Always a Step Ahead
ARDEC
ARMAMENTS

Accuracy Testing and Modeling

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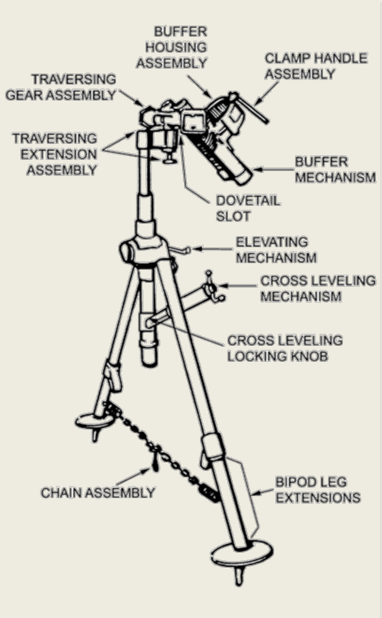
Accuracy Models

Understanding Accuracy & Developing an Accuracy Model

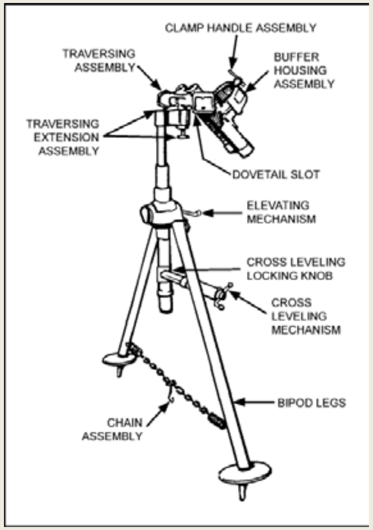
The Quandary at Hand

- Currently, weapon accuracy is for entire mortar weapon and fire control system
  - Current Models do not show the accuracy data for every critical component in a weapon system.
  - Each component and interface creates inaccuracies; quantifying each component will show overall effect on the system.



Weapon Characteristics on Accuracy

- Examples of necessary weapon characteristics
  - Mortar tube wear and its effect on range
  - Characterizing the effects of tolerances in bipods such as slop from elevating or traversing.
  - Dynamic environmental conditions



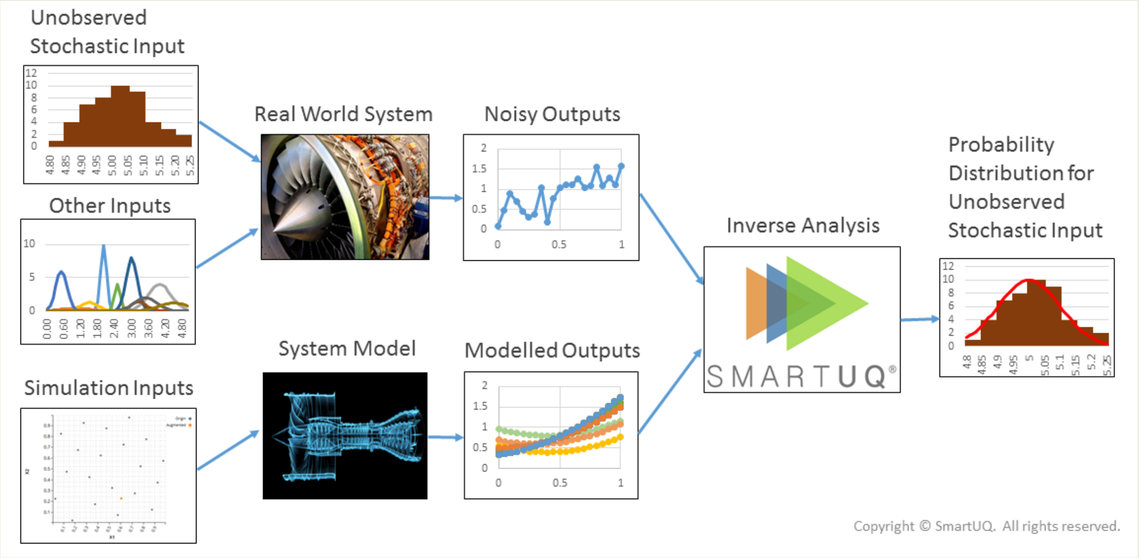
Accuracy Model

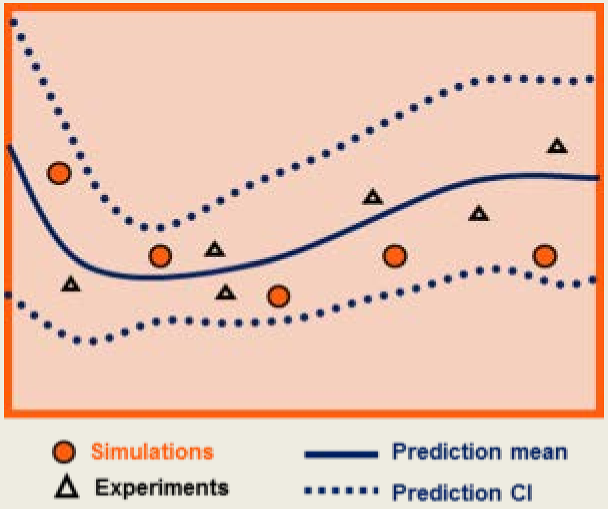
- Greater understanding of accuracy constraints and aiming tolerances
  - Better improvement planning, i.e. "greatest accuracy increase per dollar"
  - Allows for precision effects without precision rounds

Weapon modeling & simulation can assist in generating a ballistic kernel (BK) for accurate ballistic projection.
- Allows for greater accuracy for ballistic "dumb" rounds in dynamic environment

Increased accuracy is a necessity for increased range in order to maintain CEP

Uncertainty Quantification





Uncertainty Quantification (UQ)

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UNCERTAINTY QUANTIFICATION

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- The science of quantitative characterization and reduction of uncertainties.
  - Attempts to determine a complete probability distribution of outcomes of a system.
  - Utilizing simulations and experiments, UQ techniques determine likelihood of outcomes even though certain aspects of the system are unknown.

- e.g. When shooting mortars with the same direction, mortar shell, and exit velocity, UQ determines the area of scatter for the shot due to unaccounted characteristics.

Need for Orientation Measurement Systems

- Accurate weapon laying during test events and data collection needs to be performed
  - Minor errors during setup, bore sight, and control have a huge impact on accuracy.
    - 1 mil in roll error in the sight unit can translate to a 10 fold error in azimuth (AZ) error at highest elevation (EL)
  - Utilize integrated sensors on the weapon system to give real time fidelity to digital fire control systems
    - Sensors are now cheap & abundant and most are hardened to survive extreme conditions.

- Currently tasked to conduct an accuracy study for the 120mm - Dismounted Mortar system
  - Determine the effect of individual component error on the overall accuracy of the system.
  - Conduct a repeatability study on multiple bipods on multiple cannons
  - Conduct accuracy study on boresighting procedures
  - Tolerance stack up on interfaces and units of the optical fire control and mortar systems
  - Utilize Uncertainty Quantification to combine data and reduce uncertainty in variables and develop a model for mortar system performance

Current Orientation Measurement Systems for Testing

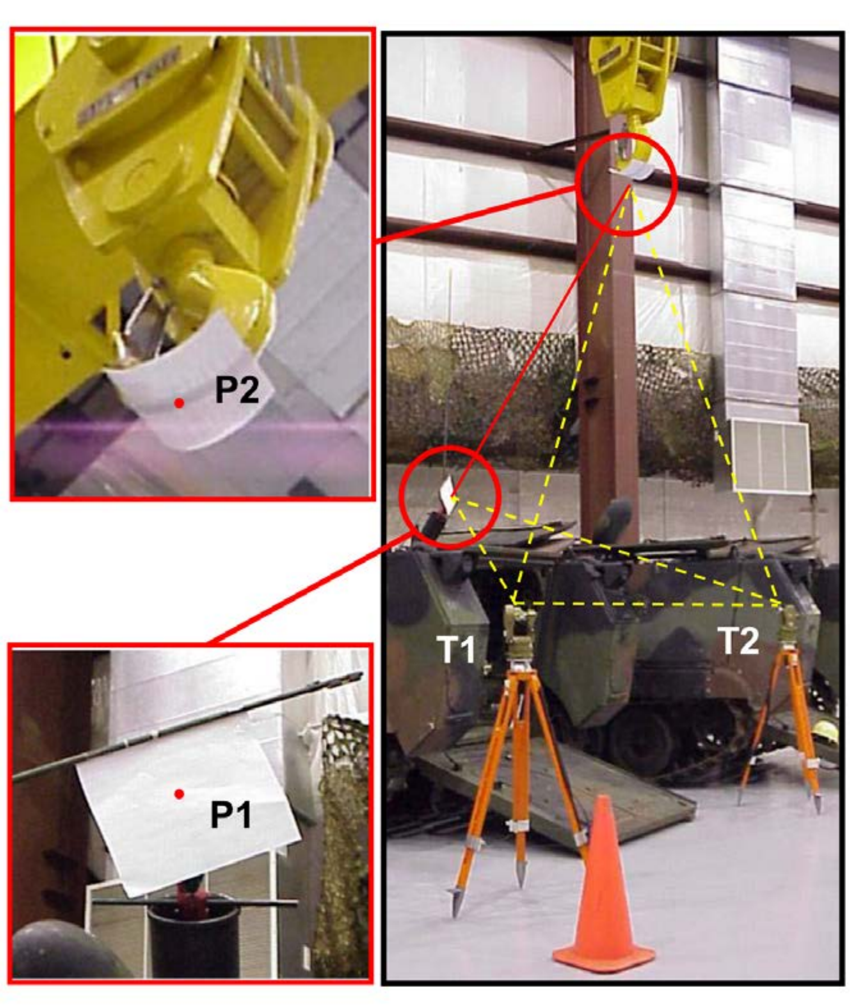
Current Orientation Measurement System

- Orientation Measurement Systems (OMS) currently being used on Indirect weapon systems are:
  - Bore Elevation Azimuth Measurement System (BEAMS)
    - Accurate to < 0.10mils
  - Optical Sight Unit
    - Accurate to within 1 mil
  - the INU
    - Accurate to < 1.00 mil
  - WULF system – in development
    - Accurate to 3 mil

There are Pros and Cons to all of these OMS

BEAMS

- BEAMS – Bore Elevation and Azimuth Measurement System
  - Uses a laser on bore and theodolites to find the AZ and EL of the system
  - Centers the mandrel by spinning the device and manually adjusting laser until point source
  - Mounts on tube via inner diameter sized brass shoes



BEAMS

- BEAMS – Bore Elevation and Azimuth Measurement System

Pros

- First accurate system determining deflection and elevation to achieve < 0.10 mils accuracy
- Centers rod directly on bore axis
- Theodolites can be placed arbitrarily, obtains Azimuth and Elevation simultaneously

Cons

- Long set up time
- Springs in plungers may not be strong enough to maintain center of bore.
- Requires an optical target imaging screen or a varying elevated platform to hold the second target sheet.

M67 Optical Sight Unit

- M67 Optical Sight Unit
  - Standard sight unit for all mortar systems
    - M224 (60mm), M252 (81mm), and M120/M121 (120mm)
  - Accurate to 1 mil utilizing bubble levels and the optical sight
  - The non-digital aiming method of all mortar systems

M67 Optical Sight Unit

- M67 Optical Sight Unit

Pros:

- Common to all mortar system with use of dovetail
- Used to verify all other OMS

Cons:

- Not as precise and repeatable as other OMS
- Suffers from parallax complications

DIGITAL FIRE CONTROL UNITS

- Inertial Navigation Unit (INU)
  - 3 Laser Ring Gyroscopes
  - Digital orientation readout with FCC
  - Accuracy to be < 1.00 mils
- Weaponized Universal Lightweight Fire-control (WULF)
  - 9 degree of freedom Gyroscopes, accelerometers and magnetometers; 2 cameras to eliminate error bias drifts
  - Digital orientation readout with Gun Computer
  - Current accuracy is 3 mils
    - Development is ongoing

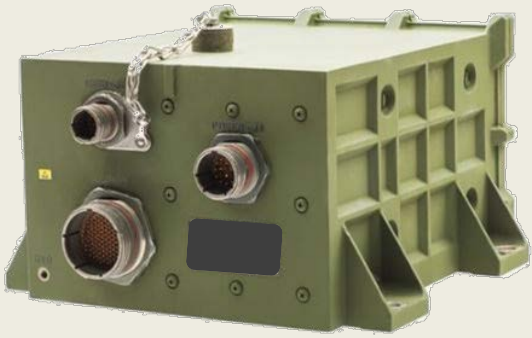
DIGITAL FIRE CONTROL UNITS

- Inertial Navigation Unit (INU)

  Pros: - Precise and accurate to <1.00 mil

  Cons: - Only on 120mm mortar and its variants

  - Long startup time



- Weaponized Universal Lightweight Fire-control (WULF)

  Pros: - Could be used for all mortar sizes

  - Short startup time

  Cons: - Still in development

  - Not as capable as the INU but development shows promise

Orientation Measuring Test devices

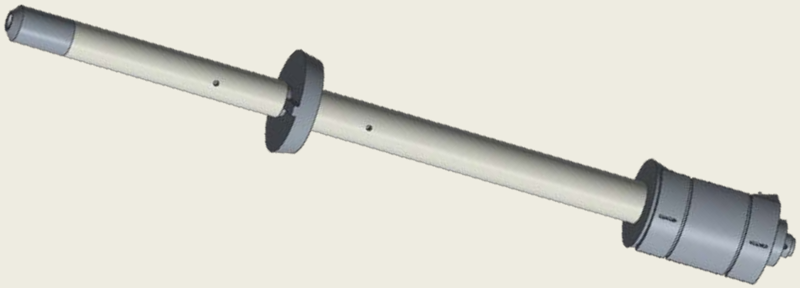
In Development

ORIENTATION MEASUREMENT SYSTEM IN DEVELOPMENT

- Orientation Measurement Systems
  - FARO Vantage Laser Tracker with self-centering mandrel
    - Absolute accuracy to be ~0.1 mils depending on the tolerances of the mandrel.
    - Relative accuracy is < 0.1 mils
  - Theodolite Mortar Laying System
    - Accurate to within 0.10 mils depending on the accuracy of the roll vial on the tube fixture.

FARO LASER TRACKER WITH SELF-CENTERING MANDREL

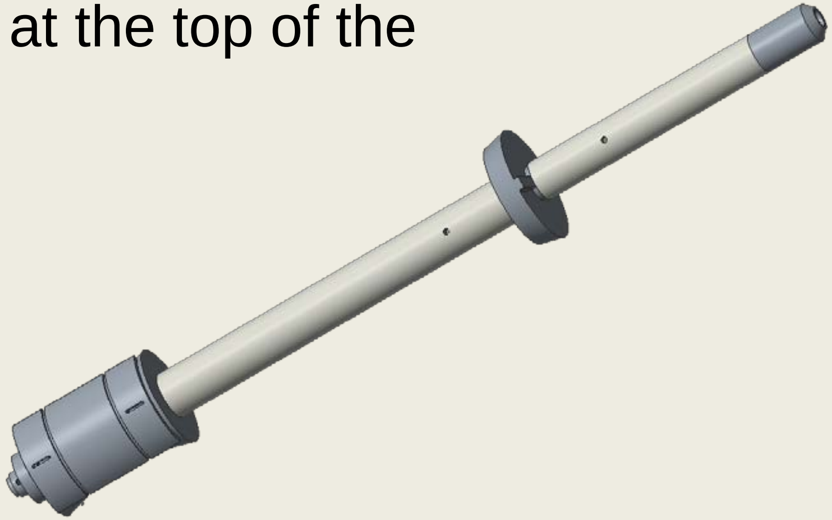
- Mandrel to be used to determine changes in azimuth and elevation
  - Movement due to various components on mortar will show its change in azimuth and elevation.
  - Mandrel allows for two points to be taken on bore
    - Points can create boreline vector with ground plane which can be used to derive azimuth and elevation.



Faro Laser Tracker with Self-Centering Mandrel

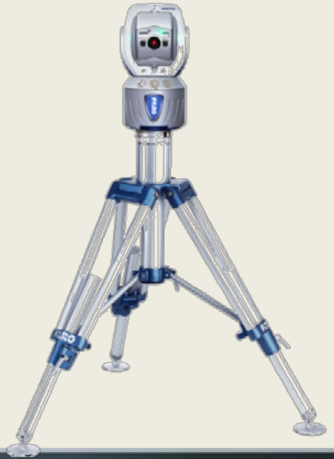
Mandrel

- Developed in-house to self-center in weapon tube
- Utilizes expanding gripper to latch on and maintains grip to the surface of the bore
- Has interchangeable blocks and gripper for all mortar weapon tube calibers
- Contains a vector block that holds two Spherically Mounted Retroreflector (SMR) at the top of the mandrel.



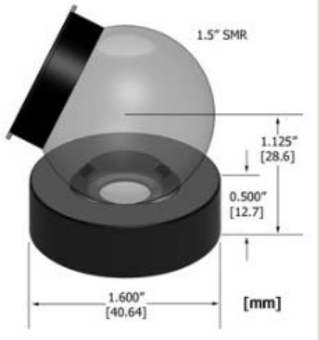
FARO LASER TRACKER WITH SELF-CENTERING MANDREL

- Final design will provide expected accuracy of ~0.1 mils in EL and AZ using only 2 points (<1 minute per reading)
- Prototype holds Bore Axis and obtains the bore line vector within an accuracy of 0.3 mils
  - Self-centering mandrel with 2 laser tracking fixtures are bore-aligned. Fixture is press fit into place.
  - Laser tracker reads both fixtures and creates a line
  - Mortar EL is derived from tracker level
  - AZ derived from bore line vector projected to tracker lever



FARO Vantage Laser Tracker

- Quick Overview
  - Accurate to 0.001 in. to a range of 240 ft.; accurate to 0.0006 in to a range of 6.5 ft.
  - Utilizes Spherically Mounted Retroreflector (SMR) to obtain distances from laser.
    - Machined surface of SMR to be within 0.0005” tolerance of designated diameter
    - 3 different diameters available;1.5”, 0.875”, 0.5”
  - Redundant encoders to obtain angle of rotation from “home” position.
  - 300° of pitch rotation, 360° of yaw rotation



FARO LASER TRACKER

FARO Software

- CAM2 Measure 10
  - Similar to 3-D CAD, can create shapes from reading points
  - Construct different shapes and angles from existing shapes or points
- Control Panel
  - Allows for quick fix onto an SMR in view
  - Controls the movement of the FARO's laser pointer
  - Re-measure internal angle accuracy and other BIT to improve accuracy

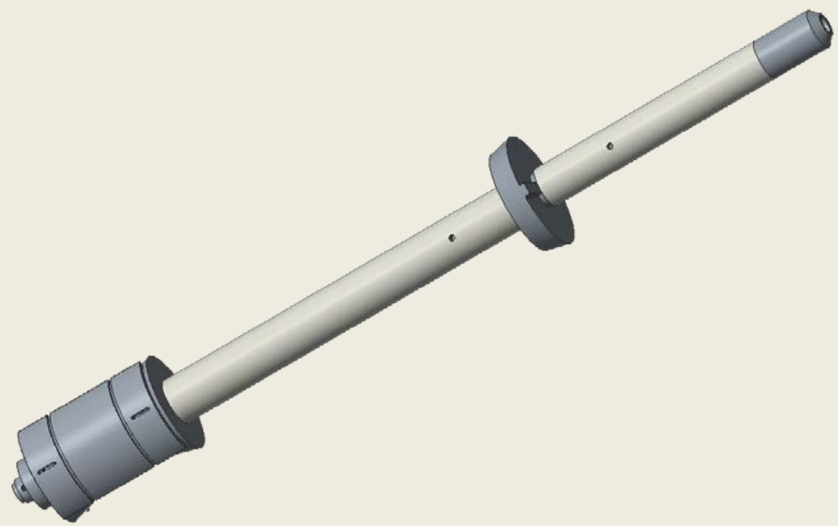
FARO Laser Tracker with Self-Centering Mandrel

- FARO Vantage Laser Tracker

Pros: - Fast, accurate, and precise readings utilize only two points

- Software quickly determines AZ and EL
- Utilize inner bore axis and stays in place thanks to expanding gripper
- Mandrel can be used for all mortar systems with appropriate gripper sizes

Cons: - 45 min warm up time for FARO to ensure internal temperature doesn't fluctuate; optional



Heading Measuring Capabilities
Single Theodolite Mortar Lay

- Single theodolite system developed by Inertial Labs for WULF testing
- Utilizing a theodolite and a mirror mounted on a V-block
  – V-Block with mirror has a bubble vial to assure center
  – Theodolite is self-sighted through mirror, aligning theodolite to mirror in 2 axis
    - Elevation is found using theodolite pitch
    - Azimuth is found through theodolite rotation

Single Theodolite Mortar Lay

- Single theodolite system developed by Inertial Labs for WULF testing

Pros: - Utilizes only 1 Theodolite for measurement and a collimator or other reference point.

- Quick and accurate method of obtaining orientation

Cons: - Assumes outside cylinder is coaxial with inner cylinder

- Awkward positioning as theodolite must be placed over the pivot point.

FARO Vantage Laser Tracker with Self Centering Mandrel

Examples of Usage

- Accuracy tests on WULF
  - Utilized the FARO to obtain absolute and relative azimuth as well as elevation to compare with the WULF pointing device
- Mils per Hand crank for Weapons Group
  - Obtained relative azimuth and elevation values to compare mils per hand crank at various bipod positions
- M67 sight units Product Quality Deficiency Report Study
  - Marines came with deadlined sight units, FARO verified M67 sight units as working correctly

FARO Vantage Laser Tracker

Future Developments

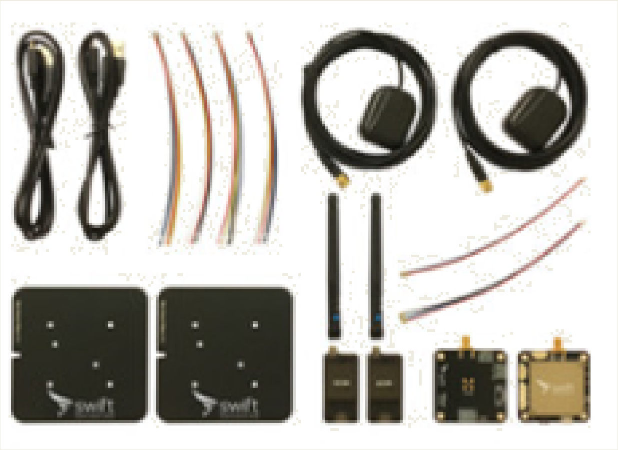
- Attachment or new mandrel to obtain roll of the mortar tube.
  - May also obtain roll through Bipod
- Include blocks and grippers for Artillery calibers
  - Include a separate mandrel for the breech to find angle of droop

Questions?

- Backup slides

Heading Measuring Capabilities: North Alignment

swift NAVIGATION



Heading Measuring Capabilities North Alignment

- Base line north vector found using 2 RTK GPS systems mounted onto theodolites, <1 mil @ 2 meters to true north
  - Theodolites aligned to each other defining north vector
  - Base theodolite then swung to point at a measurement system
  - Azimuth line from measurement system to theodolite is then defined
  - Can be used with any surveying equipment I.E. FARO, Theodolite

Method of Deriving Error

- $R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$ * $R_y = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$
  - Rotation matrix: *x* for roll, *y* for elevation.
  - This will obtain the bore axis vector, $\overrightarrow{b_{axis}}$.
- $Proj_{b_{axis}} = \overrightarrow{b_{axis}} - \frac{\overrightarrow{b_{axis}} \cdot \vec{N}}{\vec{N} \cdot \vec{N}} \vec{N}$
  - The projection of the bore axis to ground plane is obtained by subtracting the normal vector of the plane from the bore axis.
  - The projection is then the azimuth line.
- $\Delta Az = Atan2 \frac{Norm\left(\overrightarrow{b_{axis}} \times \overrightarrow{b_{axis_{init}}}\right)}{\overrightarrow{b_{axis}} \cdot \overrightarrow{b_{axis_{init}}}}$
  - The angle difference from original vector to azimuth line vector determines azimuth changed.

Azimuth Change from Nonzero Roll