ARROW TECH

If you can't get a bigger target...

Extraction of Aerodynamic Coefficients via Data Fusion

Alan Hathaway

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Outline

- Problem Statement
- Solution
- Details
- Summary & Conclusions

Problem:

- **<u>How does engineer make best use of all available aerodynamic data?</u>**
- **Background:**
  - **Multiple Instrumentation Sources Available to Extract Aerodynamics**
    - **Ground-Based Instrumentation**
      - Doppler Radar(s)
      - Position Radar
      - KTM Optical Camera Trackers
    - **On-Board Instrumentation**
      - GPS
      - Accelerometers
      - Sun Sensors
- **Instrumentation sources may cover only part of the flight**
- **Instrumentation may suffer signal drop-out & reacquisition of signal**

- *ANSWER:* **<u>Data Fusion via Parameter Identification</u>**

Extraction of Aero Coefficients is Most Accurate Using Parameter Identification

Parameter Identification

- **Assume:** System Model has unknown parameters influencing flight
  - Guided or Ballistic Flight
- **Goal:** Determine magnitude of unknown parameters to obtain simultaneous best fit all of the observed data
  - Flight Simulation with "End Model" matches observed flight path and dynamic motion with minimum errors
  - Compare predicted flight motion using standard Equations of Motion with measured motion, differentially adjust aerodynamics to minimize differences

Parameter Identification Provides Most Accurate Assessment from Largest Portions of Data

Parameter Identification

- **Start:** Standard Equations of Motion, Estimates of Initial Conditions & Aerodynamics
- Partial Differentiation for each coefficient to generate parametric equations
- Numerically integrate to obtain partial derivatives for each coefficient
- Differential correction equation from Taylor Expansion
- Solve for aerodynamics & look at residuals, plug solutions into Equations of motion & iterate until change in residuals is "zero"

Parameter Identification uses standard Equations of Motion to generate sensitivity matrix; most sensitive parameters fit first

Applications

- **On-Board Sensors & Ground Based Doppler Radar**
  - Radar Modified 4DoF
  - Linear Theory
  - 4 DoF Angular & Swerve Motion Analysis
  - 6 DoF Fixed Plane
  - Body Fixed 6 DoF with Control Forces & Moments
  - GPS Data
- **Ground Based Doppler Radar and KTM Optical Tracker**
  - Sectional Trajectory Reconstruction
  - Radar Modified 4 DoF
  - GPS Data

Data Fusion Works with a Variety of Instrumentation & Sensors

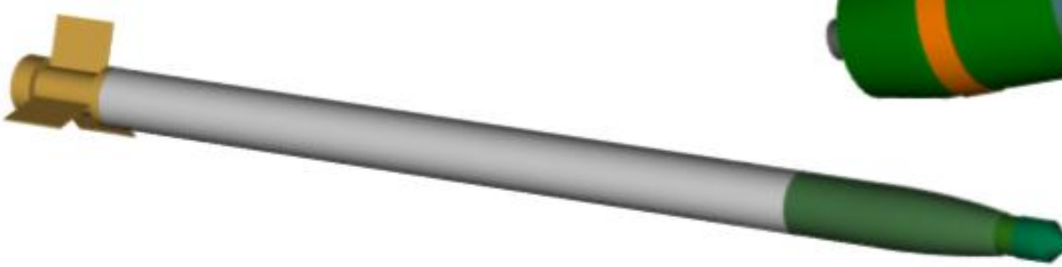
Analysis Procedure

- Data Screening (e.g. does data have large noise?)
- Estimates of Initial Velocity & Conditions (Gun QE & Az)
- Estimates of Burn-on & Burn-out times
- Overlapping 4 DoF sectional fits of complete trajectory via Equations of Motion
- Axial Force & Roll vs. Time & Mach and/or Thrust vs. Time
- Added screening for Erroneous Data based on simulations
- Complete multi-parameter 6DoF Simulations w/ Control Forces (w/ On-board sensors only)

Screen, fit, screen, fit…. Until errors are minimized,
Applicable to ballistic & guided projectiles

Results

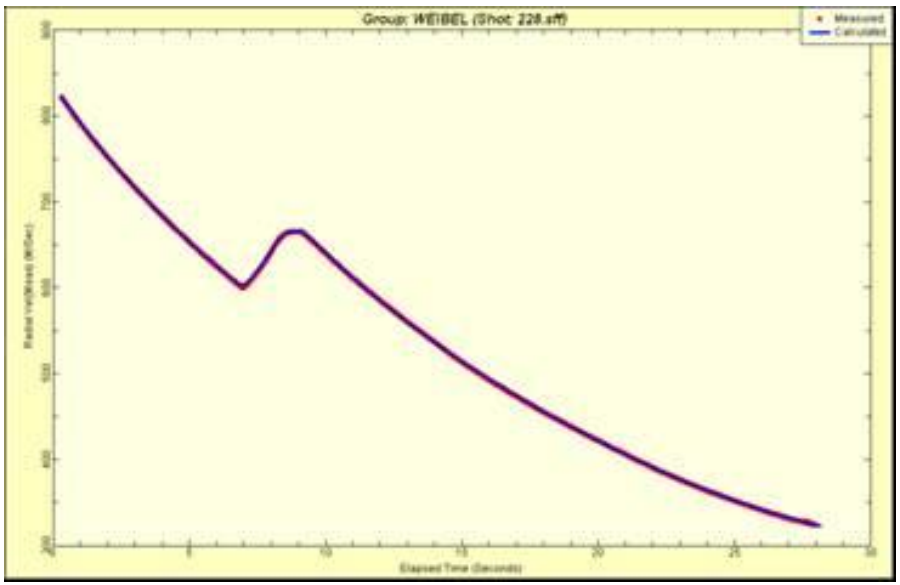
- 155mm Artillery
- Hydra 70 Rocket
- 120mm Mortar
- 105mm



Wide range of projectiles & uses;
Ballistic, Powered & Guided

Radar Data

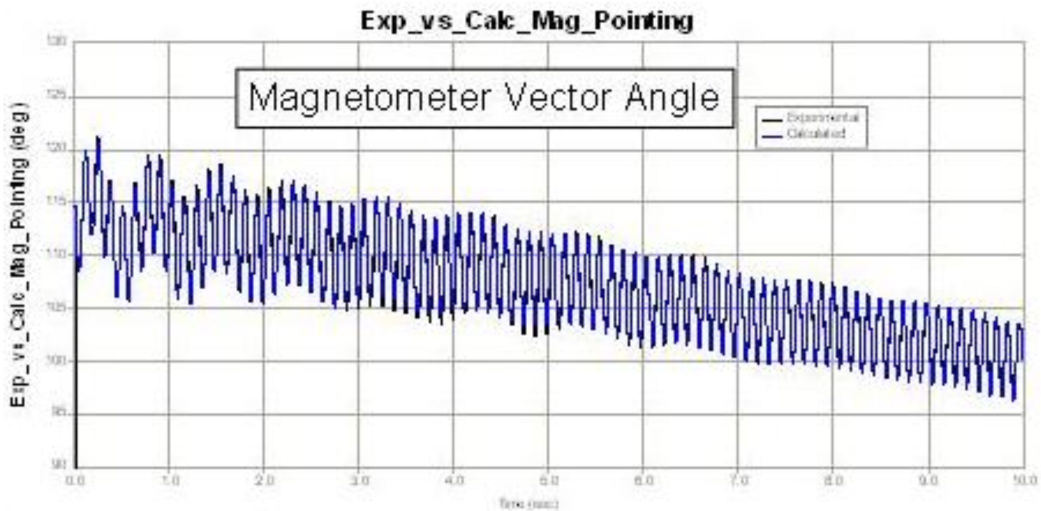
- Position & Velocity Radars
- "Behind the gun" & "Down Range" Doppler
- Position radar provides range, Az & El Data
- Tracking Doppler provides velocity, Az & El data

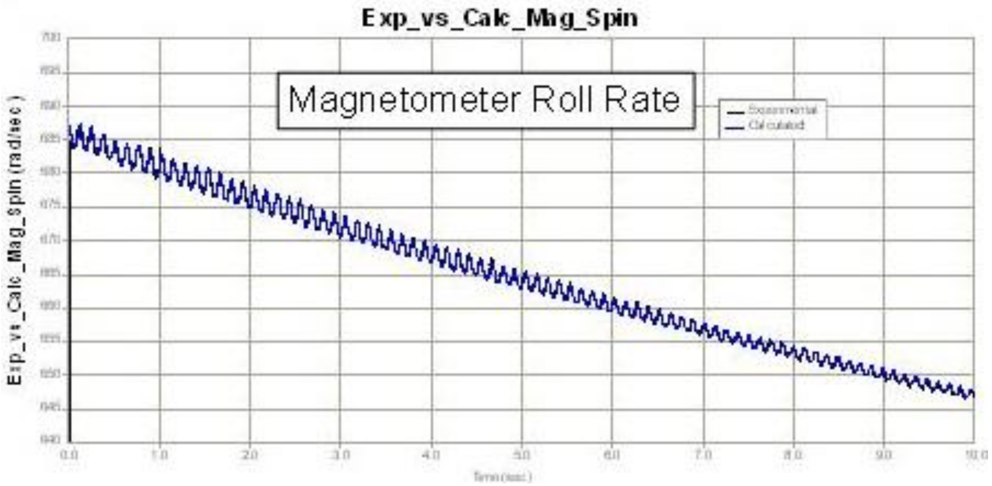


Radial Velocity vs Time
Fit Error 0.62 meters/sec

Velocity-time data basis for drag/thrust solution

Magnetometer Measured vs. Fit





Magnetometer Provides Yaw & Roll Angle Data

Angular Accelerations & Rates

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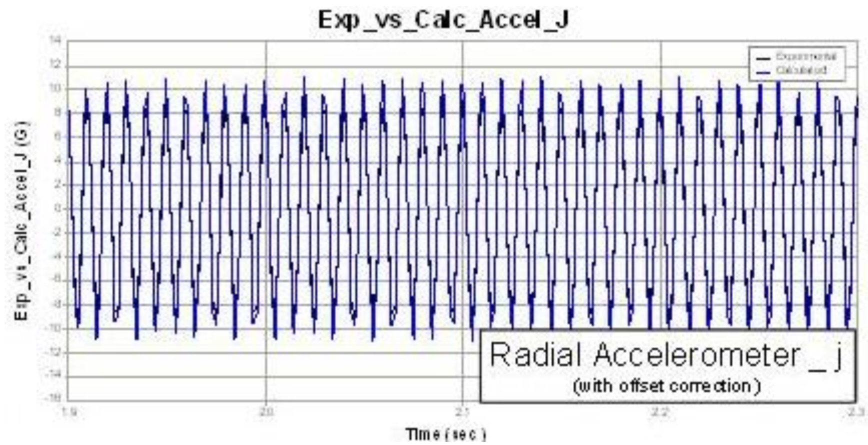

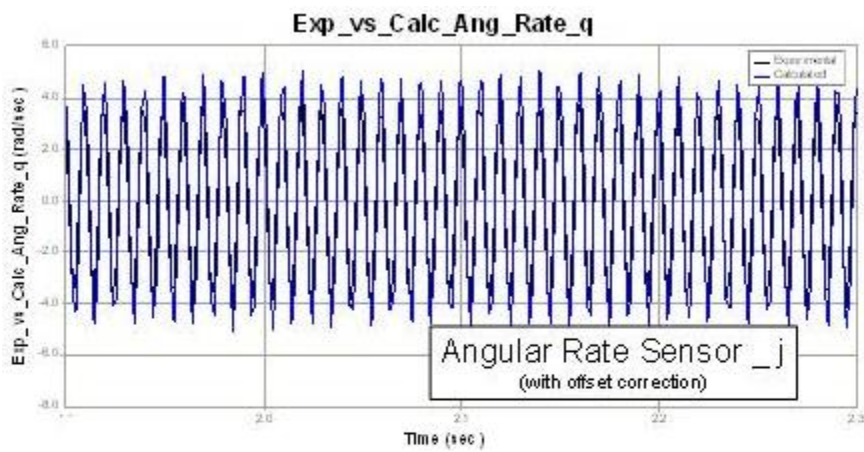

Accelerations & Angular Rates yield information about Normal force coefficient & dynamic stability

KTM Camera Data

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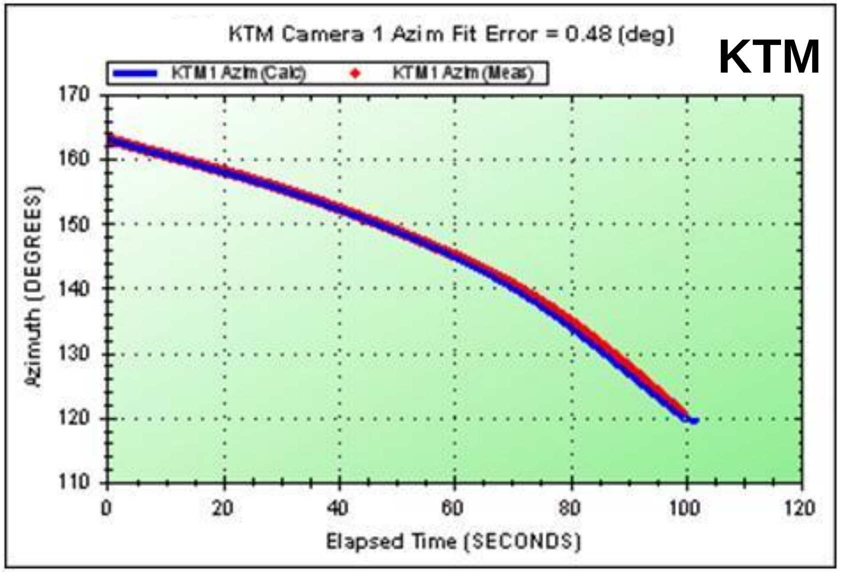
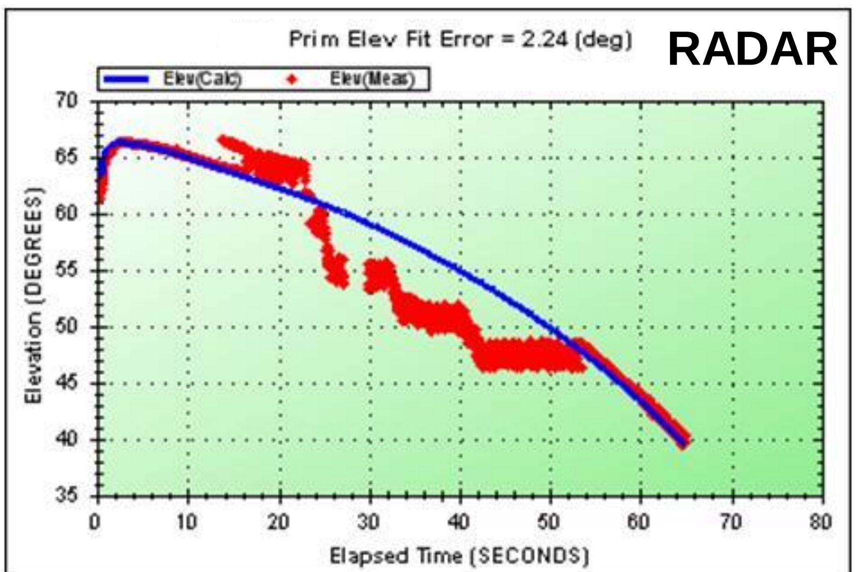
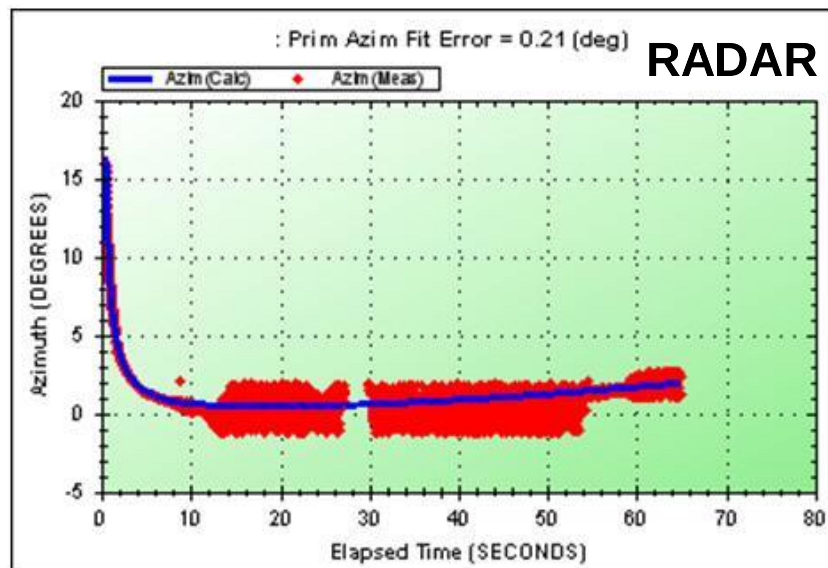


KTM and Radar eliminates internal volume claims for telemetry, compresses schedules





Summary

- **Improved Data Fusion**
  - Combining of sensor data from disparate sources
  - Improved Fit Accuracy
  - Use fewer KTM cameras to reduce test cost w/ equivalent accuracy
- **Provides Faster Turnaround of Final Results to Plan Next Test**
  - Increased Data Volume, helps narrow scope of subsequent testing
- **Feedback Loops Direct from Test to Design Activity**
  - Aerodynamics
  - Stability
  - Control Systems and Guidance and Sensors
- **Data reduction tools must be adaptable to include**
  - New data sources/instrumentation quickly
  - New control systems

•Data Fusion provides maximum use of data from different instrumentation & improves aerodynamic determination, ensuring best use of limited available resources