Beyond TSPI: Using Data Fusion to Combine Multiple Sources of Live Fire Test Data to Determine Aerodynamics and Characterize Control Events

Alan F. Hathaway
Arrow Tech Associates, Inc.
South Burlington, VT 05403
802-865-3460 x12
alan@prodas.com

NDIA Joint Armaments Forum & Exhibition, May 14, 2014
Problem:

- TSPI: Time, Space, Position, Information
  - Will Always Be Important in Live Fire Testing
- However, We Need to Look Beyond TSPI -> Data Fusion
  - How To Make Best Use of all Available Live Fire Test Data?
    - Multiple Instrumentation Sources
      - Ground-Based Instrumentation
        - Doppler Radar
        - Position Radar
        - KTM Optical Cameras
        - Etc.
      - On-Board Instrumentation
        - GPS
        - Accelerometers
        - Sun Sensors
        - Etc.
  - Instrumentation May Only Cover Portion of the Flight
    - Instrumentation Signal “Drop-Out”

Solution: Data Fusion of All Sources Combined With Parameter Identification
Parameter Identification

• **Assume:** System Model has unknown parameters influencing flight (Ballistic Flight or Guided Flight)

• **Objective:** Determine magnitude of unknown parameters to obtain simultaneous best fit all of the test data
  – Obtain flight simulation that 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 Accurate Assessment from Largest Portions of Test Data*
1. Process starts with the standard equations of motion and estimated initial conditions & aerodynamics
2. Develops partial differential equations for each test measurement and coefficient for a set of parametric equations
3. Performs numerical integration to obtain partial derivatives for each test measurement and coefficient
4. Differential correction equation from Taylor Expansion
5. Solves for aerodynamics & examines residuals, updates equations of motion & iterates until change in residuals is “zero”
   • Using a sensitivity matrix, the most sensitive parameters “fit” first.

*Parameter Identification Uses All Available Measurements*
• Preliminary Analysis
  – Data Screening (e.g. does data have large noise?)
  – Estimates of Initial Velocity & Conditions (Gun QE & Azimuth of Fire)
  – Estimates of Burn-On & Burn-Off times (if needed)
  – Overlapping Sectional Fits of Complete Trajectory via Equations of Motion
  – Axial Force & Spin vs. Time & Mach and/or Thrust vs. Time

• Parameter Identification
  – Complete Parameter Identification
    • Four Degree of Freedom (for ballistic flights)
    • Six Degree of Freedom (w/Control Forces; w/ On-board sensors only)
Examples

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

Wide Range of Uses; Ballistic, Powered & Guided
Ground-Based: Radar

- **Tracking Doppler Radars**
  - Provides Radial Velocity, Azim. & Elev.
  - “Behind the Gun” & “Down Range” Doppler

- **Position Radar**
  - Provides Range, Azim. & Elev.

*Velocity-Time Data is Basis for Drag/Thrust Solution*
Ground-Based: Radar plus KTM

**Simultaneous Reduction of Multiple Source of Data**

- **Doppler Radar:**
  - Vel Fit Error: 2.09 m/s
  - Elev Fit Error: 3.29 deg

- **KTM Camera #1:**
  - Elev Fit Error: 0.29 deg

- **KTM Camera #2:**
  - Elev Fit Error: 0.11 deg
On-Board: Magnetometers

Magnetometer Provides Yaw & Roll Angle Data
On-Board: Accelerometers

Accelerations & Angular Rates Provide Information about Normal Force Coefficient & Dynamic Stability
Data Fusion Can Help Overcome Poor Test Measurements
Summary & Conclusions

• Improved Data Fusion
  – Combining of sensor data from disparate sources
  – Improved Fit Accuracy
  – Use fewer KTM cameras to reduce test cost w/equivalent accuracy

• Feedback Loops Direct from Test to Design Activity
  – Aerodynamics
  – Stability
  – Control Systems, Guidance, and Sensors

• Tools Must be Adaptable
  – New data sources/instrumentation
  – New control systems

Data Fusion of Data from Different Sources Gathered from Live Fire Testing Can Improve Both TSPI and Aerodynamics
Alan F. Hathaway
Arrow Tech Associates, Inc.
South Burlington, VT 05403
802-865-3460 x12
alan@prodas.com