230
44	9.0690	2.5350	45	9.1490	6.3000
51	10.4980	-5.7700	52	11.4560	-3.7610
53	12.2270	-0.7260	54	12.8470	2.5200
55	13.5360	6.2730			

O B J E C T   C O N T R O L   D A T A

		Position	Std. Dev.	
	X =	0.0000 ft	0.0050	
10	Y =	0.0000 ft	0.0050	TYPE = 0
	Z =	0.0000 ft	0.0050	
	X =	0.0000 ft	0.0050	
11	Y =	0.0000 ft	0.0050	TYPE = 0
	Z =	6.0000 ft	0.0050	
	X =	-33.0000 ft	0.0050	
34	Y =	0.0000 ft	0.0050	TYPE = 0
	Z =	34.2344 ft	0.0050	
	X =	33.0000 ft	0.0050	
44	Y =	0.0000 ft	0.0050	TYPE = 0
	Z =	34.2344 ft	0.0050	

C A M E R A   S T A T I O N S   C O R R E C T I O N S

	POSITION			ATTITUDE		
	X	Y	Z	Azim.	Elev.	Swing
			Iteration 1			
lft_bot	-0.0194	0.0181	-0.0187 ft	-0.000227	0.000230	0.000051
lft_mid	-0.0204	0.0139	-0.0241 ft	-0.000235	0.000260	0.000023
lft_top	-0.0201	0.0089	-0.0243 ft	-0.000238	0.000229	-0.000015
cen_bot	-0.0308	0.0039	-0.0258 ft	-0.000282	0.000240	0.000037
cen_mid	-0.0320	0.0002	-0.0298 ft	-0.000297	0.000282	0.000022
cen_top	-0.0324	-0.0045	-0.0318 ft	-0.000293	0.000296	-0.000001
rht_bot	-0.0210	-0.0072	-0.0179 ft	-0.000221	0.000172	0.000031
rht_mid	-0.0206	-0.0092	-0.0197 ft	-0.000224	0.000208	0.000012
rht_top	-0.0208	-0.0131	-0.0223 ft	-0.000219	0.000249	-0.000016

Provisional Weighted Sum of Squares = 346.296

	X	Y	Z	Azim.	Elev.	Swing
			Iteration 2			
lft_bot	-0.0002	0.0001	0.0000 ft	-0.000003	0.000000	0.000000
lft_mid	-0.0003	0.0002	0.0002 ft	-0.000003	-0.000002	0.000000
lft_top	-0.0003	0.0002	0.0000 ft	-0.000003	0.000000	-0.000001
cen_bot	-0.0004	0.0000	0.0000 ft	-0.000004	0.000000	0.000000
cen_mid	-0.0005	0.0000	0.0000 ft	-0.000005	0.000000	0.000000
cen_top	-0.0006	0.0000	0.0000 ft	-0.000005	0.000000	0.000000
rht_bot	-0.0004	-0.0001	-0.0001 ft	-0.000004	0.000001	0.000000
rht_mid	-0.0004	-0.0002	-0.0001 ft	-0.000004	0.000001	0.000000
rht_top	-0.0005	-0.0002	-0.0001 ft	-0.000005	0.000001	0.000000

Provisional Weighted Sum of Squares = 341.811

	X	Y	Z	Azim.	Elev.	Swing
			Iteration 3			
lft_bot	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
lft_mid	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
lft_top	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
cen_bot	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
cen_mid	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
cen_top	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
rht_bot	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
rht_mid	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000
rht_top	0.0000	0.0000	0.0000 ft	0.000000	0.000000	0.000000

Provisional Weighted Sum of Squares = 341.794

T R I A N G U L A T E D   I M A G E   P O I N T S   R E S I D U A L S
(in thousandths of millimeters)

31	lft_bot	lft_mid	lft_top	cen_bot	cen_mid	cen_top	rht_bot	rht_mid	rht_top
	0	-2	1	0	-1	7	1	-5	0
	1	0	3	-2	1	-1	0	-2	0
32	lft_bot	lft_mid	lft_top	cen_bot	cen_mid	cen_top	rht_bot	rht_mid	rht_top
	0	0	1	1	0	-3	1	-1	0
	3	0	2	-2	0	1	-1	-1	-1
33	lft_mid	lft_bot	lft_top	cen_bot	cen_mid	cen_top	rht_bot	rht_mid	rht_top
	-3	0	0	0	1	0	0	1	0
	2	-1	-1	1	2	0	0	-1	-2
34*0*	lft_mid	lft_top	lft_bot	cen_bot	cen_mid	cen_top	rht_bot	rht_mid	rht_top
	1	-5	6	-3	1	0	-9	-1	-2
	-12	-12	-8	-9	-8	-7	-7	-13	-12
35	lft_mid	cen_bot	lft_bot	cen_mid	cen_top	rht_bot	rht_mid		
	0	5	-5	-1	9	1	-6		
	4	4	4	-1	-1	-6	-5		
25	lft_top	cen_bot	lft_mid	cen_mid	lft_bot	cen_top	rht_bot	rht_mid	rht_top
	-1	-3	2	0	2	0	-4	1	2
	7	-1	2	-4	1	2	-3	-4	-4
21	cen_bot	cen_mid	lft_top	lft_mid	cen_top	lft_bot	rht_bot	rht_mid	rht_top
	1	-1	7	0	-3	-3	0	0	0
	-1	-1	0	-2	-2	-2	3	3	5
22	lft_top	cen_bot	cen_mid	cen_top	lft_mid	rht_bot	lft_bot	rht_mid	rht_top
	2	-1	0	-1	0	1	-1	0	0
	0	0	1	0	-3	3	-2	1	0
23	lft_top	cen_mid	cen_bot	cen_top	rht_bot	lft_mid	rht_mid	lft_bot	rht_top
	2	-2	-1	-3	0	0	1	0	2
	2	0	0	0	3	-1	-1	0	-2
10*0*	rht_bot	lft_mid	rht_mid	rht_top	lft_bot	lft_top			
	-6	0	-11	-17	0	5			
	11	0	14	7	0	-6			
11*0*	cen_top	cen_bot	rht_bot	lft_bot	rht_mid	lft_mid	cen_mid	rht_top	lft_top
	-10	-4	0	-4	-5	-5	-8	-9	-1
	9	11	12	8	15	9	13	6	-4
51	lft_bot	cen_bot	cen_top	rht_bot	rht_mid	cen_mid	rht_top		
	0	4	0	0	-1	1	-2		
	3	7	11	-11	-5	0	0		
52	cen_bot	cen_top	lft_bot	rht_bot	lft_mid	rht_mid	cen_mid	lft_top	rht_top
	1	-2	1	1	0	1	-2	-1	0
	-3	-5	4	0	2	5	2	-3	-1

T R I A N G U L A T E D I M A G E P O I N T S R E S I D U A L S
(in thousandths of millimeters)

53	cen_mid	cen_top	cen_bot	rht_bot	rht_mid	lft_top	lft_mid	lft_bot	rht_top
	-2	0	-2	1	1	3	0	-4	0
	0	-2	-1	2	-1	0	2	2	-1
54	lft_mid	cen_mid	rht_bot	cen_bot	lft_top	cen_top	rht_mid	lft_bot	rht_top
	-1	0	-2	-4	7	2	2	-6	0
	-1	-2	2	1	4	-2	1	-2	-2
43	lft_top	rht_bot	lft_bot	cen_mid	cen_bot	rht_mid	lft_mid	cen_top	rht_top
	-3	0	16	-2	-3	0	0	-2	2
	0	-3	-11	6	-3	0	-1	2	8
42	cen_mid	cen_bot	lft_bot	lft_mid	rht_mid	rht_bot	lft_top	rht_top	cen_top
	0	2	-1	3	1	0	-4	-2	1
	0	-2	0	0	6	0	-9	4	-3
24	rht_mid	cen_mid	cen_top	cen_bot	lft_mid	rht_top	lft_top	rht_bot	
	0	-3	0	4	0	0	-1	0	
	-2	3	-2	2	4	-5	2	-4	
41	lft_mid	cen_bot	rht_bot	cen_top	rht_mid	lft_top	rht_top	cen_mid	
	4	0	4	0	-1	-10	-5	7	
	1	-2	5	-4	3	-1	0	-3	
44*0*	rht_bot	lft_top	cen_bot	rht_mid	lft_mid	cen_top	rht_top	cen_mid	
	18	-3	8	16	0	10	22	7	
>3σ	-8	12	-4	-12	-3	0	1	-2	
55	lft_mid	rht_mid	cen_mid	cen_bot	rht_bot	cen_top	rht_top		
	0	3	-1	0	1	-2	-2		
	-1	-1	-1	0	3	5	-3		
45	rht_mid	cen_bot	cen_mid	rht_bot	rht_top				
	0	-1	5	-9	6				
	0	4	-5	-4	4				

Weighted Sum of Squares (Camera)	=	0.0
Weighted Sum of Squares (Object)	=	41.6
Weighted Sum of Squares (Plates)	=	239.7
Weighted Sum of Squares (Total)	=	281.3
Degrees of Freedom............	=	310

a posteriori Variance of Unit Weight = 0.907

T R I A N G U L A T E D   C A M E R A   S T A T I O N S
(Terrestrial->Ph)

Ident		Position	Error Ellipsoid			--->	Length
	X =	-45.8566 ft	+0.0102	-0.1717	+0.9851	--->	0.1153 ft
lft_bot	Y =	-88.8758 ft	-0.8226	+0.5586	+0.1059	--->	0.0695 ft
	Z =	7.2754 ft	+0.5685	+0.8115	+0.1356	--->	0.0238 ft

	Azim. =	22 49 31.4017		00 02 15.3811
Attitude:	Elev. =	09 38 14.0472	Std Dev:	00 04 20.2418
	Swing =-	02 00 09.7240		00 00 52.1031

	X =	-41.3167 ft	-0.2916	+0.1814	+0.9392	--->	0.1161 ft
lft_mid	Y =	-91.2999 ft	+0.7840	-0.5172	+0.3433	--->	0.0694 ft
	Z =	22.6691 ft	+0.5481	+0.8364	+0.0086	--->	0.0218 ft

	Azim. =	20 04 16.5059		00 02 26.5482
Attitude:	Elev. =	00 47 32.4810	Std Dev:	00 04 06.2165
	Swing =-	01 37 44.3851		00 00 44.5085

	X =	-40.0444 ft	-0.4722	+0.5295	+0.7048	--->	0.1388 ft
lft_top	Y =	-87.7159 ft	+0.6653	-0.3105	+0.6790	--->	0.0708 ft
	Z =	42.0707 ft	+0.5783	+0.7894	-0.2057	--->	0.0222 ft

	Azim. =	20 22 41.8904		00 03 08.5308
Attitude:	Elev. =-	11 23 49.8395	Std Dev:	00 04 26.8838
	Swing =	00 17 55.5141		00 00 51.3082

	X =	0.0478 ft	+0.0989	-0.1813	+0.9784	--->	0.1366 ft
cen_bot	Y =	-104.0121 ft	-0.9951	-0.0213	+0.0966	--->	0.0972 ft
	Z =	7.9112 ft	-0.0034	+0.9832	+0.1825	--->	0.0205 ft

	Azim. =	359 19 50.6801		00 02 55.9239
Attitude:	Elev. =	08 33 09.7663	Std Dev:	00 04 22.8336
	Swing =-	00 04 58.5523		00 00 41.8080

	X =	0.3065 ft	+0.1575	-0.0275	+0.9871	--->	0.1327 ft
cen_mid	Y =	-103.6608 ft	+0.9875	+0.0095	-0.1573	--->	0.1053 ft
	Z =	23.2872 ft	-0.0051	+0.9996	+0.0286	--->	0.0201 ft

	Azim. =	359 05 52.1563		00 03 13.1696
Attitude:	Elev. =	01 40 10.0777	Std Dev:	00 04 18.1911
	Swing =	00 19 03.4294		00 00 39.8244

	X =	0.2490 ft	+0.3419	+0.1126	+0.9330	--->	0.1274 ft
cen_top	Y =	-103.6585 ft	+0.9397	-0.0388	-0.3397	--->	0.1198 ft
	Z =	37.6182 ft	-0.0020	+0.9929	-0.1191	--->	0.0205 ft

	Azim. =	359 12 26.1008		00 03 37.5073
Attitude:	Elev. =-	06 31 33.0861	Std Dev:	00 04 04.8738
	Swing =-	00 25 19.1743		00 00 41.8463

	X =	30.5076 ft	+0.3111	-0.0240	+0.9501	--->	0.1197 ft
rht_bot	Y =	-94.6763 ft	+0.8517	+0.4506	-0.2675	--->	0.0714 ft
	Z =	10.2770 ft	-0.4217	+0.8924	+0.1606	--->	0.0209 ft

	Azim. =	344 10 25.2940		00 02 28.3635
Attitude:	Elev. =	07 16 56.1461	Std Dev:	00 04 04.5495
	Swing =	01 04 10.6991		00 00 42.7132

T R I A N G U L A T E D   C A M E R A   S T A T I O N S
(Terrestrial->Ph)

Ident	Position		Error Ellipsoid			--->	Length
	X =	30.2500 ft	+0.4012	+0.1647	+0.9010	--->	0.1200 ft
rht_mid	Y =	-92.5323 ft	-0.8077	-0.4004	+0.4328	--->	0.0700 ft
	Z =	22.9733 ft	+0.4321	-0.9014	-0.0276	--->	0.0201 ft
		Azim. = 343 39 12.7349					00 02 39.1122
	Attitude:	Elev. = 00 30 52.7467		Std Dev:			00 04 04.5073
		Swing = 00 06 10.4941					00 00 41.2954
	X =	30.0157 ft	+0.5462	+0.4155	+0.7273	--->	0.1313 ft
rht_top	Y =	-93.0833 ft	-0.7097	-0.2317	+0.6653	--->	0.0748 ft
	Z =	41.4006 ft	+0.4450	-0.8796	+0.1683	--->	0.0211 ft
		Azim. = 343 44 12.6986					00 03 07.2612
	Attitude:	Elev. =- 09 22 22.7541		Std Dev:			00 04 00.7174
		Swing =- 01 19 26.2052					00 00 45.7613

S U M M A R Y   S T A T I S T I C S   F O R   C A M E R A   S T A T I O N S

RMS For Standard Deviations

	X = 0.0873 ft	Azim. =	00 02 54.2656
Count = 9	Y = 0.0461 ft	Elev. =	00 04 12.2820
	Z = 0.1184 ft	Swing =	00 00 44.7674

T R I A N G U L A T E D   O B J E C T   P O I N T S

Ident		Position (feet)	Error Ellipsoid --->			Length (ft)
	X =	0.0058	-3.345E-02	-9.884E-01	+1.478E-01	0.0047
10 *0*	Y =	0.0017	+9.990E-01	-3.726E-02	-2.310E-02	0.0044
	Z =	-0.0053	-2.834E-02	-1.469E-01	-9.887E-01	0.0044
	X =	0.0094	-4.395E-02	-9.864E-01	+1.584E-01	0.0047
11 *0*	Y =	-0.0021	+9.989E-01	-4.126E-02	+2.023E-02	0.0043
	Z =	5.9840	+1.342E-02	-1.591E-01	-9.872E-01	0.0042
	X =	-38.2552	+1.286E-01	-9.882E-01	+8.260E-02	0.0344
21	Y =	0.2242	+8.501E-01	+1.528E-01	+5.040E-01	0.0117
	Z =	7.1021	+5.107E-01	-5.381E-03	-8.597E-01	0.0106
	X =	-40.9036	+1.638E-01	-9.854E-01	+4.547E-02	0.0330
22	Y =	0.1737	+9.157E-01	+1.690E-01	+3.647E-01	0.0116
	Z =	14.0425	+3.671E-01	+1.810E-02	-9.300E-01	0.0106
	X =	-42.7607	-2.057E-01	+9.785E-01	+1.319E-02	0.0314
23	Y =	0.1147	-9.756E-01	-2.040E-01	-8.145E-02	0.0114
	Z =	24.0802	+7.701E-02	+2.962E-02	-9.966E-01	0.0106
	X =	-44.0511	-2.669E-01	+9.619E-01	+5.970E-02	0.0346
24	Y =	0.0438	-9.399E-01	-2.735E-01	+2.042E-01	0.0123
	Z =	34.2495	-2.128E-01	+1.595E-03	-9.771E-01	0.0112
	X =	-44.7532	-2.211E-01	+9.571E-01	+1.872E-01	0.0350
25	Y =	-4.0226	-2.757E-01	-2.455E-01	+9.294E-01	0.0123
	Z =	45.1988	+9.354E-01	+1.539E-01	+3.182E-01	0.0117
	X =	-27.6186	+1.068E-01	-9.885E-01	+1.075E-01	0.0297
31	Y =	0.2071	-9.217E-01	-1.389E-01	-3.621E-01	0.0101
	Z =	6.6549	-3.729E-01	+6.039E-02	+9.259E-01	0.0098
	X =	-33.0732	+1.544E-01	-9.864E-01	+5.609E-02	0.0296
32	Y =	0.1813	-9.604E-01	-1.632E-01	-2.260E-01	0.0102
	Z =	14.0304	-2.321E-01	+1.897E-02	+9.725E-01	0.0100
	X =	-33.0460	-1.924E-01	+9.812E-01	+1.414E-02	0.0281
33	Y =	0.0966	+7.206E-01	+1.510E-01	-6.767E-01	0.0098
	Z =	24.0802	+6.661E-01	+1.200E-01	+7.361E-01	0.0097
	X =	-32.9980	+1.176E-03	-1.000E+00	+2.985E-03	0.0048
34 *0*	Y =	0.0002	+7.324E-01	-1.172E-03	-6.808E-01	0.0046
	Z =	34.2521	-6.808E-01	-2.987E-03	-7.324E-01	0.0046
	X =	-32.9207	-1.749E-01	+9.643E-01	+1.987E-01	0.0382
35	Y =	-0.1454	-4.802E-01	-2.597E-01	+8.379E-01	0.0120
	Z =	45.9864	+8.596E-01	+5.112E-02	+5.085E-01	0.0116
	X =	27.5610	-1.775E-01	-9.745E-01	+1.371E-01	0.0350
41	Y =	0.0709	+7.547E-01	-4.539E-02	+6.545E-01	0.0104
	Z =	6.6936	+6.316E-01	-2.197E-01	-7.435E-01	0.0101

T R I A N G U L A T E D   O B J E C T   P O I N T S

Ident	Position (feet)		Error Ellipsoid --->			Length (ft)
	X =	32.9914	-2.405E-01	-9.689E-01	+5.874E-02	0.0327
42	Y =	0.0085	-5.631E-01	+8.995E-02	-8.215E-01	0.0102
	Z =	14.0684	+7.907E-01	-2.306E-01	-5.672E-01	0.0101
	X =	32.9785	+2.455E-01	+9.693E-01	+1.305E-02	0.0319
43	Y =	0.0039	+2.992E-01	-8.857E-02	+9.501E-01	0.0100
	Z =	24.1032	+9.221E-01	-2.294E-01	-3.117E-01	0.0098
	X =	32.9828	+4.776E-03	+1.000E+00	-1.389E-03	0.0048
44 *0*	Y =	0.0002	-7.490E-01	+2.656E-03	-6.626E-01	0.0046
	Z =	34.2380	+6.626E-01	-4.205E-03	-7.490E-01	0.0046
	X =	32.8321	+1.103E-01	+9.745E-01	+1.955E-01	0.0615
45	Y =	-0.2546	+2.464E-02	-1.994E-01	+9.796E-01	0.0135
	Z =	45.8741	+9.936E-01	-1.032E-01	-4.600E-02	0.0119
	X =	38.1270	-2.151E-01	-9.698E-01	+1.147E-01	0.0416
51	Y =	-0.0052	+5.472E-01	-2.170E-01	-8.084E-01	0.0118
	Z =	7.1186	+8.089E-01	-1.111E-01	+5.774E-01	0.0115
	X =	40.7659	-2.663E-01	-9.624E-01	+5.327E-02	0.0368
52	Y =	-0.0353	+8.662E-01	-2.632E-01	-4.247E-01	0.0115
	Z =	14.0930	-4.228E-01	+6.696E-02	-9.038E-01	0.0109
	X =	42.5834	+2.782E-01	+9.605E-01	+1.213E-02	0.0364
53	Y =	-0.1776	-9.460E-01	+2.718E-01	+1.765E-01	0.0115
	Z =	24.0662	-1.662E-01	+6.057E-02	-9.842E-01	0.0109
	X =	43.8769	+2.765E-01	+9.582E-01	+7.395E-02	0.0379
54	Y =	-0.1806	-9.334E-01	+2.861E-01	-2.167E-01	0.0123
	Z =	34.1768	+2.288E-01	+9.102E-03	-9.734E-01	0.0111
	X =	44.5966	+2.460E-01	+9.517E-01	+1.838E-01	0.0474
55	Y =	-3.9806	+5.592E-01	-2.942E-01	+7.751E-01	0.0135
	Z =	45.1475	+7.917E-01	-8.788E-02	-6.046E-01	0.0124

S U M M A R Y   S T A T I S T I C S   F O R   O B J E C T   P O I N T S

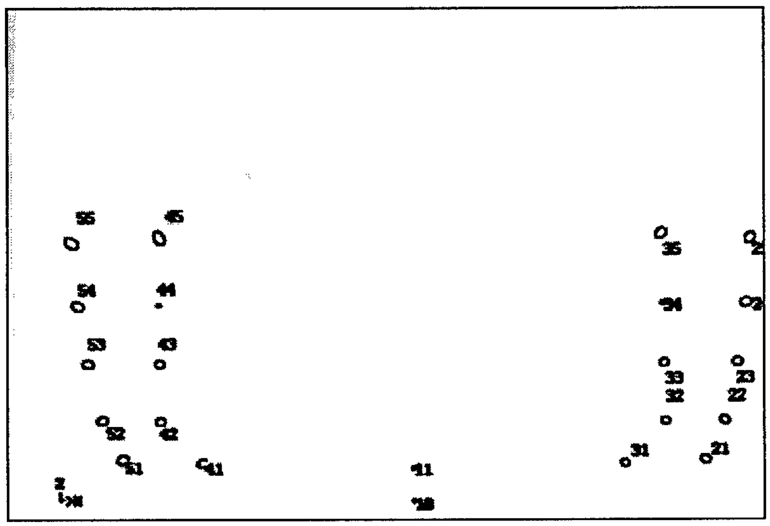
RMS For Standard Deviations

Count =	18	X =	0.0134 feet
Count =	18	Y =	0.0361 feet
Count =	18	Z =	0.0120 feet

C O R R E C T I O N S   A P P L I E D   T O   O B J E C T   C O N T R O L

	X =	0.0058 ft		X =	0.0094 ft
10	Y =	0.0017 ft	11	Y =	-0.0021 ft
	Z =	-0.0053 ft		Z =	-0.0160 ft
	X =	0.0020 ft		X =	-0.0172 ft
34	Y =	0.0002 ft	44	Y =	0.0002 ft
	Z =	0.0177 ft		Z =	0.0036 ft

X .... Number of Components = 4 RMS = 0.0103 feet
Y .... Number of Components = 4 RMS = 0.0013 feet
Z .... Number of Components = 4 RMS = 0.0124 feet



Error Ellipsoids - ZX plane