M&S Validation for the Joint Air-to-Ground Missile

Brent Crabtree, Andrew Cseko, Tom Johnson, Joel Williamson, Kelly Avery

Institute for Defense Analyses

The System: What is JAGM?

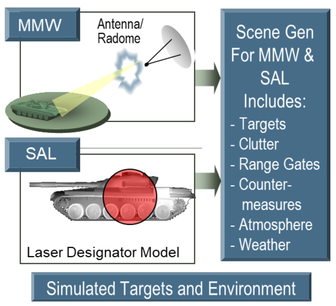
- JAGM is a precision guided missile to attack and destroy vehicles and small boats

- Dual mode seeker (Millimeter Wave and Semi-active Laser) expands air-to-ground missile employment options
- Performance is primarily defined by probability of hitting the intended target
- Targets include tanks, other mechanized and wheeled vehicles, personnel in buildings or in rugged terrain, and small boats

- Flight testing of live missiles is limited by missile and target costs

The M&S: What is the IFS?

- The Integrated Flight Simulation (IFS) was developed to investigate JAGM performance throughout employment envelope
- Simulates both the targets and the environment



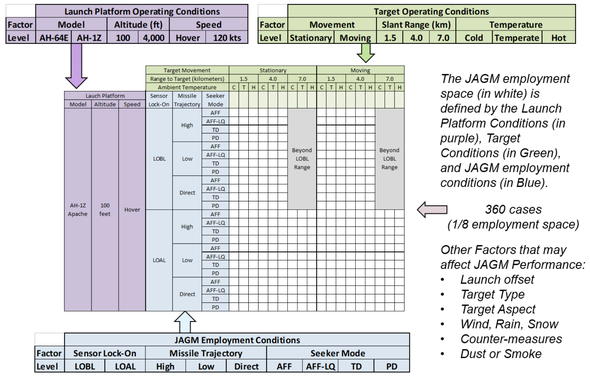
- Estimates hit/miss and point of closest approach for each simulated missile shot

Goals

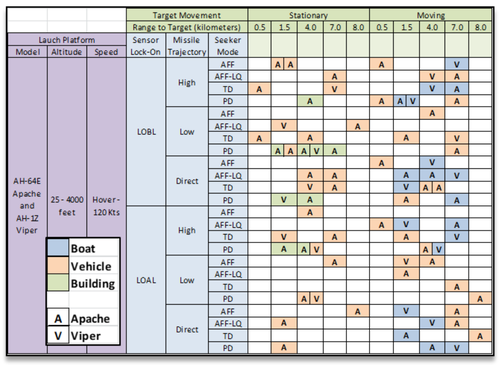
- Select live flight test points to both characterize JAGM performance across the operational space and support validation of the IFS
- Use appropriate statistical design and analysis techniques to support rigorous M&S validation

Live Test Design

- Evaluation should examine missile performance across thousands of allowable combinations of factors such as lock-on modes, seeker modes, trajectories, ranges, launch vehicle motion, target signatures, target motion, clutter, and countermeasures



- Design of experiments (DOE) techniques can produce an efficient and balanced test design without sampling in every possible combination of factors
- A modified D-optimal design with 79 runs provides information about all modes, trajectories, and ranges



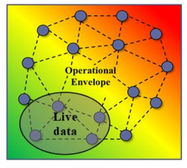
- Design supports statistical response surface modeling for each platform (main effects and most two-way interactions)
- For each model term we can determine the impact of that factor or interaction on the miss distance of JAGM

Power to Detect Significant Factors at the 90% Confidence Level

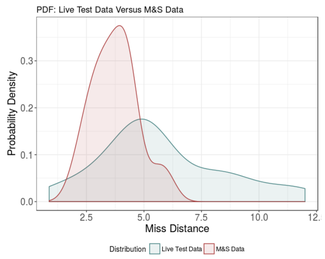
Factor	S:N = 1
Sensor Lock-On	0.90
Seeker Mode	0.32 – 0.89
Trajectory	0.66 – 0.99
Range to Target	0.95 – 0.97
Temperature	0.74 – 0.78
Target Movement	0.44 – 0.99
Two-way Interactions	0.30 – 0.97

M&S Validation Design & Analysis

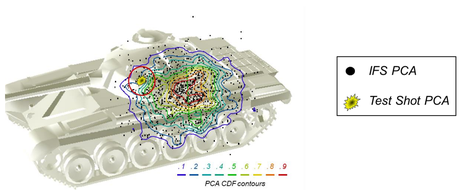
- Explore the entire IFS space (may be larger than the live test design space!) using a 500 run D-optimal design



- Initial validation should use the IFS DOE to explore the M&S space itself
  - Sensitivity analysis
  - Monte Carlo variation analysis
  - Statistical emulators (prediction models)
- Comparison of M&S output to live data using multiple analysis methods can provide differing and confirmatory evidence of the validity of the IFS
- Three-pronged approach:
  1. Kolmogorov-Smirnov Test
     - An initial big-picture look at the data
     - Evaluates whether the overall distribution of the simulated miss distances matches well with the distribution of observed miss distances.



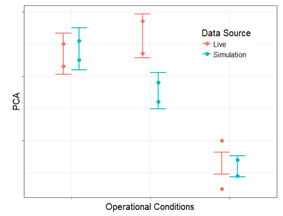
  2. Fisher's Combined Probability Test
     - Compares live test and IFS data under a specific set of test conditions
     - For each live test shot, perform a set of runs in the IFS under the same conditions to estimate point of closest approach (PCA)



     - Calculate the fraction of IFS runs outside the live shot PCA for each test shot (P-tail)
     - If the distribution of P-tail values is evenly distributed between 0 and 1, then the simulation is unbiased
  3. Regression modeling
     - Formally tests for differences between live and M&S while controlling for the effect of other factors
     - Requires matched designs (same DOE conditions executed in both live and simulation environment)
     - Pool live and M&S data to build a statistical model

$$\textbf{PCA} = \beta_0 + \beta_1 Source + \sum_1^n \beta_n Factor_n + \sum_1^n \beta_n (Source * Factor_n) + \epsilon$$

     - If the *Source* effect is statistically significant, then the M&S runs are not consistent with the live runs
     - If an interaction term with *Source* is significant, there many be a problem with the simulation under some conditions but not others
- The above approaches can be used to characterize how well the IFS matches live test data across the operational envelope, and quantify uncertainty in those results



- Statistical validation results, along with subject matter expertise and other qualitative validation methods, inform whether the M&S is adequate for the intended use (and can also be used to calibrate the IFS and inform future live testing!)

Conclusions

- Design of experiments can be used to efficiently cover large operational spaces and choose appropriate live flight test points to facilitate characterization of missile performance and M&S validation
- A statistical approach to model validation provides quantitative evidence that the M&S does or does not work as intended in various operational conditions
- Using a scientifically validated model can reduce risk and save costs by filling in gaps from flight test that would otherwise require additional missiles

Sources

- Based on the IDA JAGM M&S Test Concept and other publically released material
- Poster prepared by Dr. Kelly Avery