

# **TRISS ERROR ANALYSIS**

## **Part II – More Analysis Cases**

**By**

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# **1. INTRODUCTION**

## **1.1 Scope**

This document summarizes the analysis conducted to evaluate the susceptibility of the Tracking Infrared Scoring System (TRISS) to site measurement errors and camera calibration errors for different TRISS configurations.

## **1.2 Background**

TRISS is a ground based scoring system that uses two cameras with infrared lenses to determine the distance between a pre-selected target and the position where the deployed warhead hits the ground. TRISS also determines the scoring angle with respect to the aircraft that deployed the bomb (i.e. ingress angle).

# **2. CONCLUSION**

The analysis shows that the accuracy of the scoring error is totally dependent in the accuracy of the internal angles between the cameras and the target used for scoring and the accuracy of the position of Cameras 1 and 2. The analysis also shows that the absolute position of C1 and C2 is not necessarily needed as long as the distance between C1 and C2 is accurately known and TRISS “knows” where true North is. The analysis also indicates that TRISS is very sensitive to Camera calibration errors.

# **3. TRISS MATHEMATICAL MODEL**

The analysis was conducted using a Monte-Carlo simulation model of TRISS. This model was developed using the MATLAB program. The MATLAB program is a 4<sup>th</sup> generation language that provides the user with the necessary tools to easily generate math models of complex physical systems.

The TRISS mathematical model assumes that the target is co-centric to cameras 1 and 2. Camera 1 position is fixed and Camera 2 rotates around the target. The TRISS model computes the estimated target position error every time C2 is rotated one degree around the target. The user has the capability to modify C1 and C2 starting positions as well as the radius between C1 and the target. The user also has the capability to vary camera position and add angular measurement errors. The user also has the capability to simulate camera calibration errors.

## 4. ANALYSIS RESULTS

### 4.1 Case 1 Analysis

For this case scenario, the cameras were positioned 90 degrees apart. The target was in the center approximately 1 mile from cameras 1 and 2. It was assumed that both cameras experienced an angular misalignment standard deviation error (SDE) of 0.1degrees with the respect to the target. Figure 1-1, subplots 1 and 2 depict the expected TRISS error estimating target position under different geometries on two different scales. The x-axis is the number of degrees that Camera 2 is rotated (counterclockwise) around the target. The y-axis represents the standard deviation of the measurement error. The plot shows the standard deviation errors when C2 is rotated around the target and C1 remains stationary. Notice that the errors increased exponentially when C2 was exactly opposite to C1 (0 degrees) and when C2 and C1 were on the same spot (180 degrees). Figure 1-1 shows that the best accuracy is given when the angular separation between C1 and C2 is within 80-130 degree range. These analysis results make sense since good geometry is needed to estimate the target position. If C1, C2, and the target are in the same plane the geometry is poor and the errors are considerably amplified. Figure 1-2 shows the internal angles A, B and C of triangle formed by C1, C2 and the target. Figure 1-3 shows the distances estimated by TRISS between C1 and the Target and between C2 and the target using equations 1 and 2.

$$C1\_T = C1\_C2 * \sin(d2r*ANGLE\_B) / \sin(d2r*ANGLE\_C); \quad (\text{Equation 1})$$

$$C2\_T = C1\_C2 * \sin(d2r*ANGLE\_A) / \sin(d2r*ANGLE\_C); \quad (\text{Equation 2})$$

Notice in Figure 1-3 that the computation of the estimated distances became “unstable” when ANGLE\_C approaches 0 degrees and when ANGLE\_A or ANGLE\_B approaches 0 degrees at the same time ANGLE\_C approaches 0 degrees (system singularities). Remember the ratios  $k/0$ , and  $0/0$  are numerically unstable. If TRISS becomes a dynamic system it is recommended to eliminate these singularity points.

Figure 1-4 shows the TRISS scoring error when the “bomb” is rotated 100 feet around the target. A 0.1degree standard deviation calibration error was assumed for both cameras and as before, a 0.1 degree angular misalignment SDE was assumed between both cameras and the target. Notice the scoring error is pretty much constant (~ 20 feet) around the target. Figure 1-5 shows the internal angles A, B and C of the triangle formed by C1, C2 and the bomb. Notice that the angles barely change when the bomb is rotated around the target. Notice also that the internal angles never approached 0 degrees. This explain why the scoring error is pretty constant around the target as depicted in Figure 1-4

Figure 1-6 illustrates an X-Y plot indicating the position of C1 and C2 with respect to the target. Notice the cameras were positioned exactly 90 degrees apart.

Figure 1-7 shows the trajectory of the bomb rotating around the target (100 feet radius circle) and the multiple positions predicted by the TRISS Monte Carlo simulation model.

## **4.2 Case 2 Analysis**

This simulation case is identical to Case 1 with the exception that the Cameras were positioned 40 degrees apart with respect to the target. This was done to show the importance of placing the cameras as close as possible 90 degrees with respect to the target. Figure 2-1 shows the TRISS scoring error when the “bomb” is rotated 100 feet around the target. As before a 0.1degree standard deviation calibration error was assumed for both cameras and a 0.1 degree angular misalignment SDE was assumed between both cameras and the target. Notice the scoring error is no longer constant and at some scoring angles, the scoring error was close to 40 feet.

Figure 2-2 illustrates an X-Y plot indicating the position of C1 and C2 with respect to the target. Notice the cameras were positioned exactly 40 degrees apart.

Figure 2-3 shows the trajectory of the bomb rotating counterclockwise around the target (100 feet radius circle) and the multiple positions predicted by the TRISS Monte Carlo simulation model. Notice that the scoring inaccuracies were almost doubled by repositioning the cameras closer together (From 90 degrees to 40 degrees).

## **4.3 Case 3 Analysis**

For this case scenario, the angular misalignment errors between C1 and the target and between C2 and the target were varied from 0 degrees to 0.5 degrees. The intention of this simulation test was to show how sensitive TRISS is to angular misalignment errors even under perfect geometry situations. C1 and C2 were placed 90 degrees apart with respect to the target. The target was placed 5200 feet from C1 and C2. Figure 3-1 depicts a plot showing TRISS scoring errors in the y-axis versus angular misalignments of C1 and C2 in the x-axis. Notice the error increases from 0 feet to more than 70 feet for 0.5 degrees of angular misalignment. For this experiment zero calibration errors were assumed for C1 and C2.

## **4.4 Case 4 Analysis**

For this case scenario, the angular misalignment errors between C1 and the target and between C2 and the target were assumed to be zero degrees. However, the camera calibration errors were varied from 0 to 1 degree. The intention of this simulation test was to show how sensitive TRISS is to camera calibration errors even under perfect geometry situations. C1 and C2 were placed 90 degrees apart with respect to the target. The target was placed 5200 feet from C1 and C2. Figure 4-1 depicts a plot showing TRISS scoring errors versus camera calibration errors. Notice the error increased from 0 feet to more than 90 feet for a 1 degree standard deviation camera calibration error.

## **5. SUMMARY OF RESULTS AND RECOMENDATIONS**

5.1 The analysis of Cases 1 and 2 show that the best geometry is obtained when the cameras C1 and C2 are placed 80-130 degrees apart.

5.2 Case 3 clearly shows that TRISS is extremely sensitive to angular inaccuracies.

5.3 Case 4 clearly indicates that TRISS is also very sensitive to camera calibration inaccuracies

5.4 Therefore, it is strongly recommended (imperative) that the positions of C1, C2 and the target be properly surveyed using specialized GPS surveying equipment. The total cost of the GPS equipment is approximately \$6000 for 3 GPS surveying sites.

5.5 The analysis also shows that the scoring error shall be very constant around the target if the separation angle between the target and C1 and C2 is close to 90 degrees.

## APPENDIX A -- TRISS MATLAB PLOTS

Figure 1-1

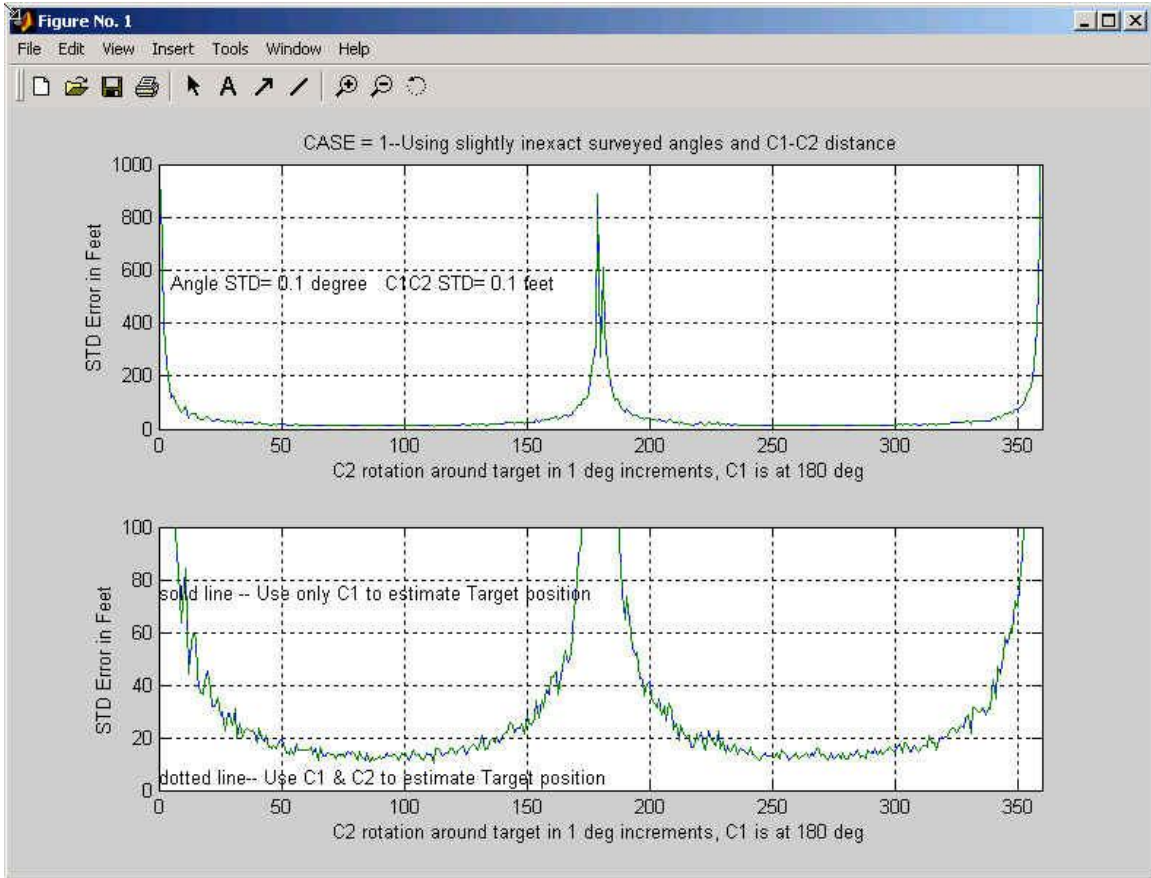
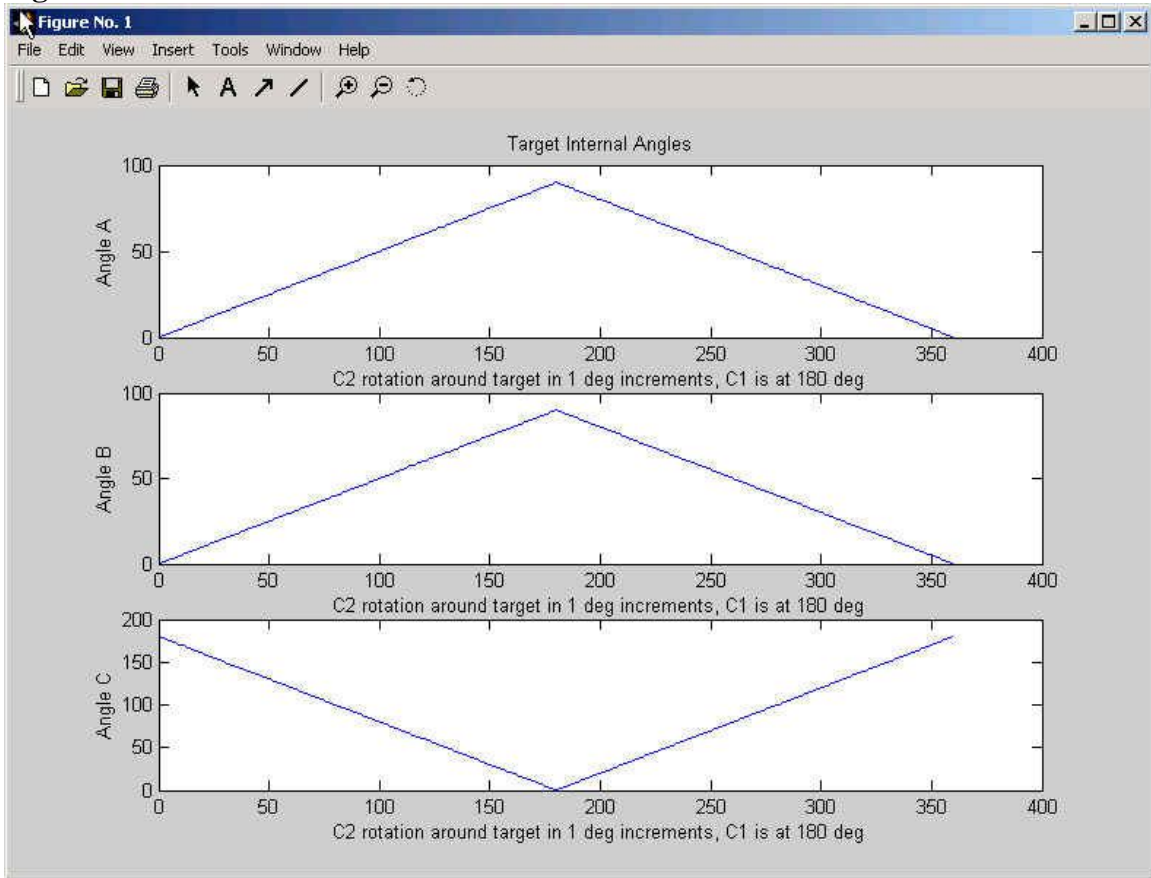


Figure 1-2



**Figure 1-3**

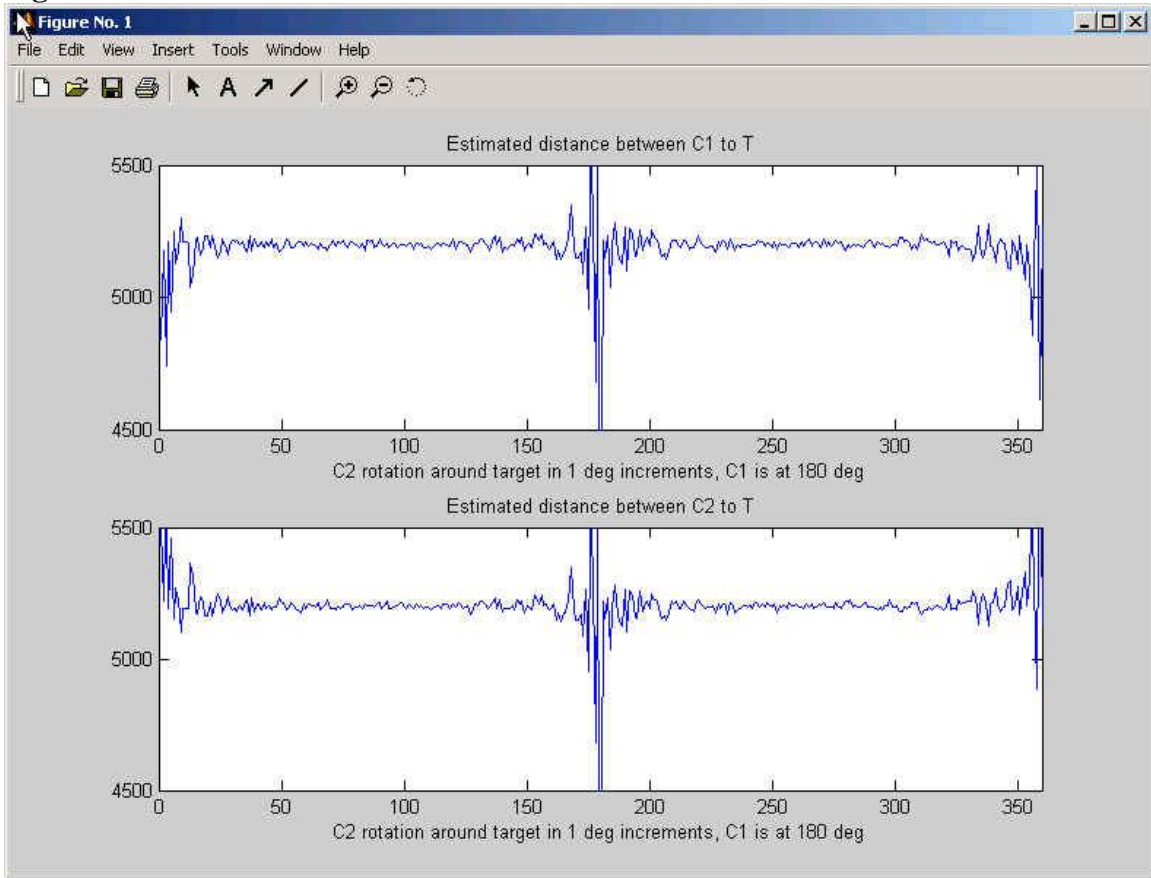


Figure 1-4

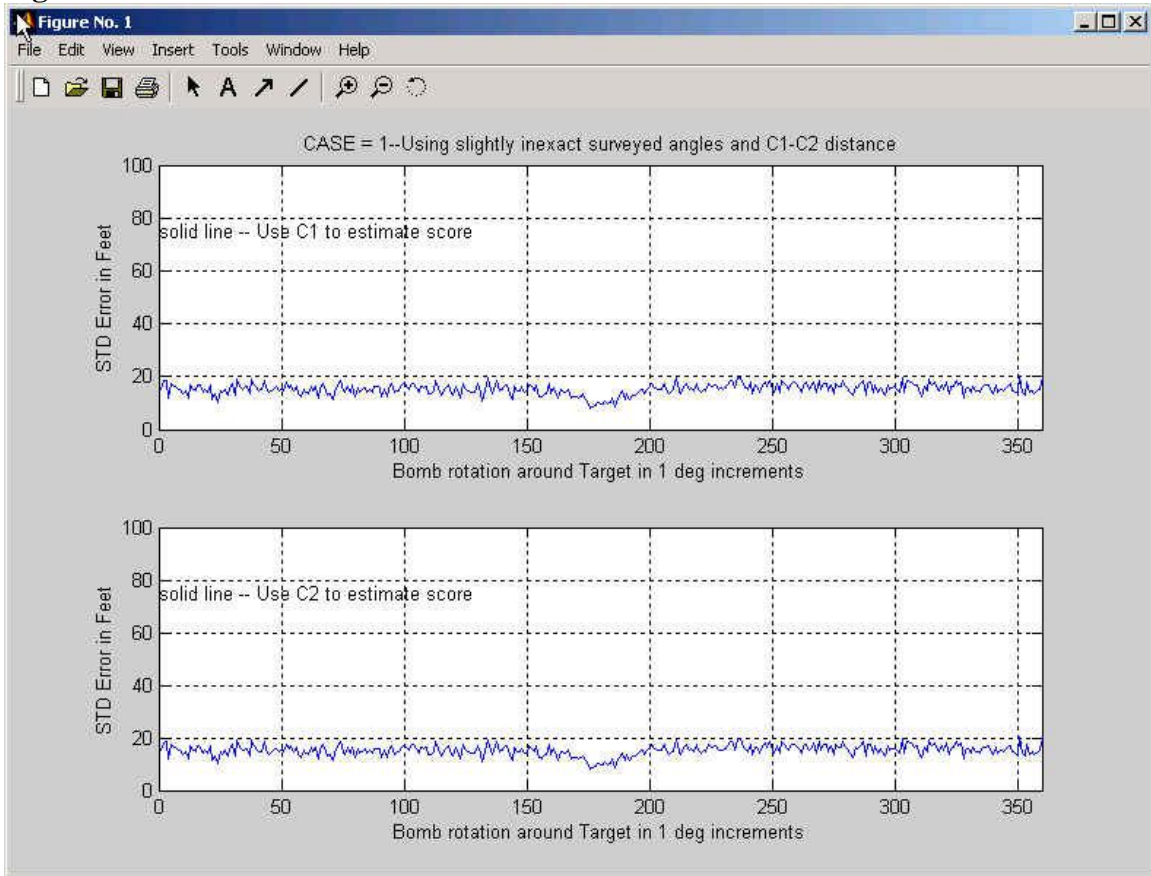
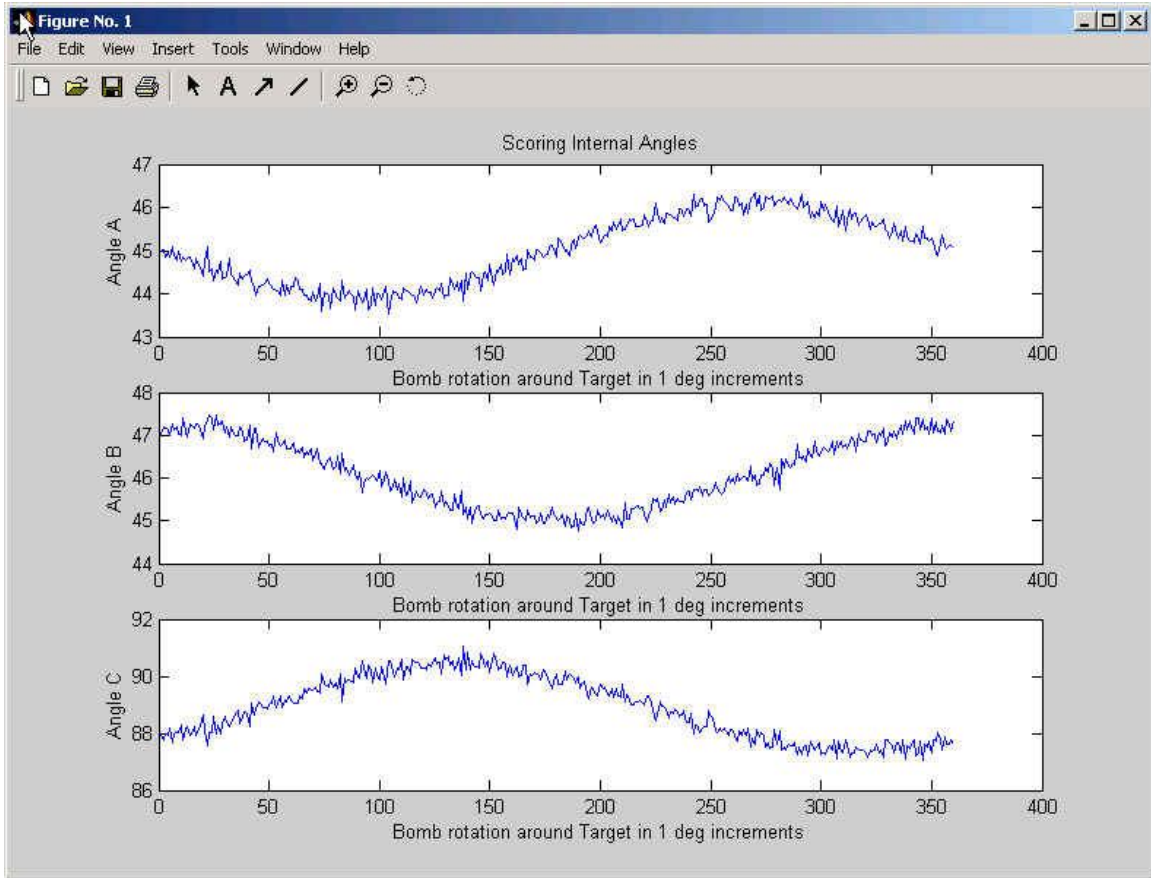
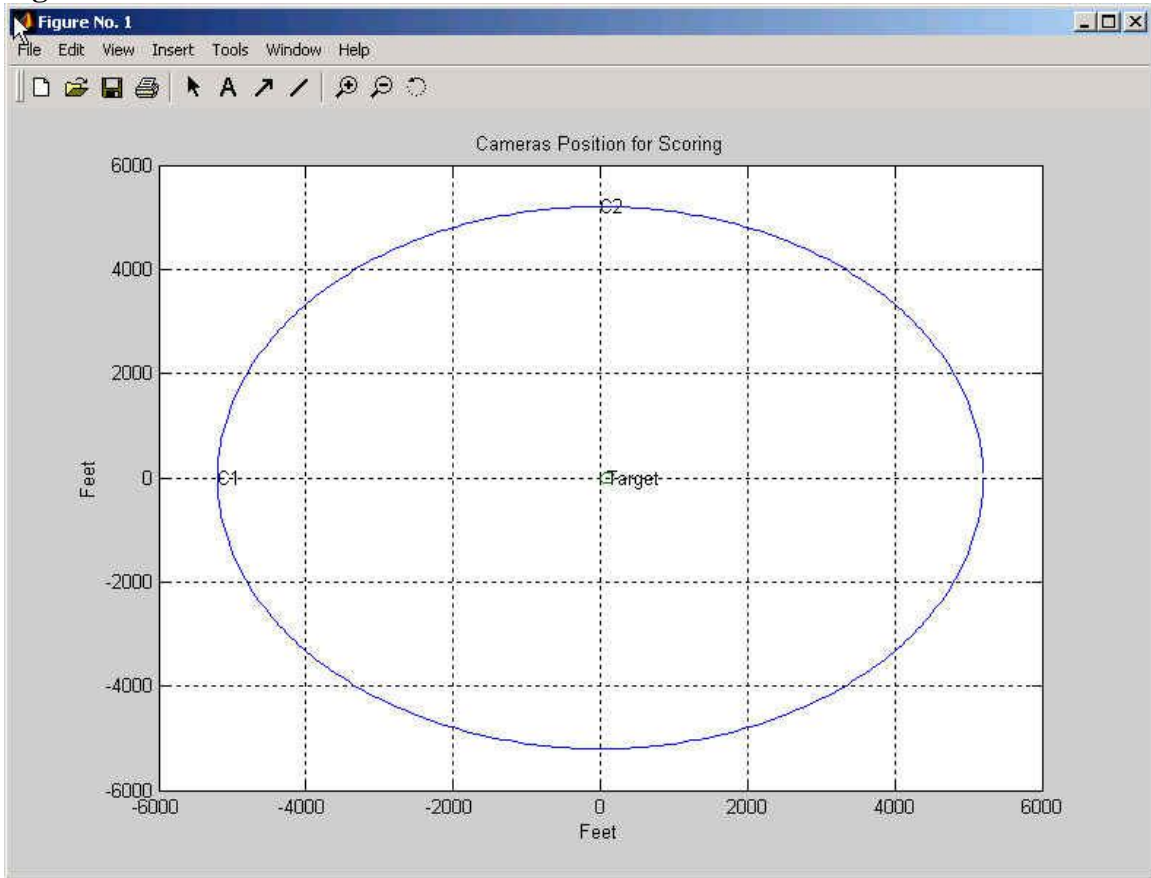


Figure 1-5



**Figure 1-6**



**Figure 1-7**

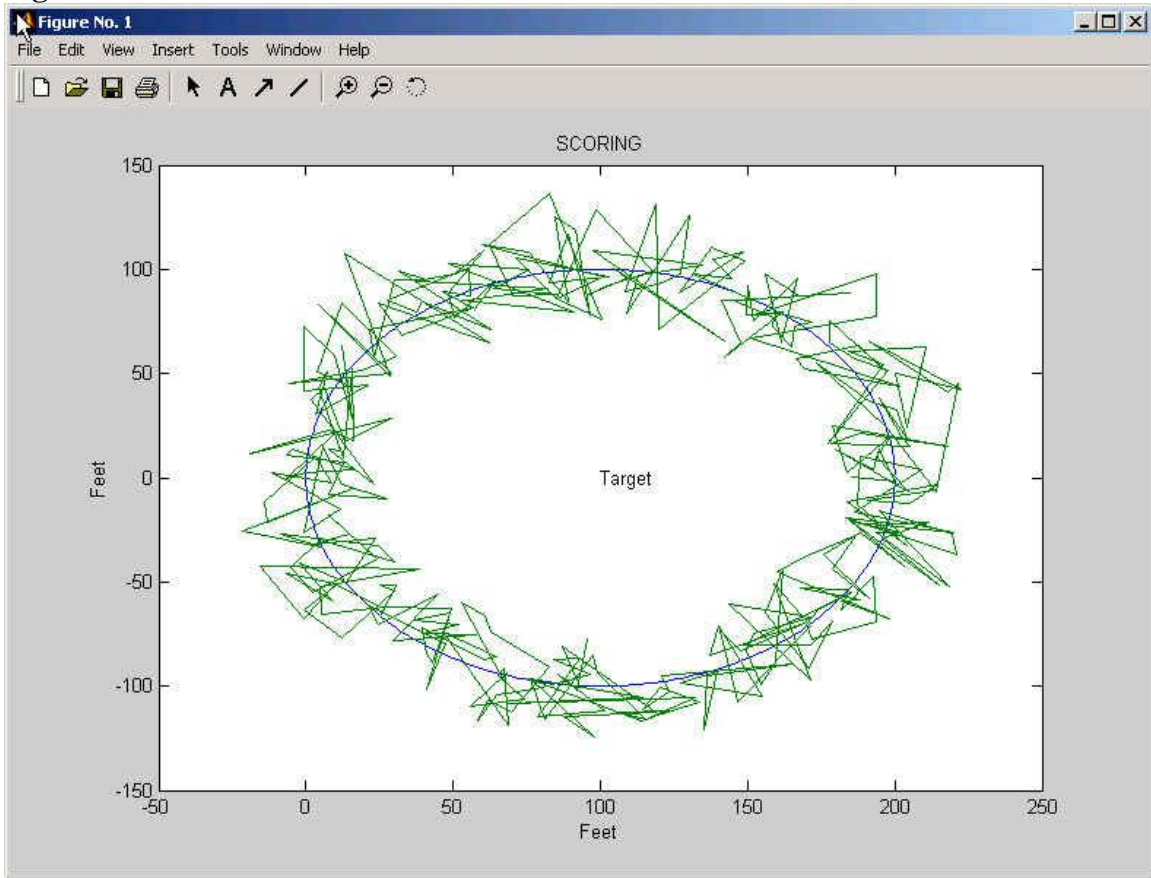
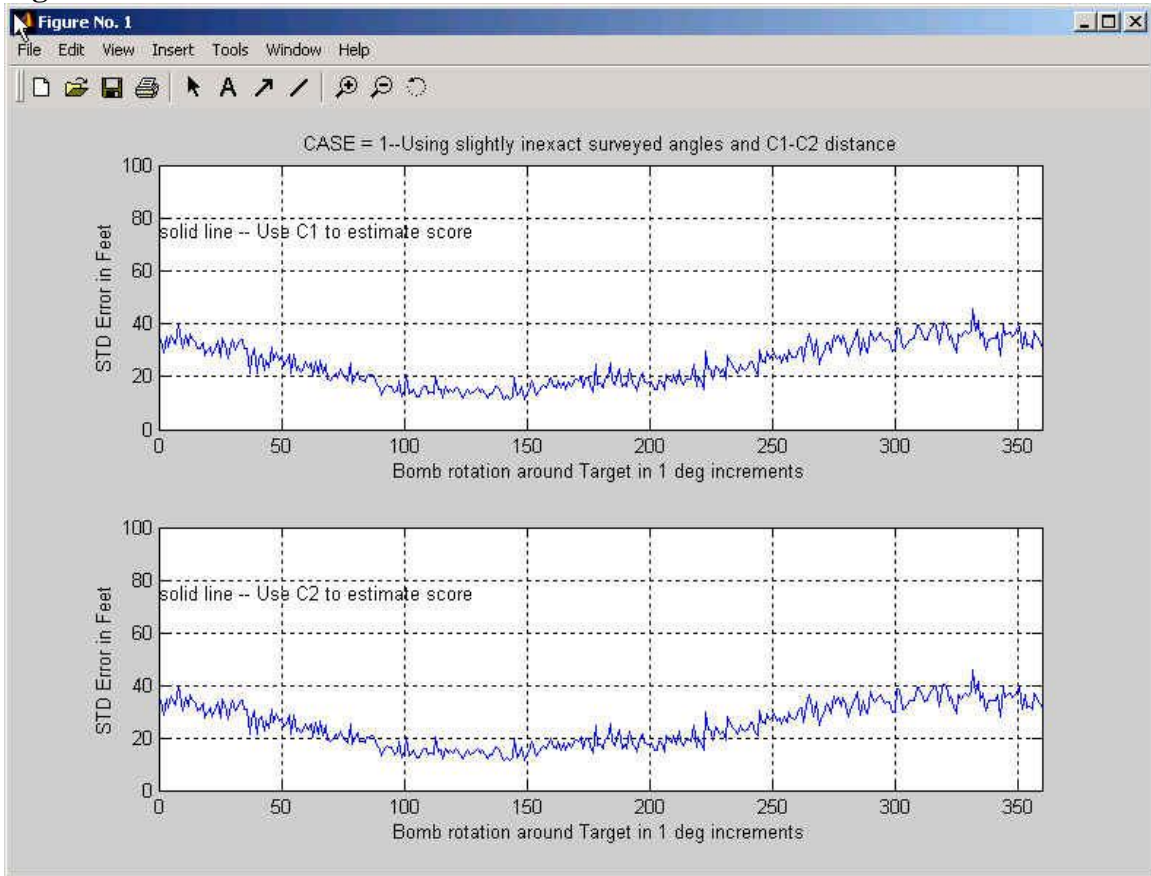
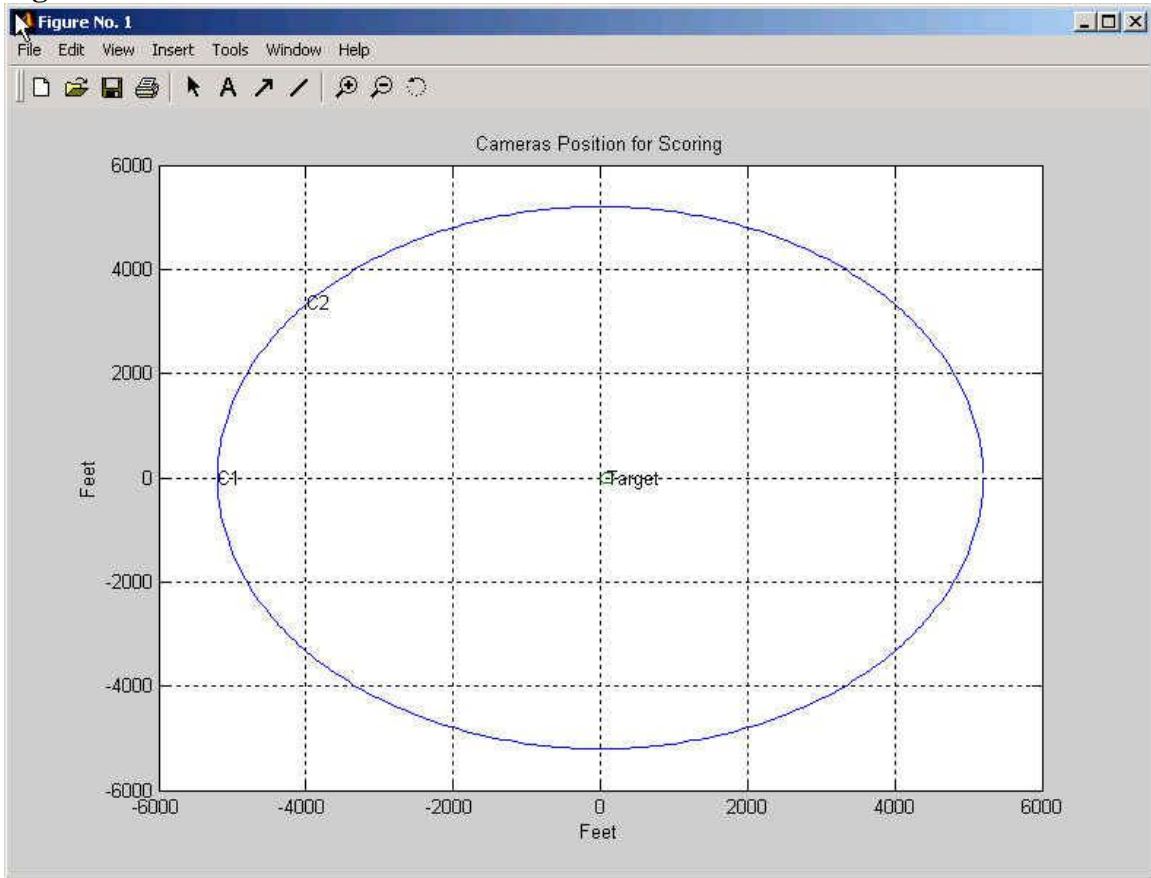


Figure 2-1



**Figure 2-2**



**Figure 2-3**

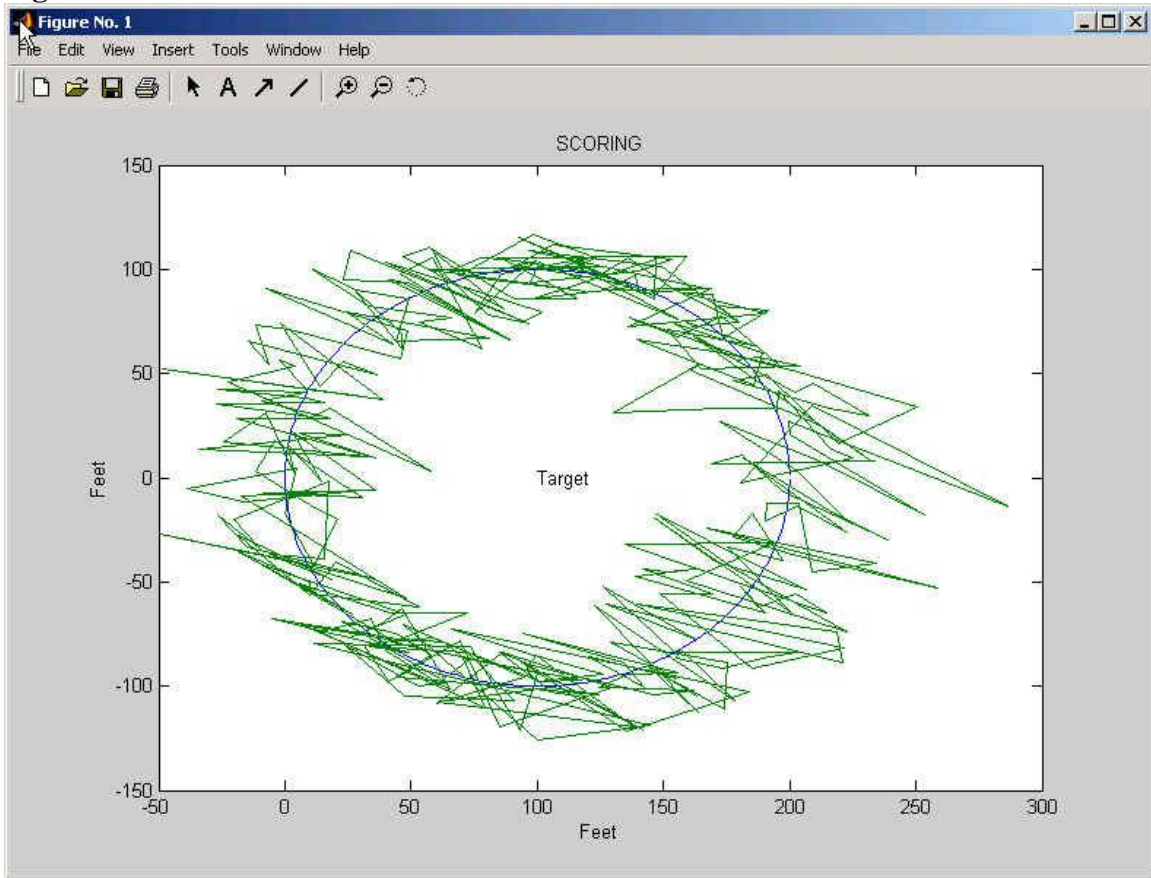


Figure 3-1

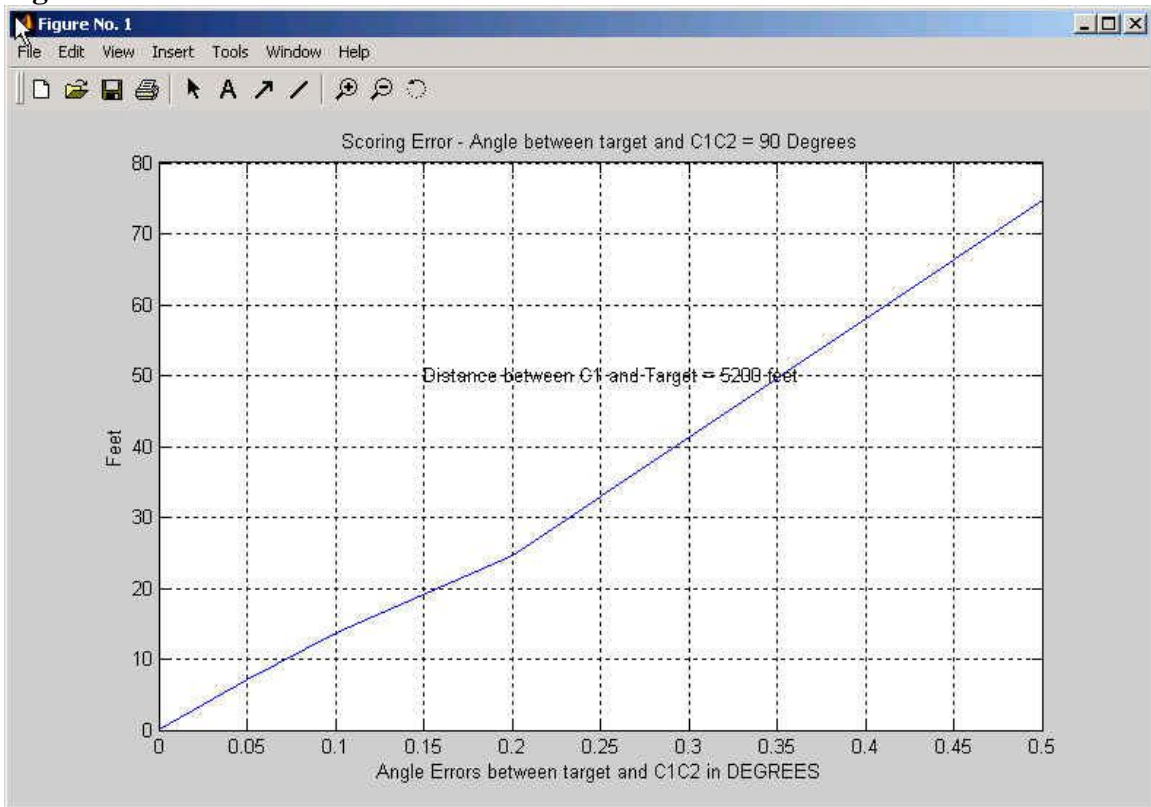


Figure 4-1

