NATIONAL DEFENSE INDUSTRIAL ASSOCIATION

ACCURACY MODELING OF THE 120MM M256 GUN AS A FUNCTION OF BORE CENTERLINE PROFILE

BRIEFING FOR THE GUNS, AMMUNITION, ROCKETS & MISSILES SYMPOSIUM - 25-29 APRIL 2005

Providing America Advanced Armaments for Peace and War

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ACCURACY MODELING OF THE 120mm M256 GUN AS A FUNCTION OF BORE CENTERLINE PROFILE

BACKGROUND AND MOTIVATION FOR THE CONDUCTION OF THIS STUDY

It is a well known fact that the centerline profile of the bore affects the in-bore dynamics and exit conditions of the projectile.

The exit state of the projectile serves as initial conditions to the projectile's flight path to its intended target.

A relatively accurate and quick running model of this would be beneficial to assess accuracy, especially for the newer, lightweight ordnance weapons.

Since simulations are just mathematical models of reality, validation is an extremely important aspect of their use.

The subject weapon has a plethora of field generated experimental data regarding accuracy and dispersion for several unique gun tubes.

We are submitting a validation effort of our modeling techniques through the attempted reproduction of this data using dedicated models and statistics knowing full well that replication of field generated data is most difficult.

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M1A2 TANK IN DESERT CAMOFLAUGE

DESCRIPTION OF THE ANALYSIS MODELS

Simulation of Barrel Dynamics (SIMBAD)

A quick running finite element code, which employs beam elements for the gun tube and a variety of options for modeling the projectile, mount and cradle.

Designed to predict the motion of the gun barrel and projectile during the firing phase, ultimately passing the exit conditions of the projectile to the flight prediction model.

Barrel employs three dimensional beam finite element structural representation using an Euler-Bernoulli formulation.

Shot is represented as a two piece flexible structure consisting of a projectile and sabot, both of which employ beam finite element formulation.

The dynamic equations for barrel, sabot and projectile are cast in a standard matrix form.

Since this type of problem is highly non linear, a modified Runge-Kutta time marching integration technique is employed.

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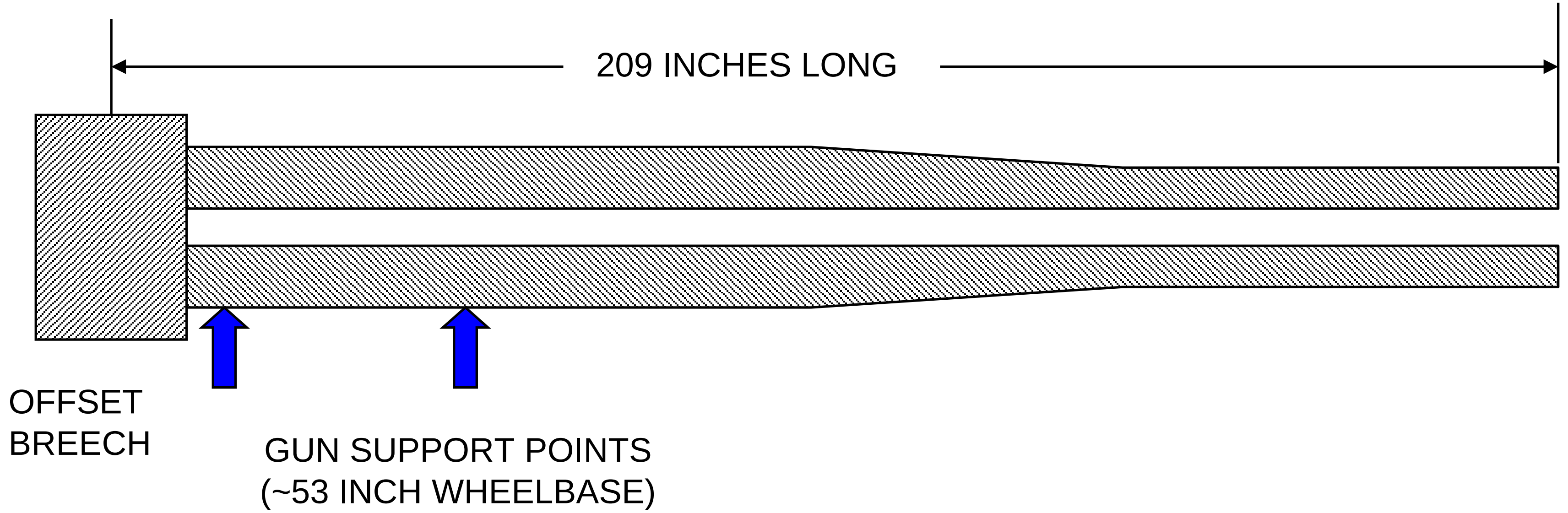
GUN BARREL MODEL IN SIMBAD



SIMBAD FINITE ELEMENT MODEL: 40 NODES; 41 ELEMENTS

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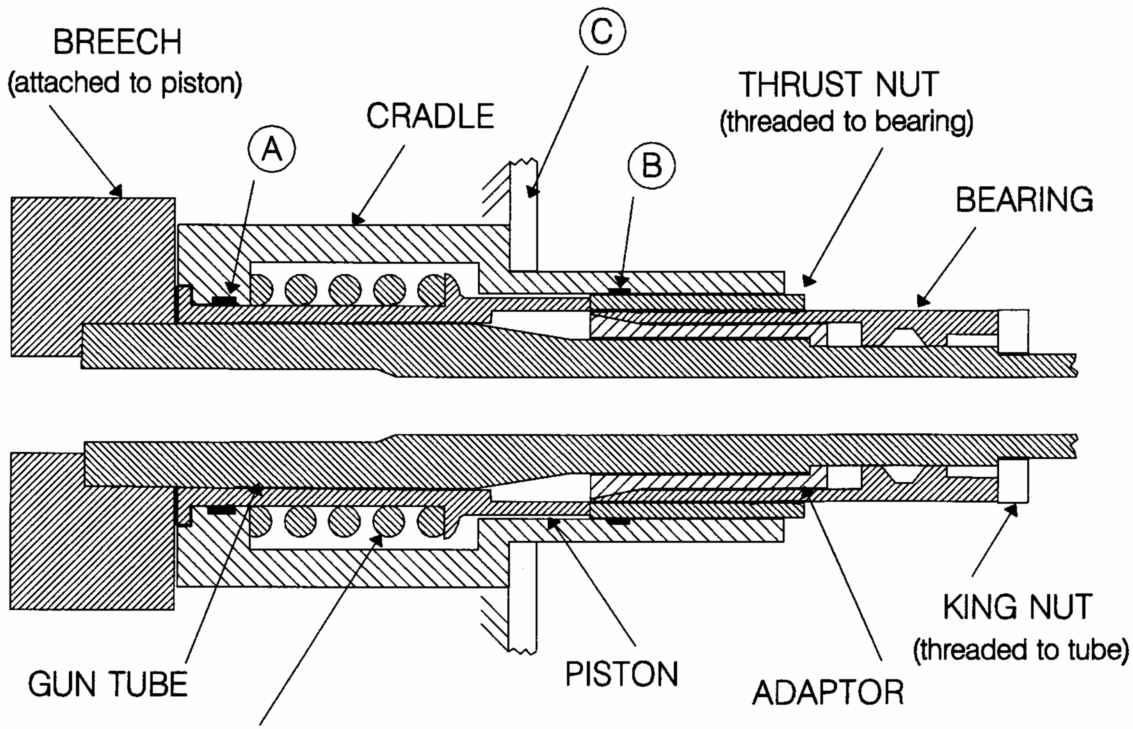
120mm M256 CANNON and MOUNT



For Clarity the radial scale is exaggerated and numerous features are not shown.

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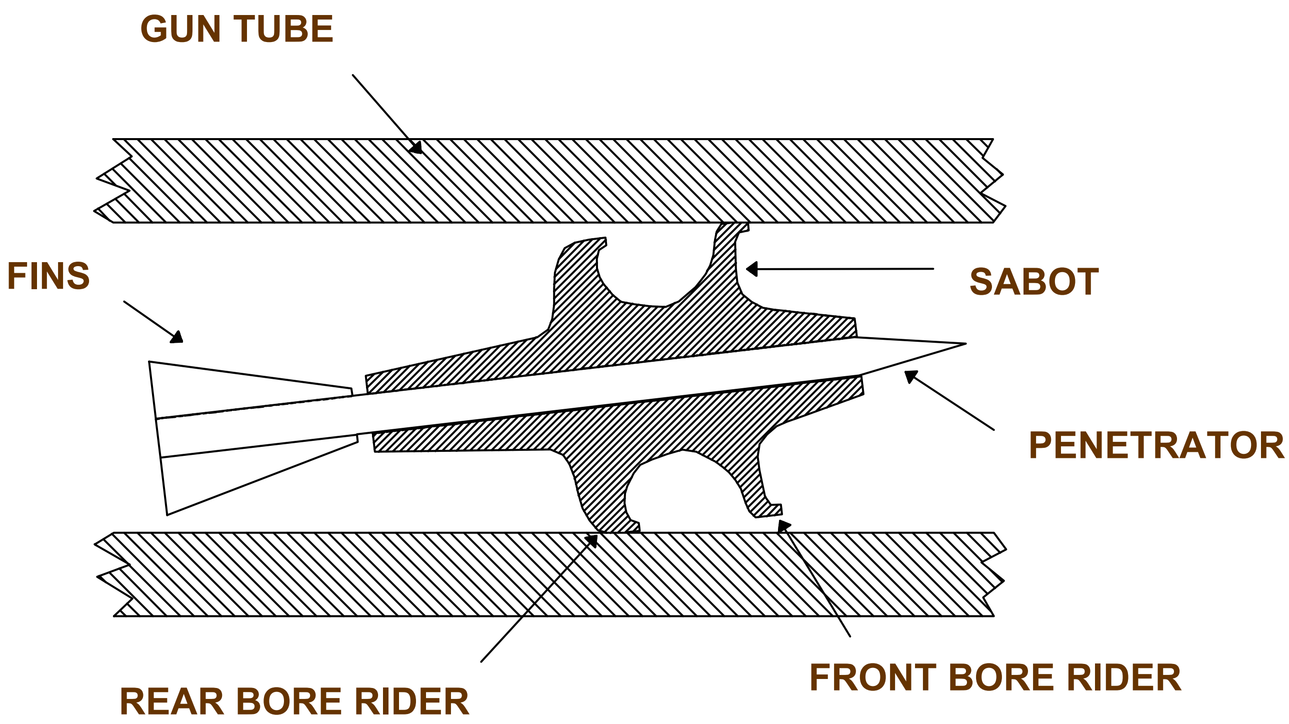
PROJECTILE MODEL IN SIMBAD



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DESCRIPTION OF THE ANALYSIS MODELS

BOOM

A six degree of freedom (dof) rigid body aerodynamics code used to predict the external flight path of ordnance projectiles.

The six dof's are comprised of three body inertial position coordinates as well as three Euler angle body attitudes.

The dynamic equations are written with respect to body a frame coordinate system.

The total applied force is composed of weight and body aerodynamic force terms (lift, drag, etc).

A considerable amount of empirical data (which is projectile dependent) used for lift and drag calculations has been generated at the Army Research Lab Test Center.

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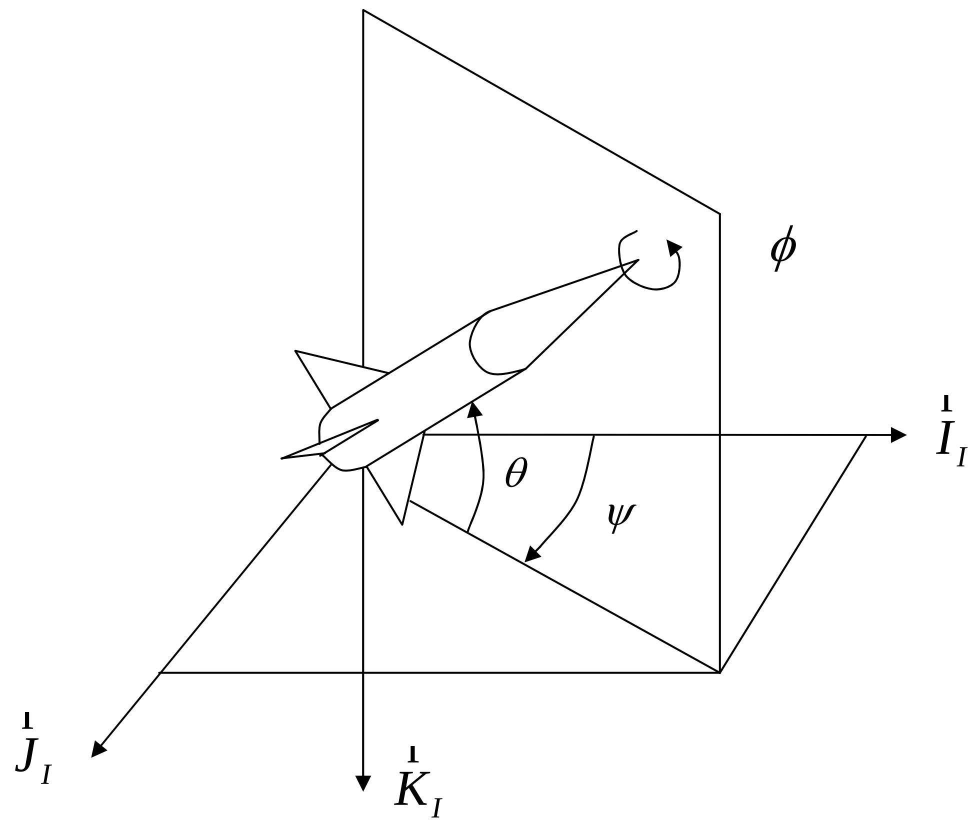
RIGID PROJECTILE MODEL IN BOOM



DESCRIPTION OF THE ANALYSIS MODELS

TRANSFER OF DATA FROM SIMBAD TO BOOM

Each of the computer codes are stand-alone employing their own coordinate systems.

An interface routine was developed through a coordinated effort among Benet Labs and the developers of the two codes.

This routine employs several matrix equations to transfer projectile's exit conditions (i.e. displacement, velocity, etc) from the SIMBAD coordinate system into the coordinate system used by BOOM.

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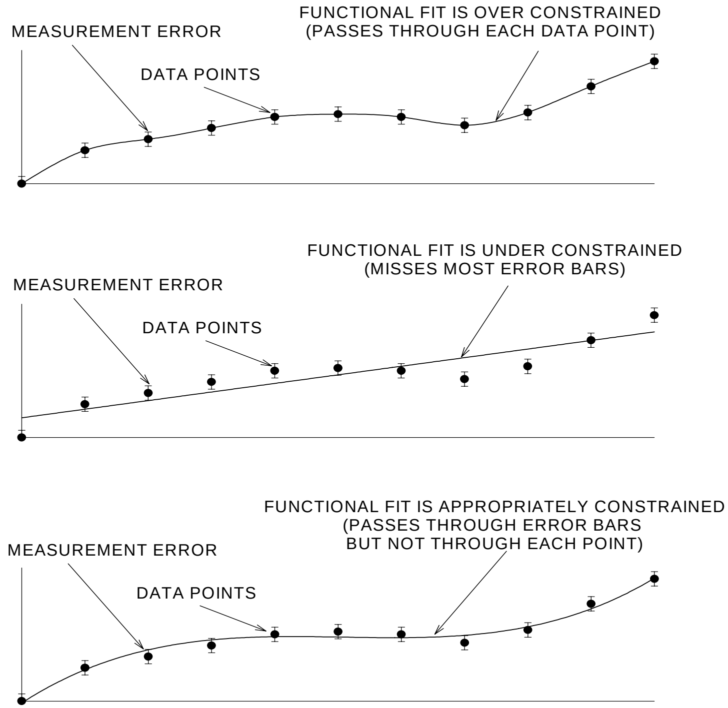
STATISTICAL METHODS FOR GENERATION OF SIMULATION DATA

BORE PROFILE FUNCTION



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ESTIMATION OF THE BORE CENTERLINE PROFILE

Bore profile centerline is derived from the inspection measurements taken during manufacture. There are usually 23 points (x_i, y_i) along the gun tube for which measurements are taken.

These measurements are used as the 'data' for a least squares polynomial fit (p_n) per the following equation:

$$p_n(x) = a_o + a_1x + a_2x^2 + a_3x^3 + \ldots\ldots + a_{n-1}x^{n-1} + a_nx^n$$

Several polynomial fits are generated (i.e. n = 2,…,14)

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ESTIMATION OF THE BORE CENTERLINE PROFILE

The coefficients for each polynomial order is determined by minimizing the residual (defined below) for each fit.

$$\sum_{i=0}^{22}[y_i - p_n(x_i)]^2$$

The change in residual from one order to the next is compared.

To determine which polynomial order yields the appropriate fit an F-test is conducted.

When the improvement from consecutive orders does not change significantly (using a 10% significance level) the lower order polynomial is chosen and the testing is terminated.

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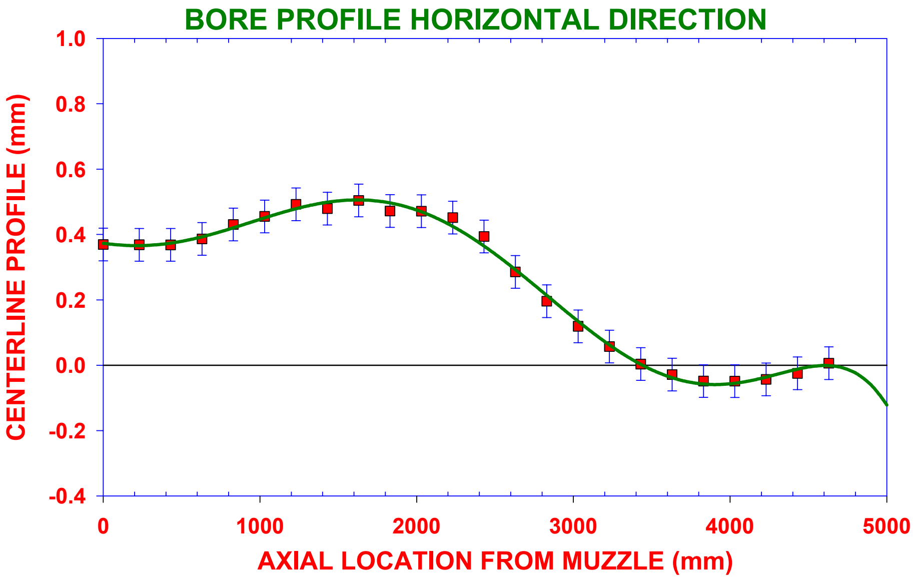
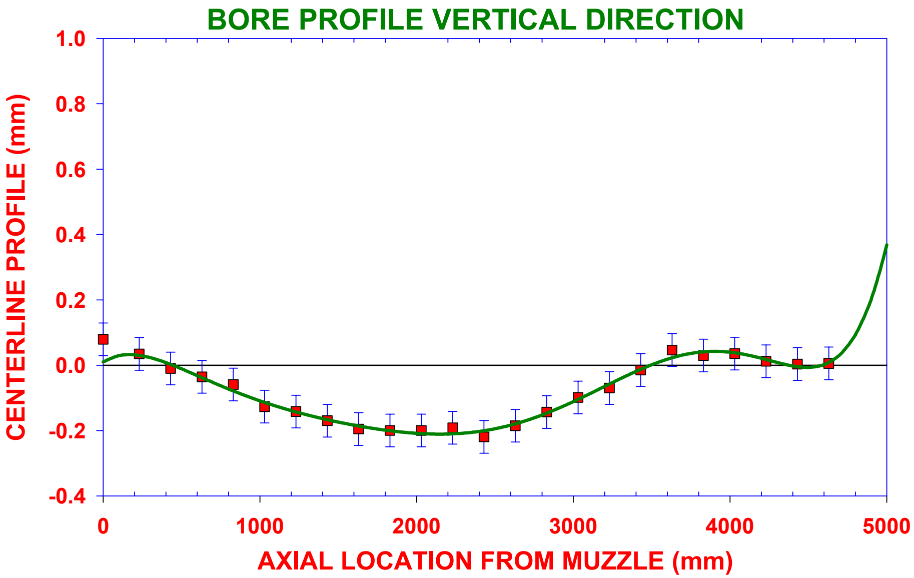
BORE CENTERLINE PROFILE DATA AND POLYNOMIAL FIT FOR TYPICAL GUN TUBE





STATISTICAL METHODS FOR GENERATION OF SIMULATION DATA

BALLISTIC PRESSURE AND MUZZLE VELOCITY

Peak pressure and muzzle velocity was recorded for each round in the test.

Each round type and bore profile configuration was fired 3 times on 3 occasions.

This provided the basis for developing a random array of muzzle velocity scale factors applied to the ballistic driving force for each simulated shot.

STATISTICAL METHODS FOR GENERATION OF SIMULATION DATA

PROJECTILE STIFFNESS AND CLEARANCE

The front and rear bore rider diameters have nominal dimensions with tolerance values as do any other engineered part.

A normal distribution of the diameters was assumed with the nominal value set at the midpoint of the diameter range.

The standard deviation of the distribution was set at one-third of the tolerance which would keep nearly all of the random diameter values within the tolerance range.

We had no way of knowing the actual values of these diameters.

COMPARISON OF TEST DATA TO SIMULATED RESULTS

The simplest method of comparing simulations to test data is in the form of 'target' plots indicating the angular offset from the aim point of the data and simulations at the target location.

These 'target' plots employ a 2.00 milli-radian square window with the aim point shown as a green cross.

For each gun tube bore profile there are 3 sets of 3 shots each for the test data and a 10 shot simulation employing the statistical variances in the input values previously discussed.

A total of 20 configurations were compared but only a few will be presented and discussed here.

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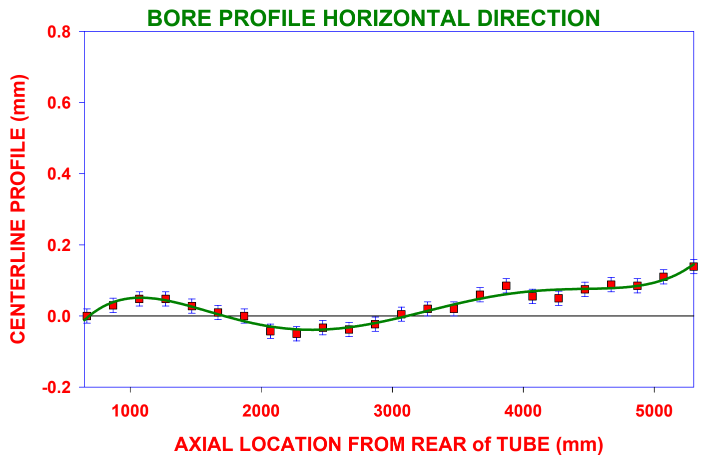
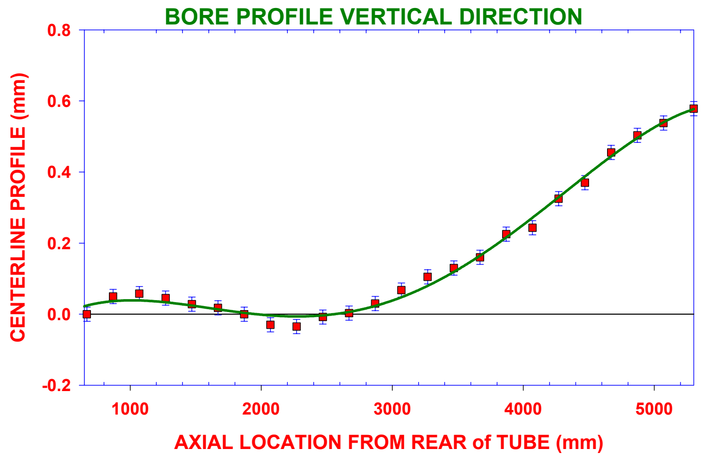
TUBE #1: PROFILE





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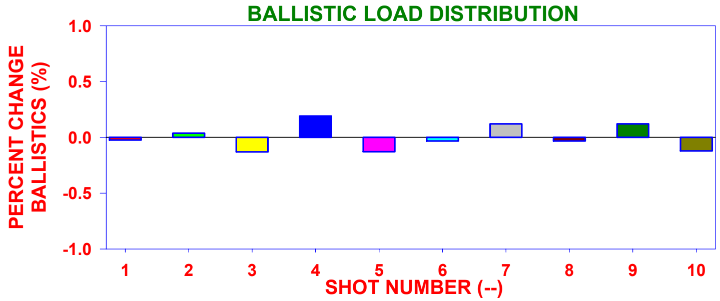
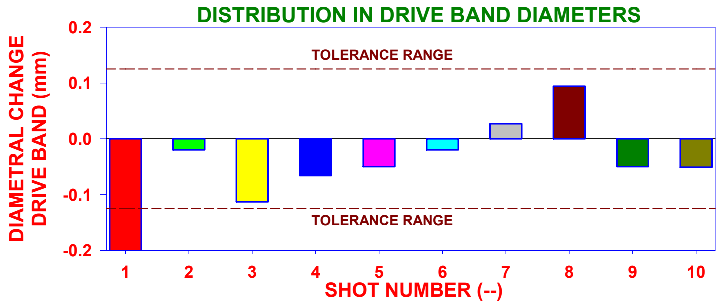
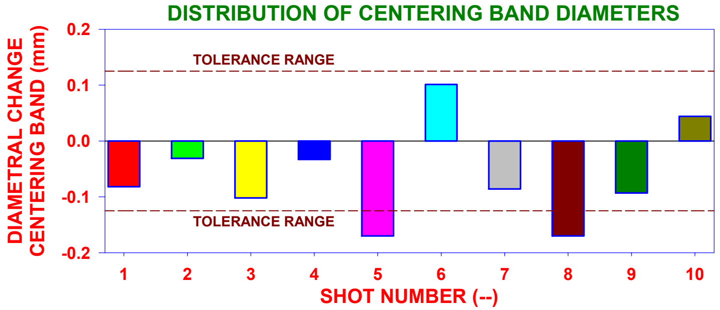
TUBE #1: LOAD / PROJECTILE DISTRIBUTIONS







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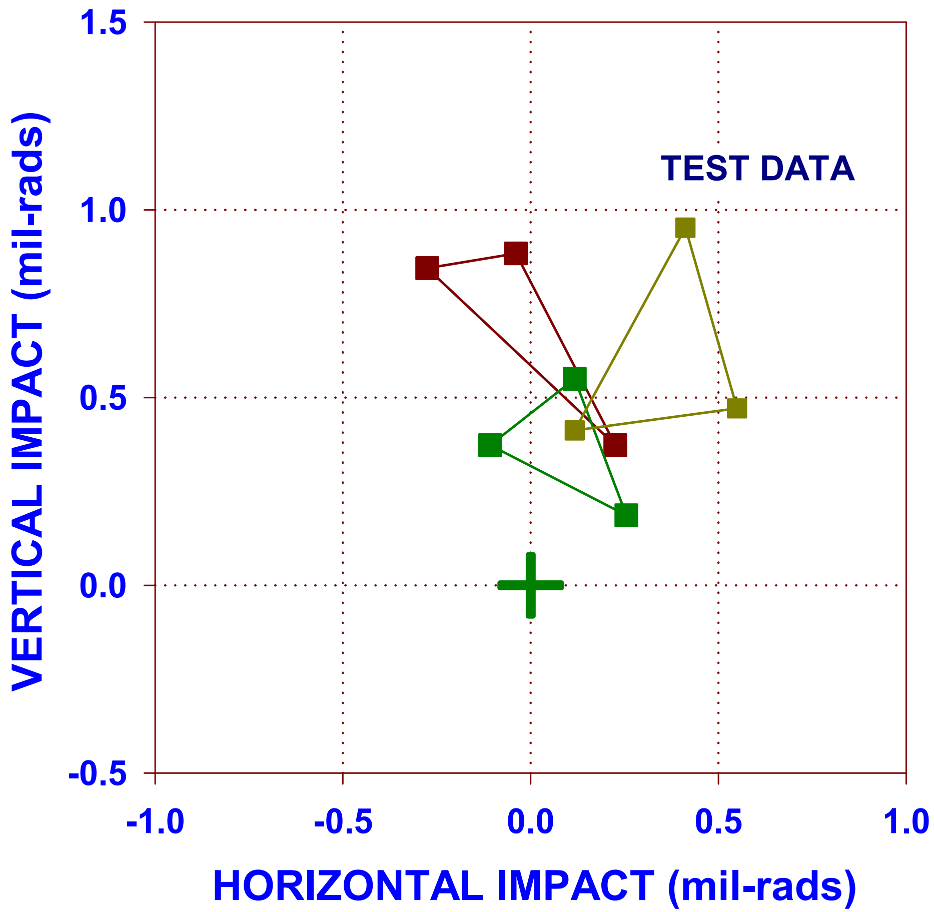
RESULTS for TUBE #1: DATA



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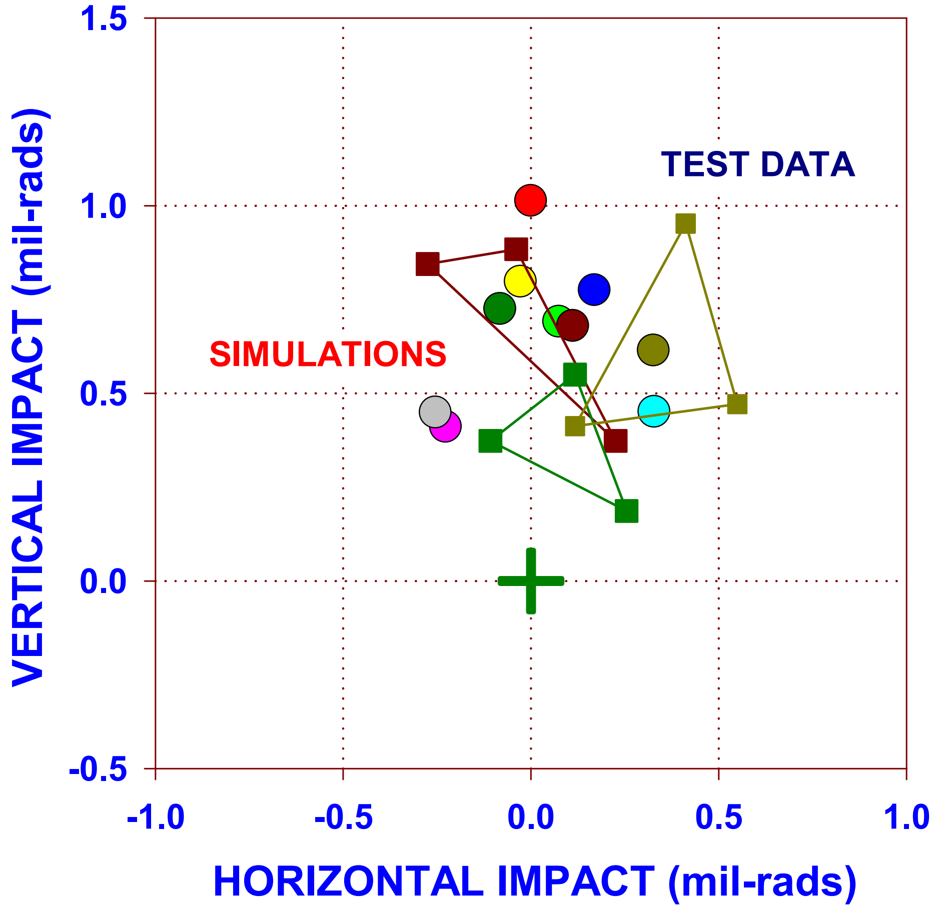
RESULTS for TUBE #1: DATA & SIMULATIONS



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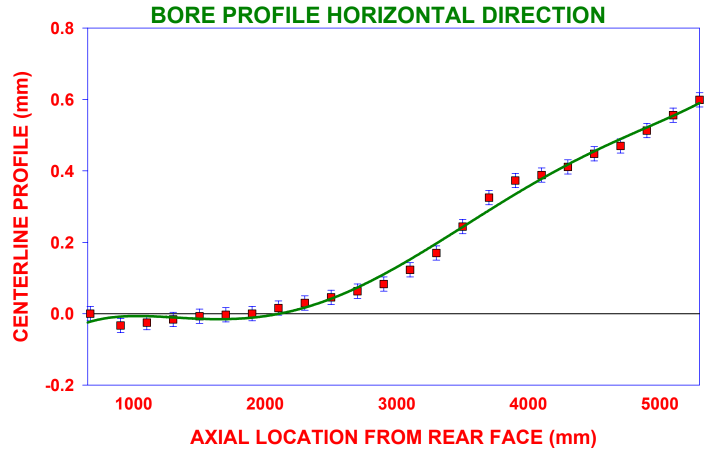
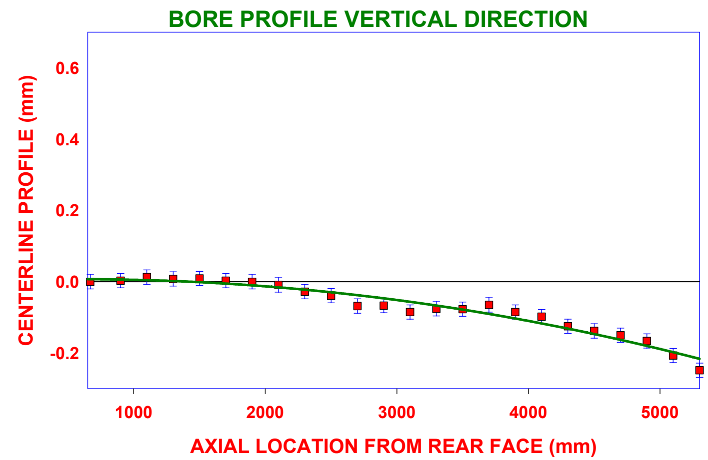
TUBE #2: PROFILE





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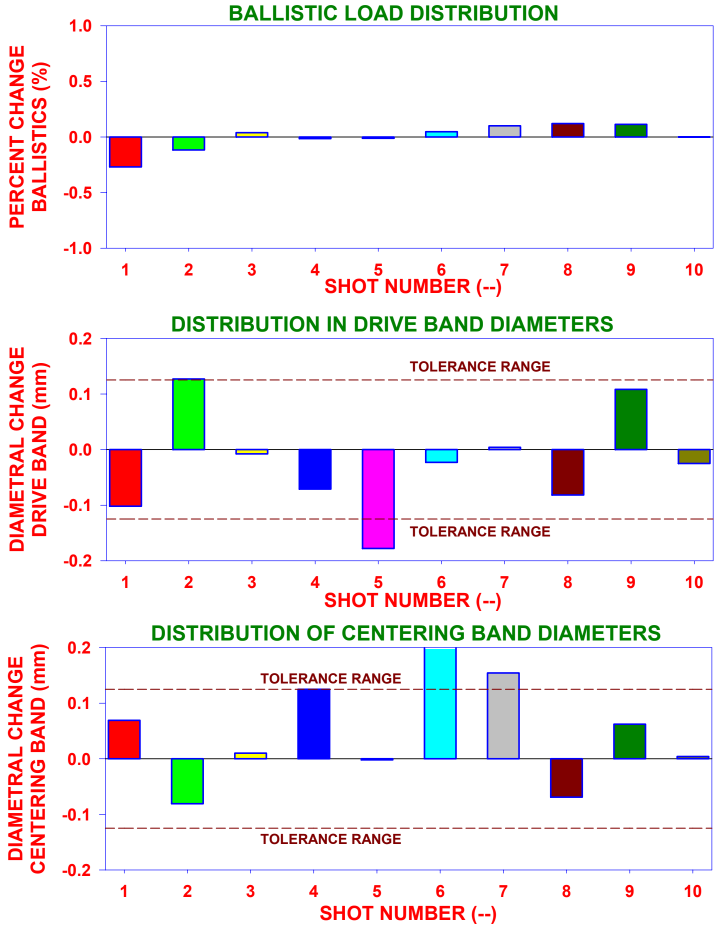
TUBE #2: LOAD / PROJECTILE DISTRIBUTIONS



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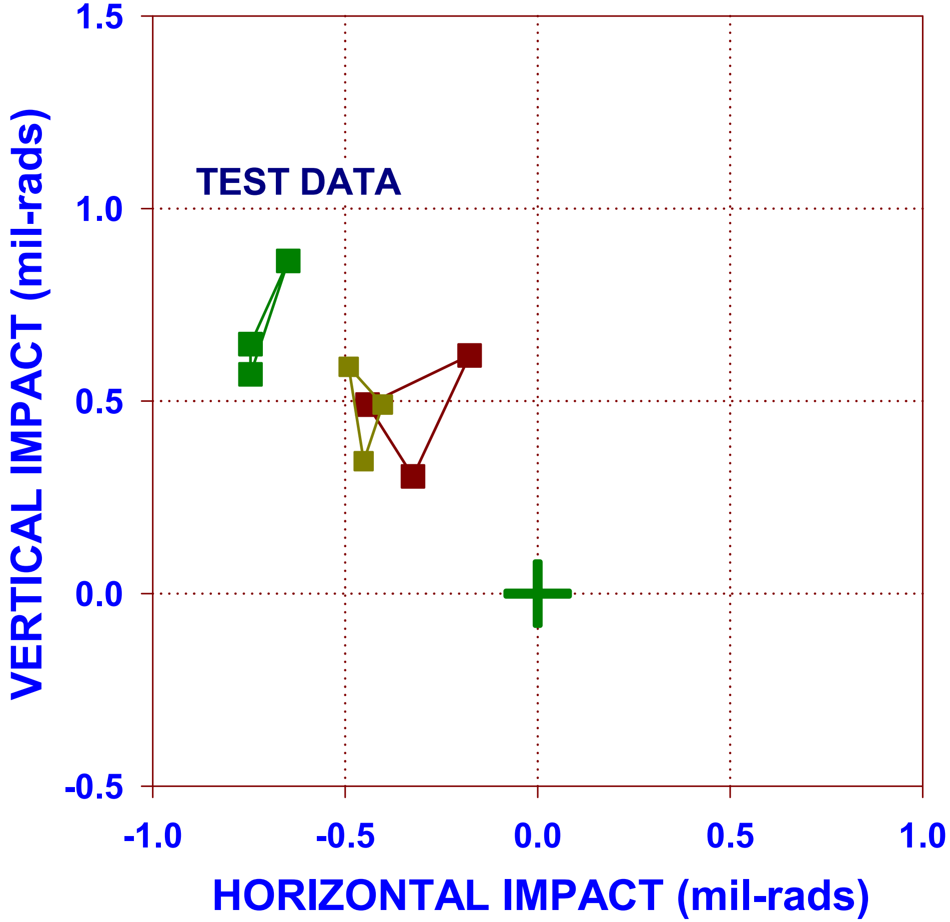
RESULTS for TUBE #2: DATA



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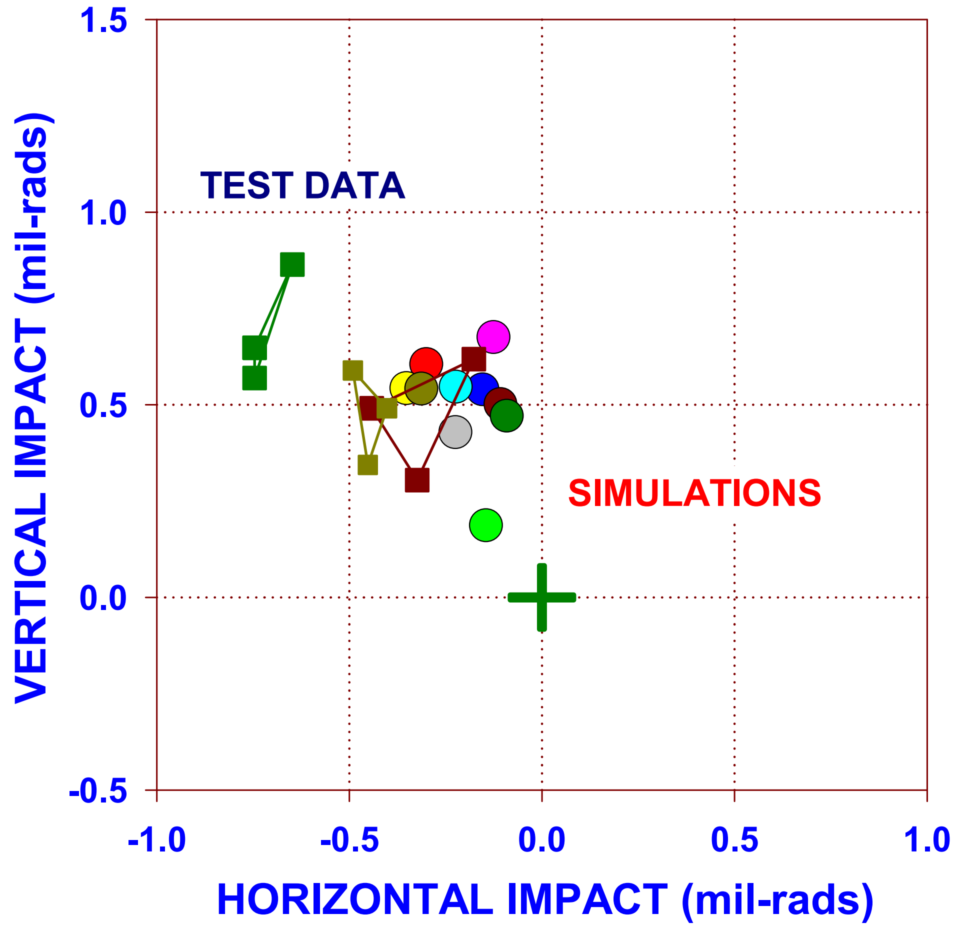
RESULTS for TUBE #2: DATA & SIMULATIONS



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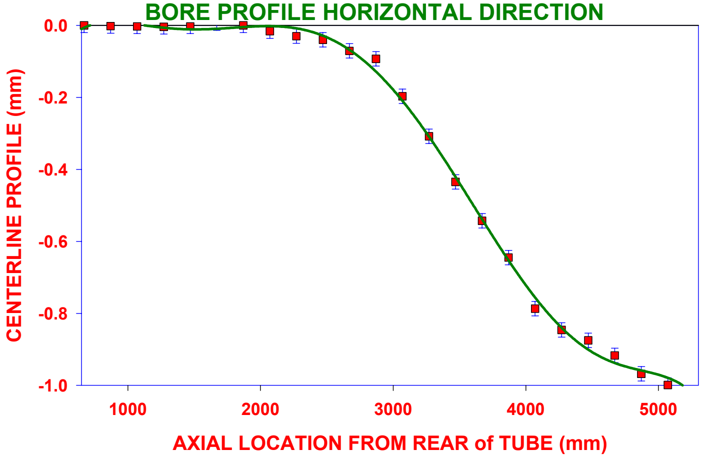
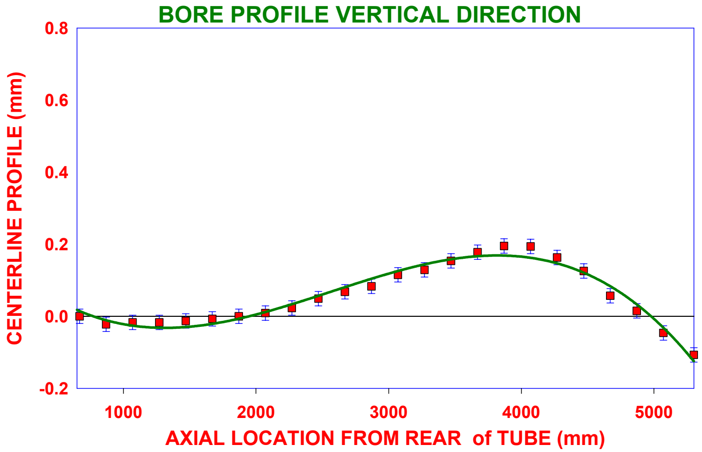
TUBE #3 PROFILE





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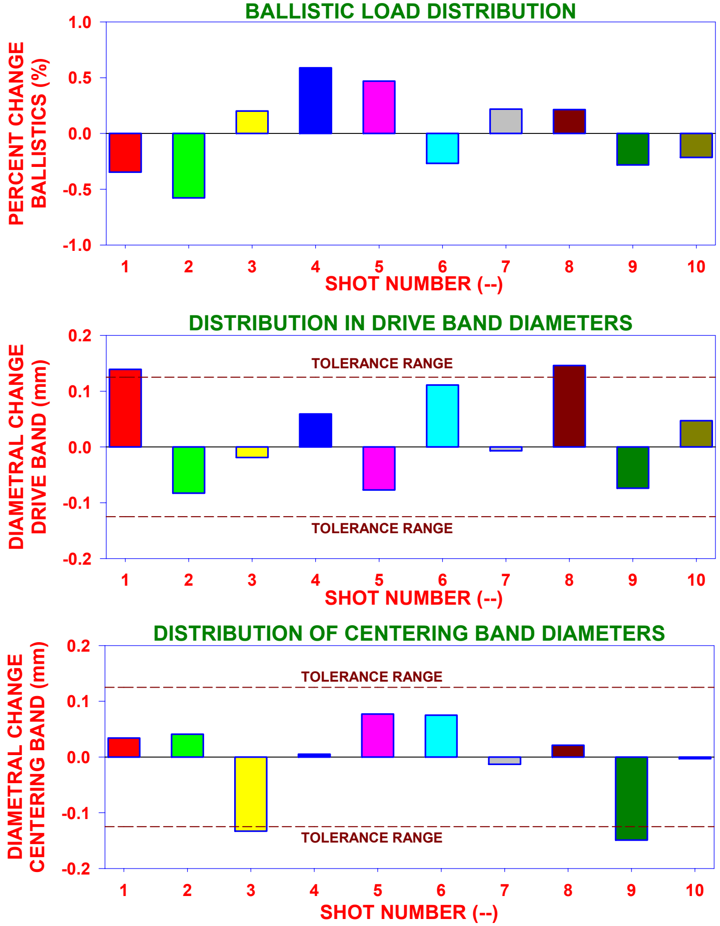
TUBE #3 LOAD / PROJECTILE DISTRIBUTIONS



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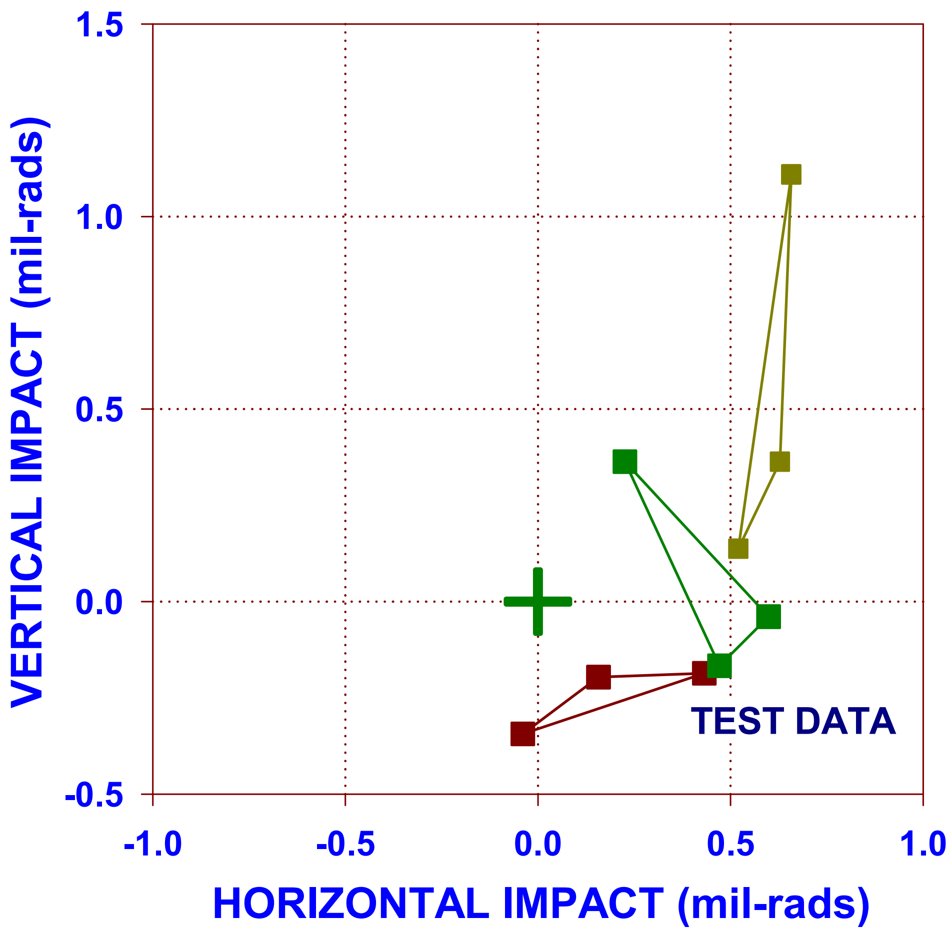
RESULTS for TUBE #3: DATA



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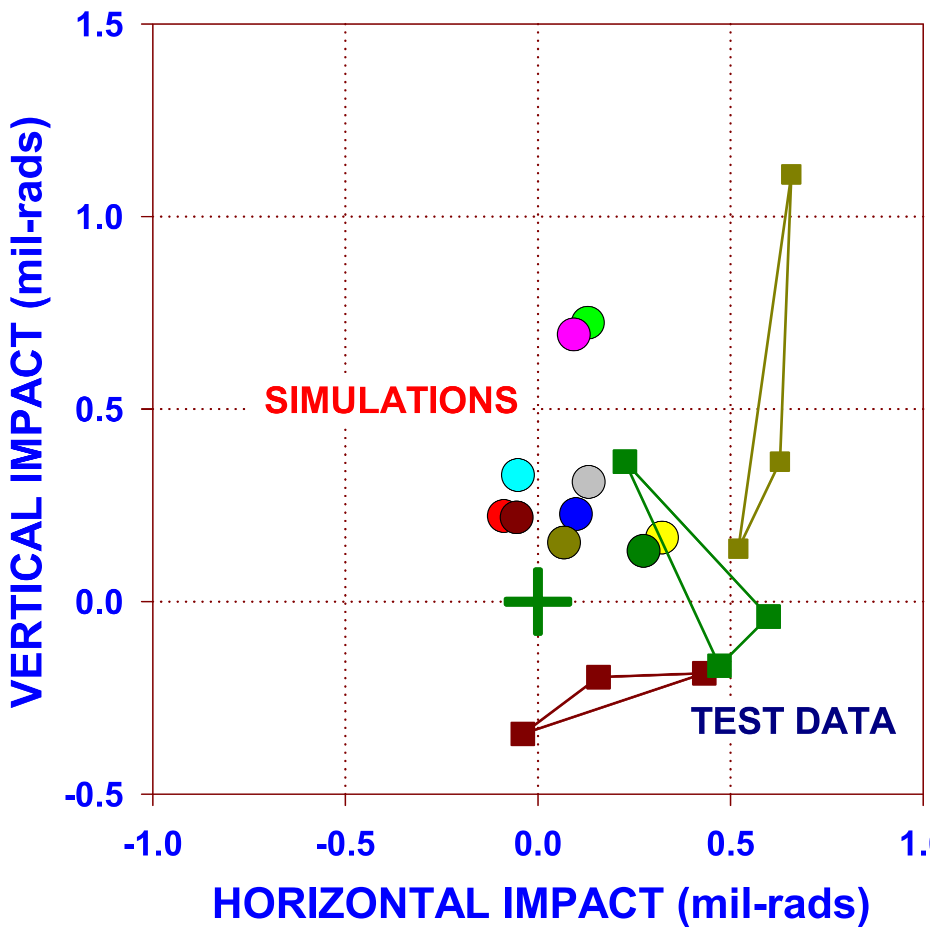
RESULTS for TUBE #3: DATA & SIMULATIONS



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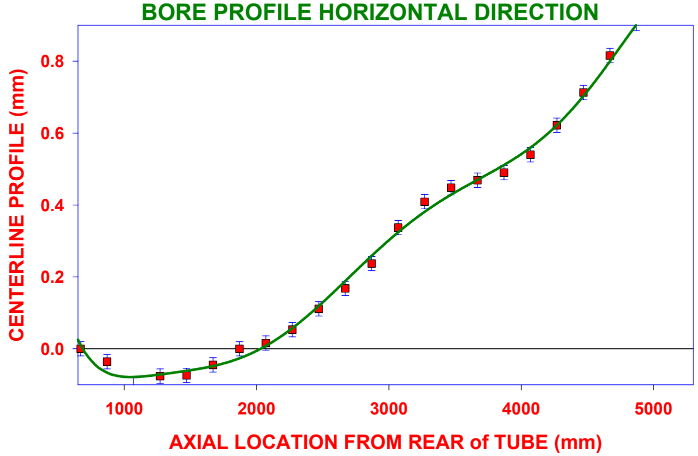
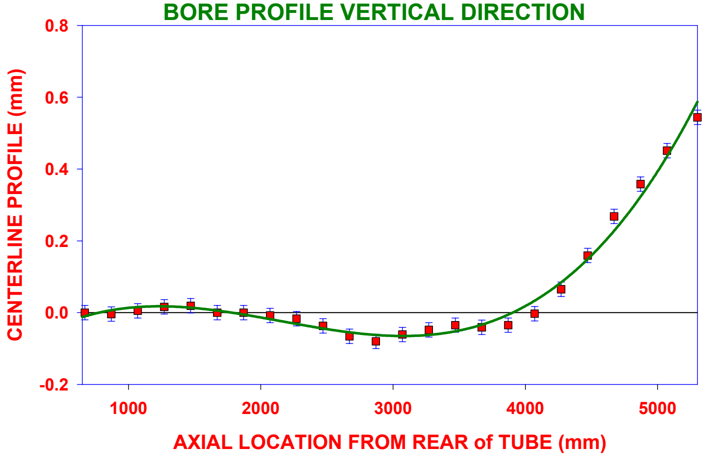
TUBE #4 PROFILE





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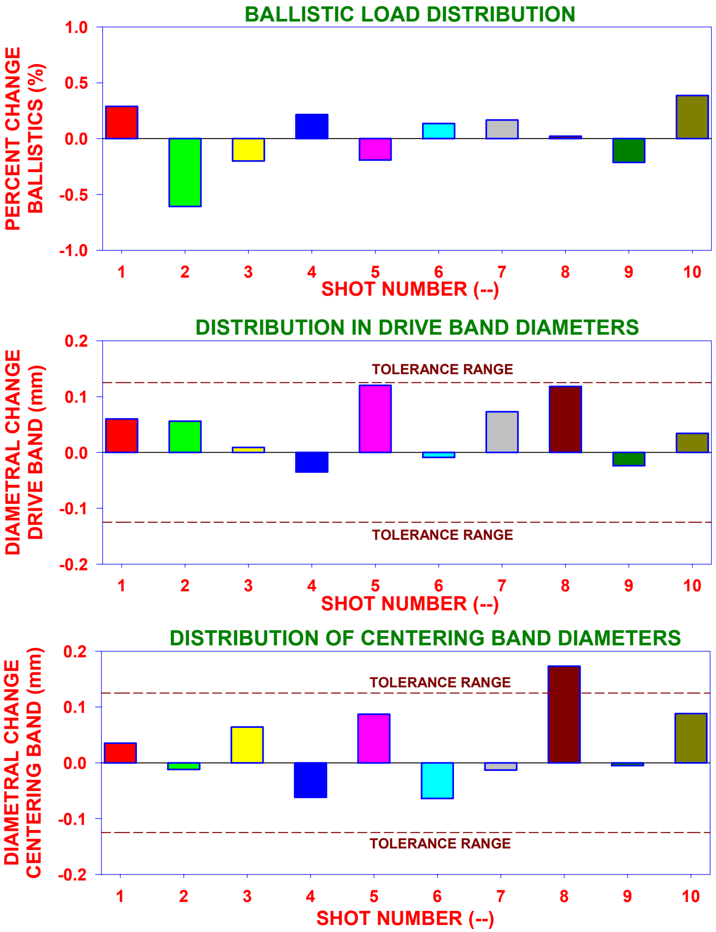
TUBE #4 LOAD / PROJECTILE DISTRIBUTIONS



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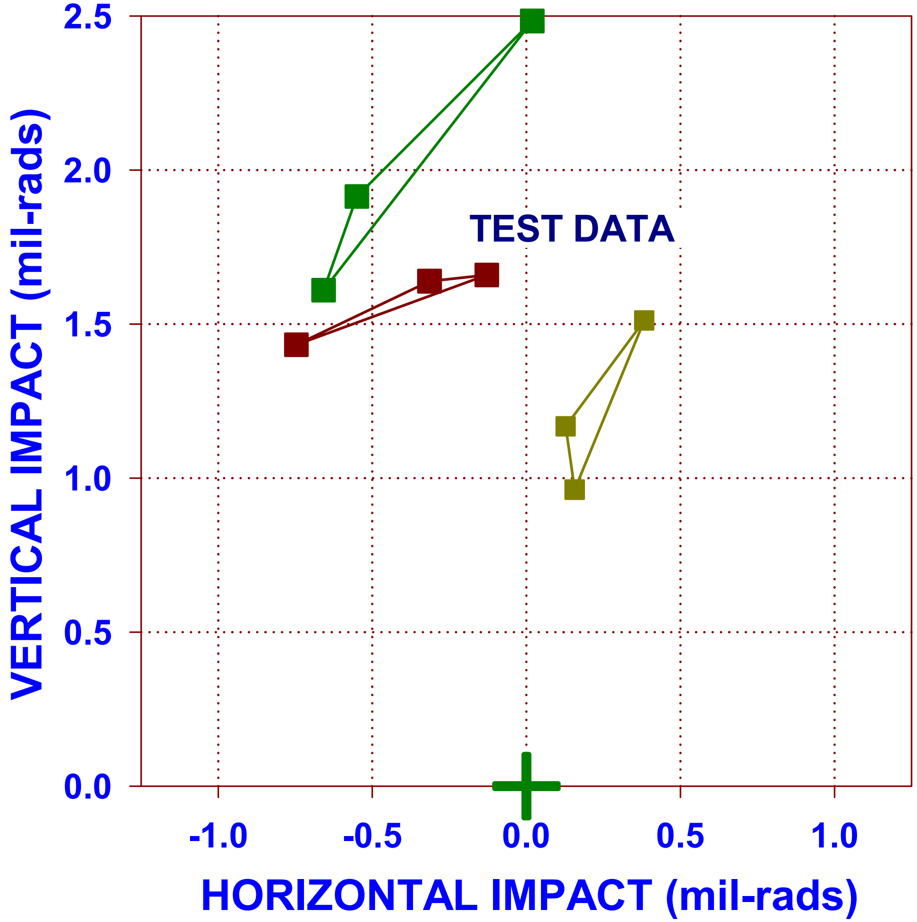
RESULTS for TUBE #4: DATA



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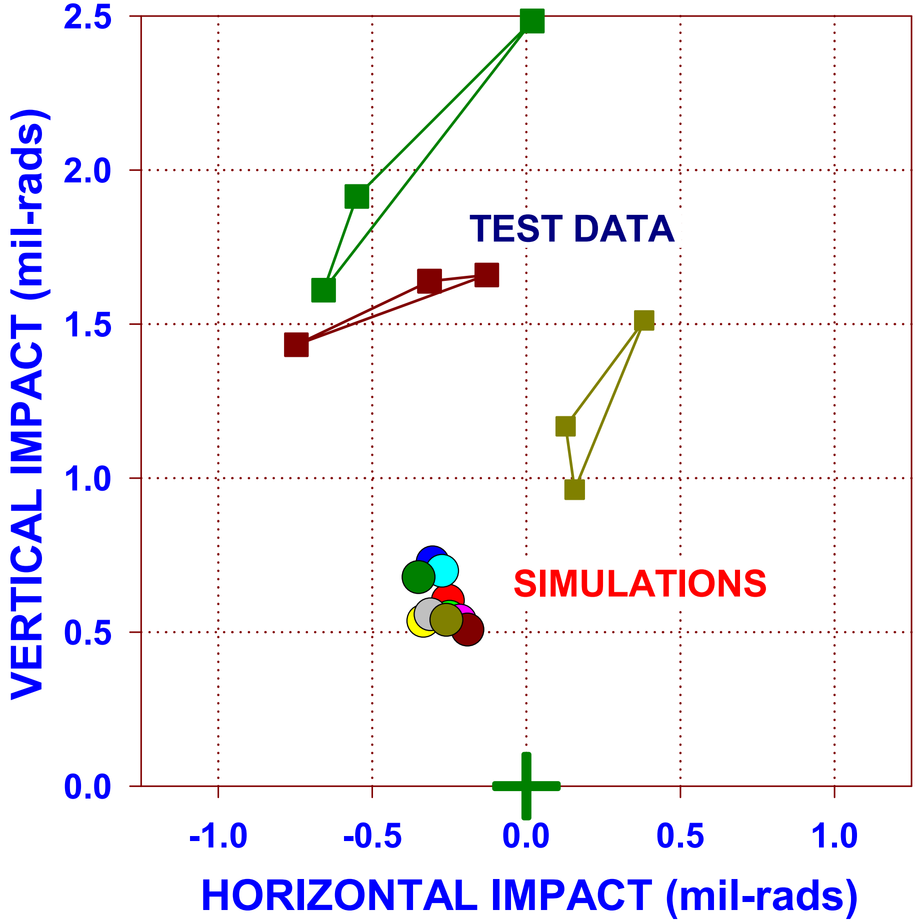
RESULTS for TUBE #4: DATA & SIMULATIONS



SUMMARY OF INDIVIDUAL TUBE RESPONSES

These four cases span the best to the worst in regard to accurately simulating test results.

Reiterating considerable amount of data, which impacts the test is unknown.

Projectile specifications were 'guessed' using nominal values and tolerances.

As shown in the simulations, band diameters that are out of tolerance tend to indicate shot impact locations that reside on the outskirts of group distributions.

STATISTICAL ANALYSIS OF PREDICTIONS AND TEST DATA

The analysis and discussion of these four cases does not allow one to claim the validity of the model.

It would be impossible to predict with a great degree of reliability any one shot, however, trends in shot patterns may offer more representative information.

To this end I suggest that we compare mean impact and dispersion values for the test and simulation groups.

We have nearly 200 test and simulation shots to use in this averaging process.

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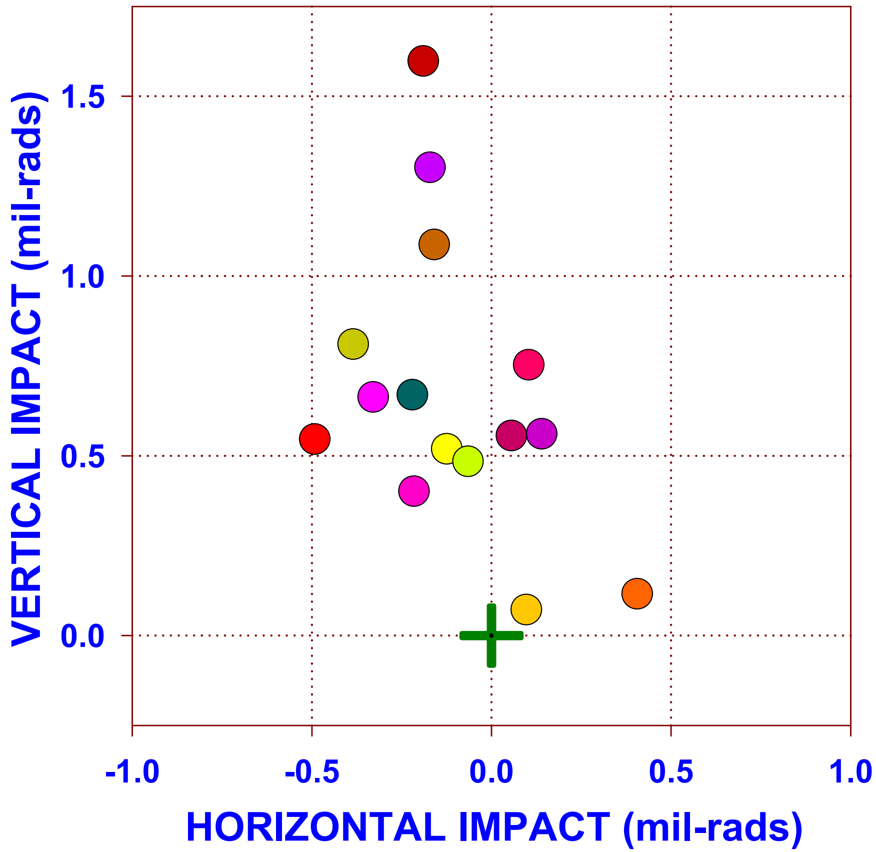
COMPILATION OF RESULTS FOR ALL 20 CASES

MEAN IMPACT LOCATIONS FOR TEST DATA



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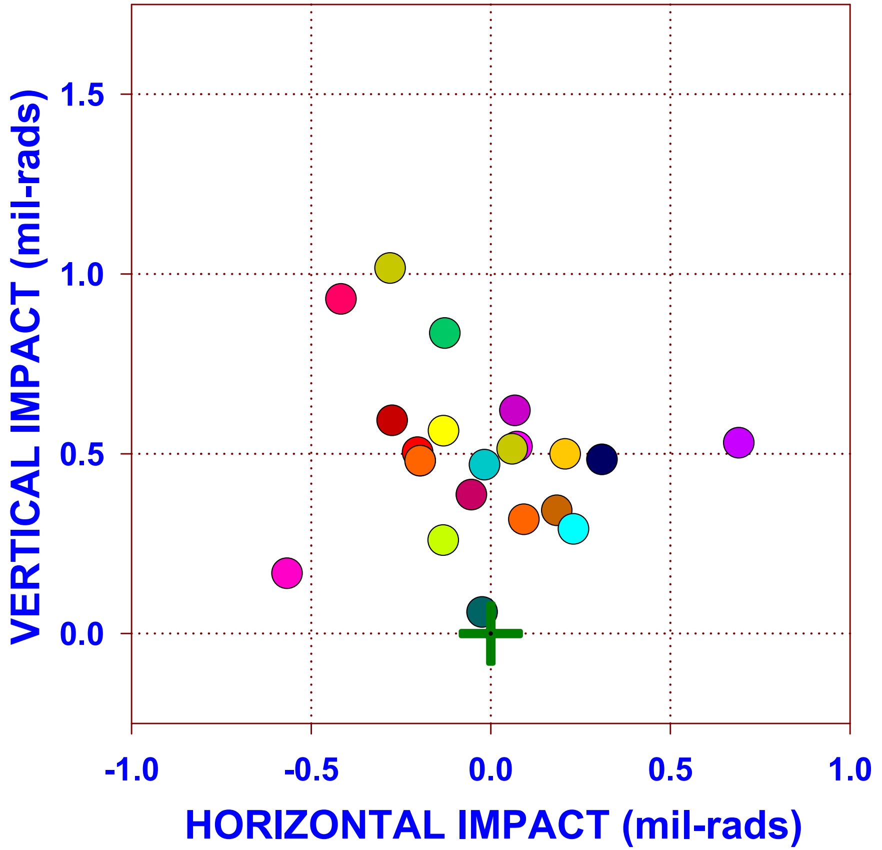
COMPILATION OF RESULTS FOR ALL 20 CASES

MEAN IMPACT LOCATIONS FOR SIMULATED RESULTS



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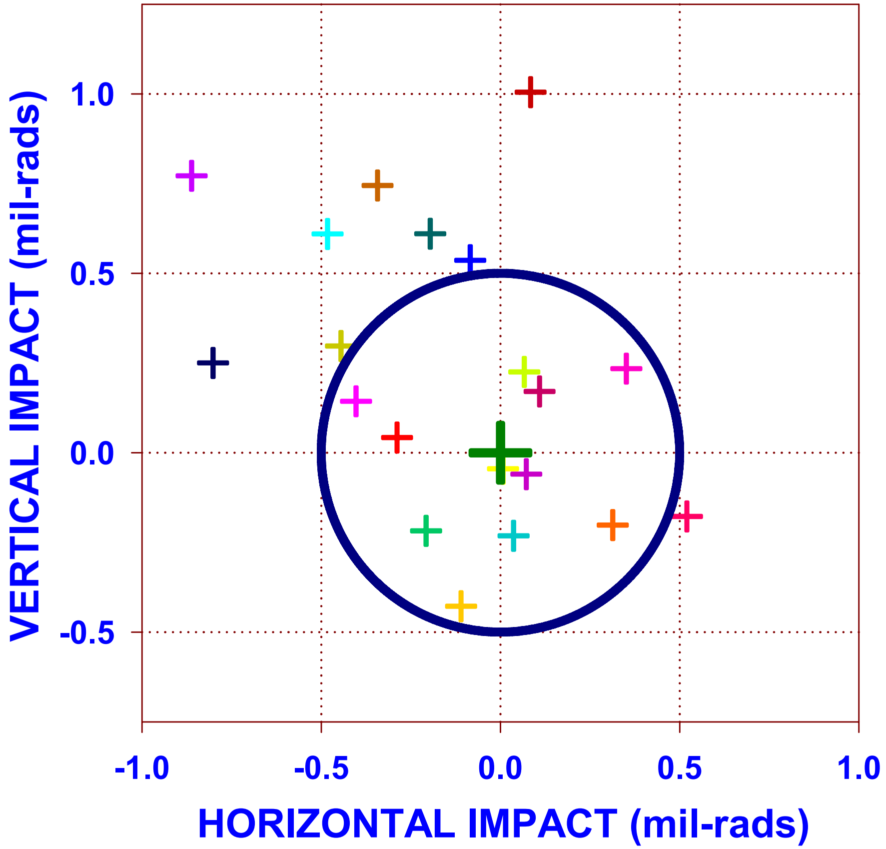
COMPILATION OF RESULTS FOR ALL 20 CASES

DIFFERENCE IN MEAN VALUES (TEST - SIMULATION)



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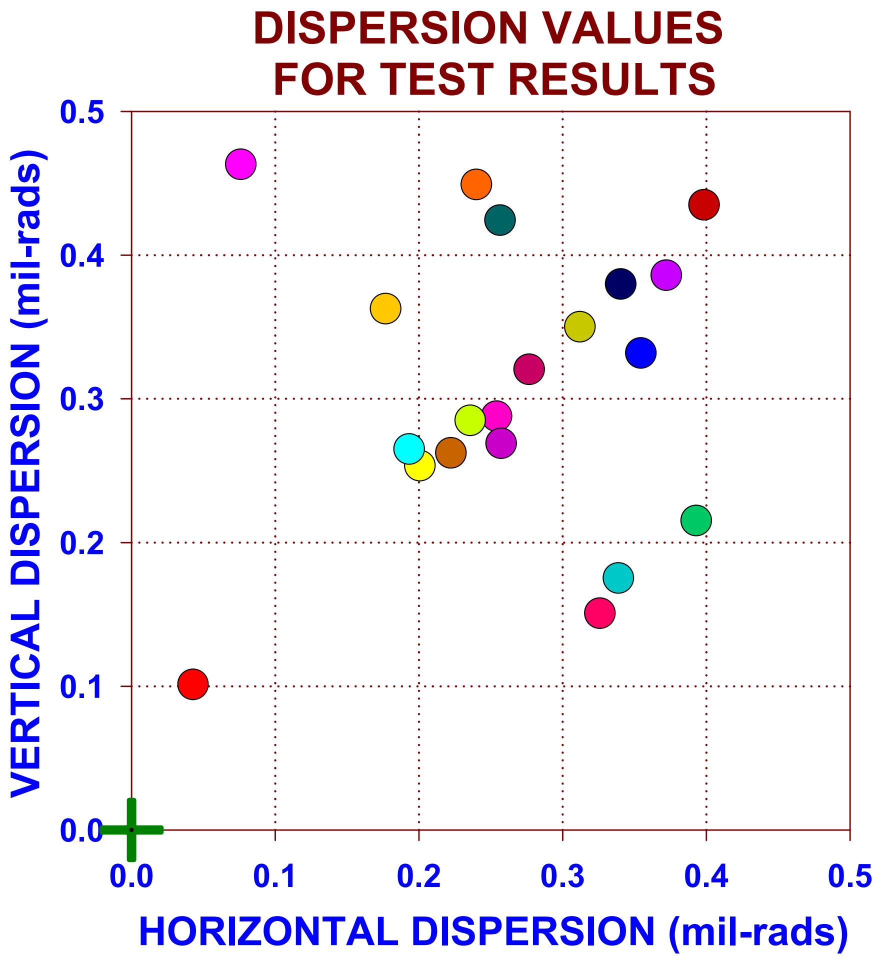
COMPILATION OF RESULTS FOR ALL 20 CASES



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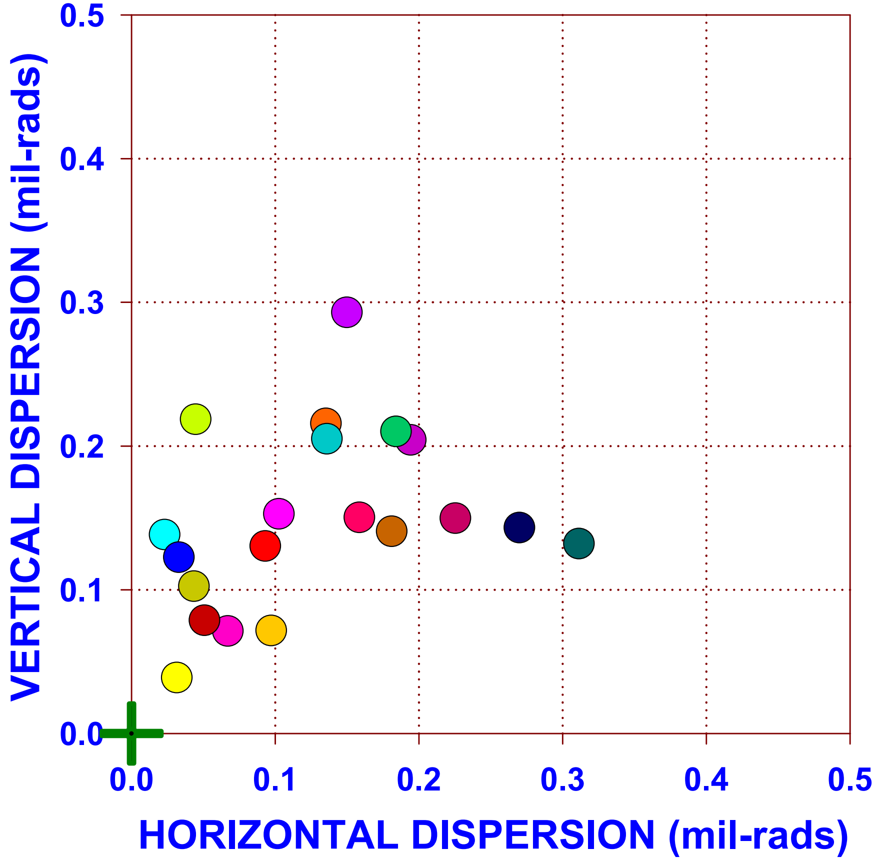
COMPILATION OF RESULTS FOR ALL 20 CASES

DISPERSION VALUES FOR SIMULATED RESULTS



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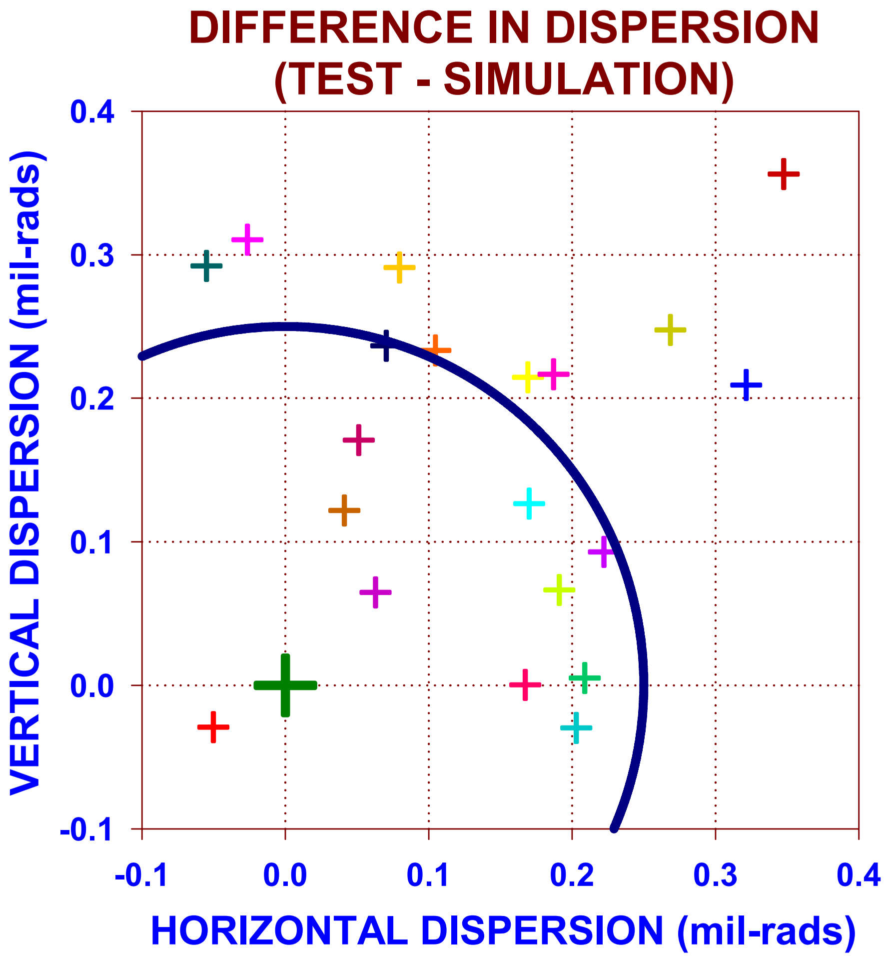
COMPILATION OF RESULTS FOR ALL 20 CASES



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DISCUSSION AND CONCLUSIONS

An attempt was made to validate coupled simulation routines for predicting projectile impact locations as a function of the bore profile of the gun tube.

Predictions were made for individual shots as well as an averaging method applied to groups of shots.

Mean and dispersion values were compared, the results of which indicated the following:

In 70 percent of the cases the difference between predicted and simulated mean values was equal to or less that 0.50mr

In 60 percent of the cases the difference between predicted and simulated dispersion was less than 0.25mr

Given the level of uncertainty of several parameters we feel that these results are quite good.

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