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U.S. Army Research, Development and Engineering Command

Trajectory Matching Procedure/Practice for a Guided Projectile using MATLAB/Simulink

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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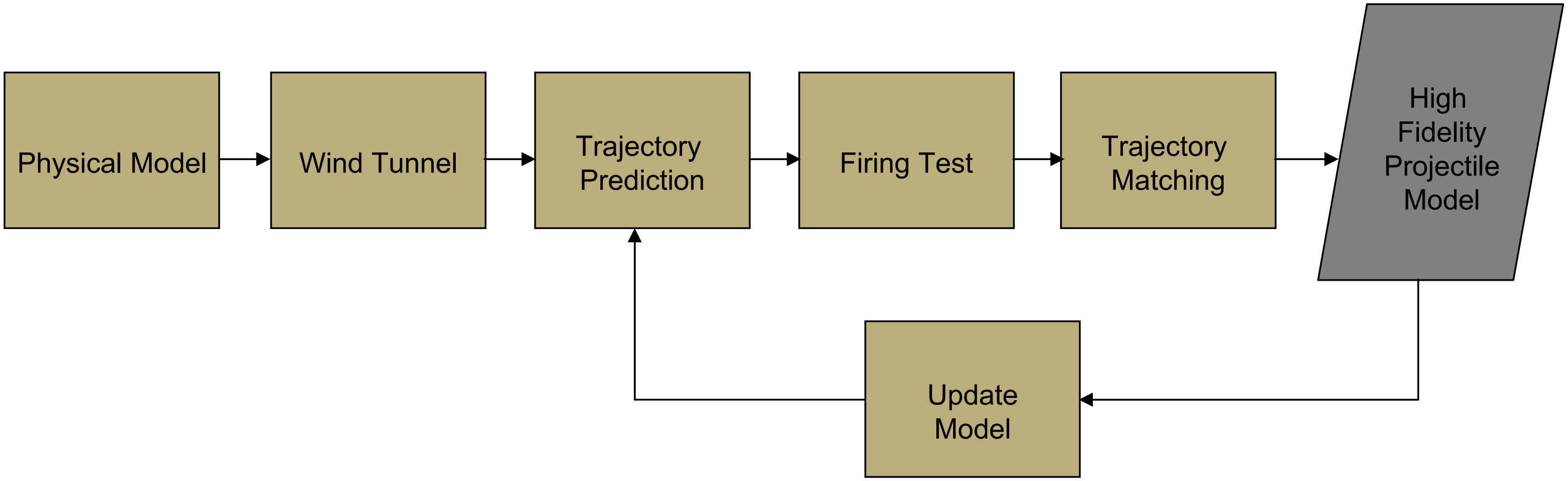
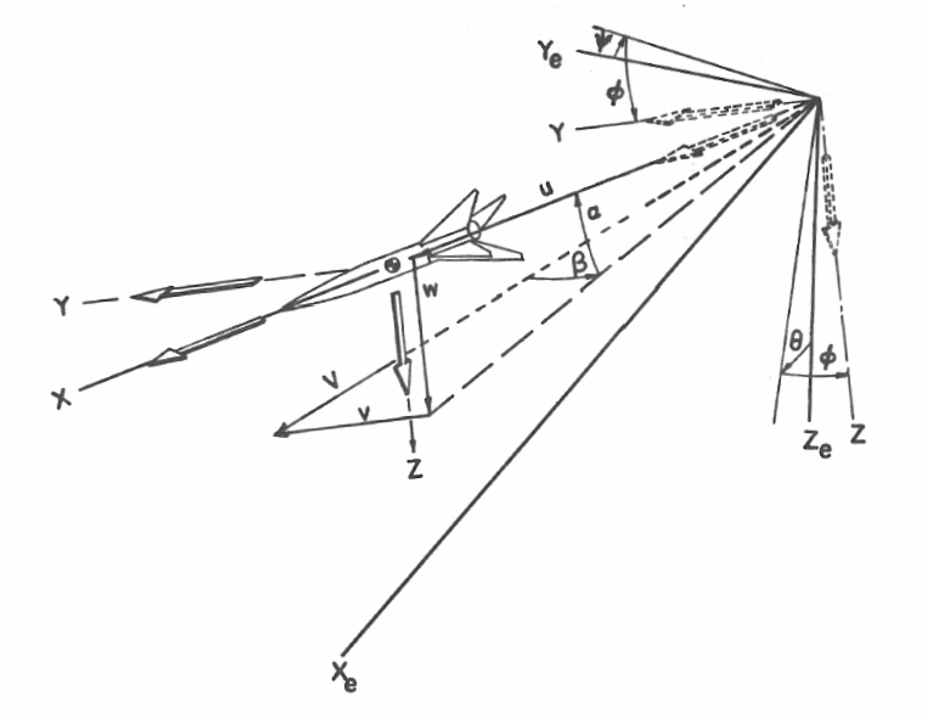
Process Overview

- Objective: to Obtain a High Fidelity Simulation of Guided Munitions.
  - Statistical Testing is too expensive
  - Predict Performance
  - Conduct Root Cause Analysis

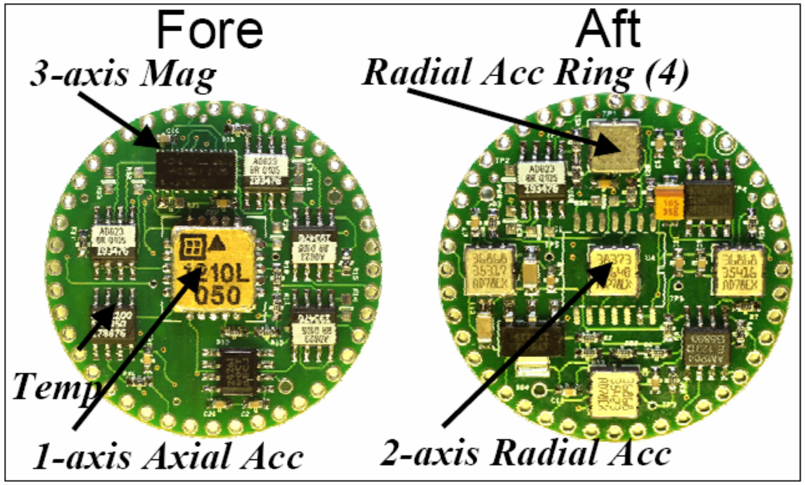


- Basic Forces and Moments Acting on the Body
  - Aerodynamic Forces
  - Aerodynamic Moments
  - Gravity
- Effects due to External Conditions
  - Wind
  - Pressure/Altitude
  - Temperature
  - Location
- Types of Projectiles
  - Spinners
  - Finners



Background: Sensors & Controls

- Sensors
  - Measure Location, Speed, Orientation
    - IMU
      - Accelerometers
      - Rate Gyros
    - GPS
    - Radar
    - Inclinometers
    - Solar Sondes
    - Magnetometers



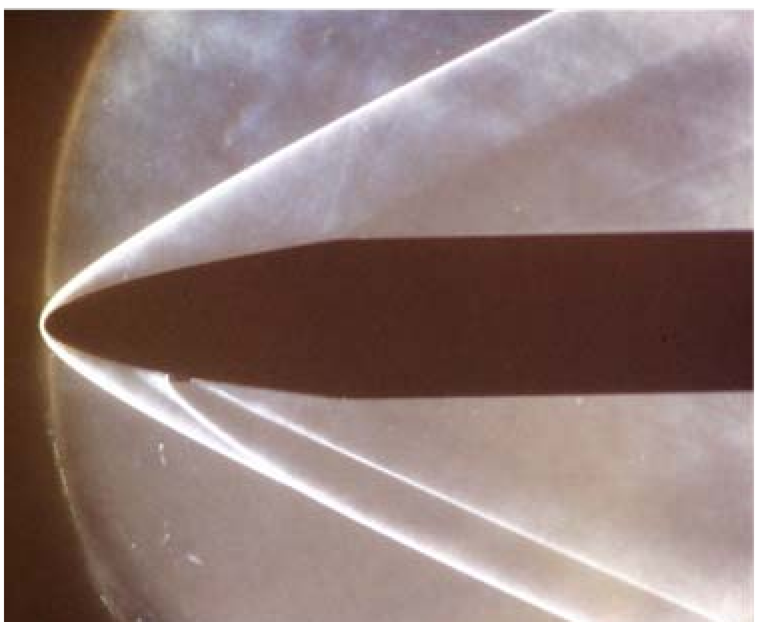
Example: ARL Sensor Suite Board

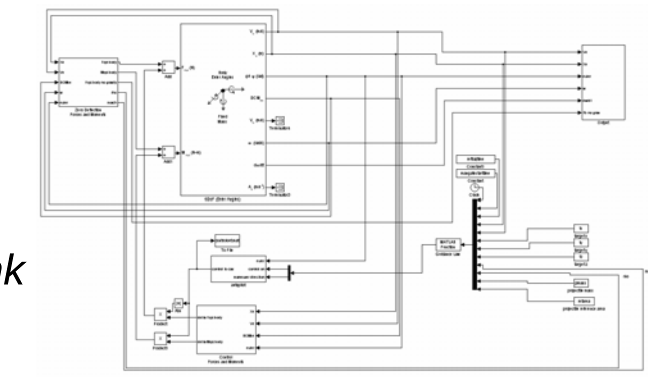
- Control Mechanisms
  - Correct the Projectile's Path to Guide to a Goal
    - Canards/Fins
    - Rocket Thrusters
    - Heating/Cooling of Ambient Air
    - Ventilation Control through Projectile Body
    - Projectile Skin Morphology (Flexures)
    - Microactuators

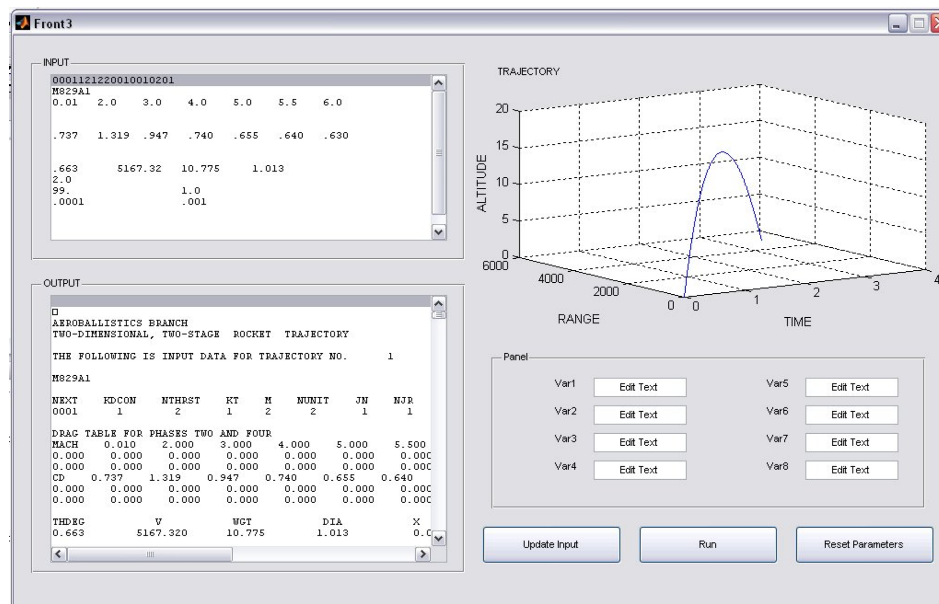
Pre-Test Modeling

- Physical Models
  - CAD (Pro Engineer)
  - PRODAS
  - Missile DATCOM
  - CFD
  - Wind Tunnel Modeling

- Trajectory Simulations
  - Aero1
  - Traj
  - Tela
  - *MATLAB/Simulink*







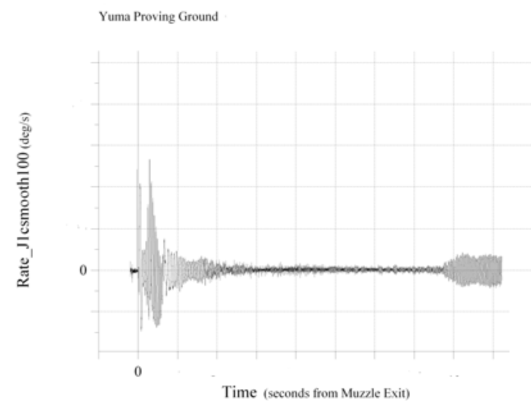
Pre-test Modeling in Practice

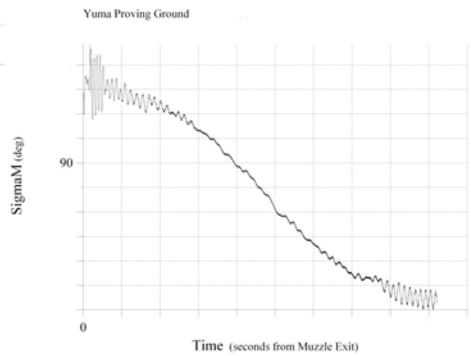
- Wind Tunnel Produced:
  - Static Coefficients
    - C_x
    - $C_{N\alpha}$
    - $C_{m\alpha}$
    - C_{lo}
  - Dynamic Derivatives
    - C_{lp}
    - $C_{m\acute{\alpha}} + C_{mq}$
- MATLAB 6-DOF
  - Wind Tunnel coefficients were used to create a trajectory
- CFD Produced:
  - Static Coefficients
    - C_x
    - $C_{N\alpha}$
    - $C_{m\alpha}$
    - C_{lo}
  - Dynamic Derivatives
    - $C_{np\alpha}$
    - C_{lp}
    - $C_{m\acute{\alpha}} + C_{mq}$

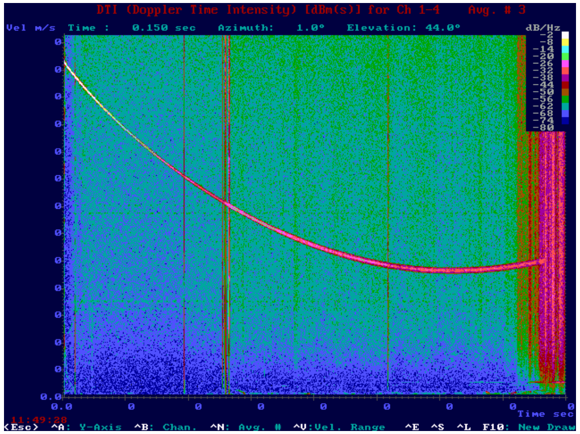
Data Acquisition/Reduction

- Wind Tunnel Test
  - Entire Range of Mach Numbers
  - Various Angles of Attack
  - Compared with CFD and aero prediction code results

- Firing Test
  - Acquires “Real” Data
    - Mass Properties
    - Pressure Gauge Data
    - Muzzle Velocity (Weibel Radar)
    - Tracking (Weibel Radar, MTS Radar)
    - ARL Sensor Package
      - Rate Sensors Data
      - Magnetometer Data
      - Accelerometers
      - Solar Sondes
    - Exact GPS Location of Gun and Impact
    - Met Data for Time of Fire







Trajectory Matching

- Initial conditions are adjusted as closely as possible to the day of fire.
  - Met Data
  - Mass Properties
  - Initial Velocity

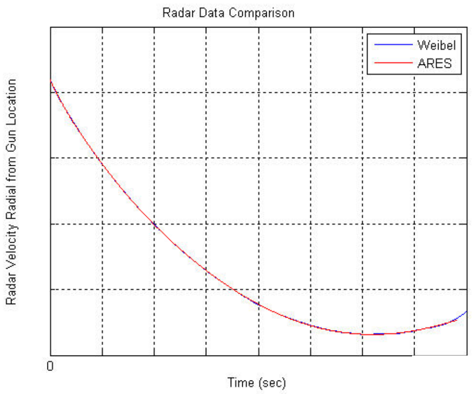
- Simulink 6DOF is run to compare the output of the simulation with the actual performance of the round

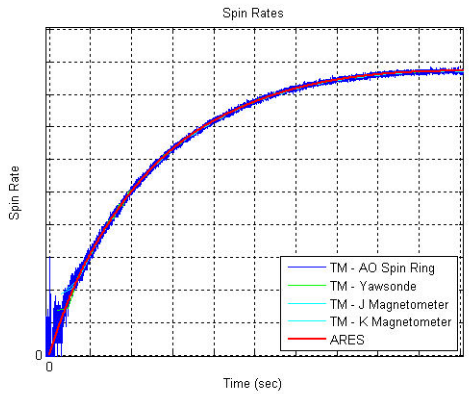
- Form Factors are applied by hand to adjust the performance of the simulation to coincide with the actual trajectory
  - Form Factors are coefficients applied to the variables governing the projectile's performance.
  - Adjustment starts with the earliest point in the trajectory and moves forward with time.
  - Adjustment cycles through:
    - Position/Velocity Matching
    - Magnetometer Matching
    - Spin Rate Matching

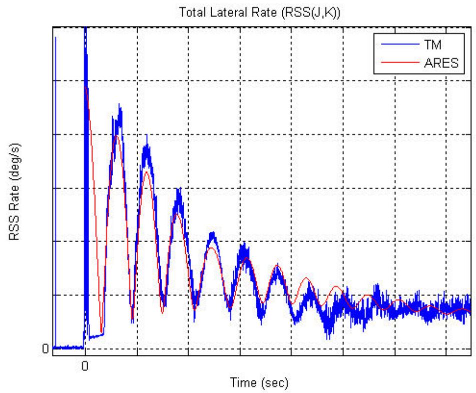
Data Reduction in Practice

- Reconcile CFD Outputs with Wind Tunnel Test Results
  - Modify Variables if Necessary
  - Chose One Set or Average Both if Numbers are Close

- Firing Test Data
  - Corrected Acceleration and Rates Loaded into MATLAB
  - Centered Smoothing Algorithm used to Remove Noise
  - Interpolate Different Sets of Data into Same Time Step
  - Root Sum Squared Accelerometer and Rate Data
  - The RSS is Examined to find Maneuver Times
  - Met Data is Loaded into the Simulation

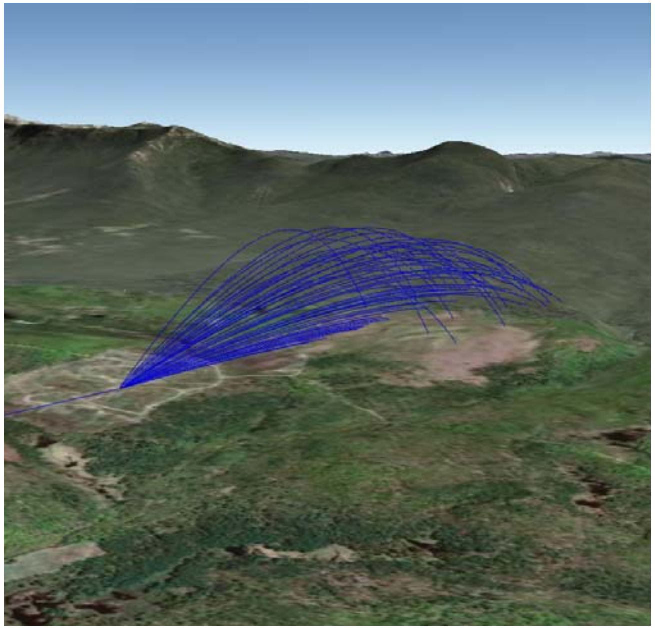






Benefits of a High Fidelity Simulation of Guided Munitions

- Immediate
  - Decrease design turn-around time
  - Higher fidelity to actual round in progress
  - Better prediction of subsequent firing tests
  - Gauges difference to goal
  - Power/effectiveness of unit maneuver
  - Number of maneuvers required to reach target
  - Suggestions for design improvement



- Future
  - Safety Danger Zone analysis
  - Root cause analysis for discrepancies
  - Affirmation of design capabilities
  - Decrease number of rounds fired to generate firing tables
  - Assist users in developing doctrine

Conclusions

- MATLAB/Simulink has been used to obtain a high fidelity simulation of a guided munition
  - Model has successfully predicted performance
    - Aiming
    - SDZ verification
  - Model was used to reproduce unforeseen projectile motion
  - Implemented Monte Carlo analysis to assist GNC development
- This analysis can easily be applied to future programs
  - MATLAB/Simulink model is easy to modify
  - Can support unique configurations/conditions
- For more information, contact the AEROBALLISTICS DIVISION, METC

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QUESTIONS?