Uncertainty Quantification-driven Model-Based Engineering for DoD System Design and Evaluation

Douglas Ray

Research Task / Overview

There is currently significant emphasis on, and need for, the use of computational modeling & simulation (M&S) as a key component of development, test and evaluation of Warfighter systems within the Department of Defense.

This work focuses on developing a framework for integrating M&S and UQ-base probabilistic methods into the DoD systems engineering process, and leveraging M&S data to augment empirical models from 'live' testing/experimentation (especially when this testing is expensive or resource intensive) using Uncertainty Quantification techniques, with an emphasis on visual data assimilation methods.

Goals & Objectives

The intent is to provide decision-makers with richer information for design decisions prior to prototype build, a simplified and credible approach to determine the utility of the M&S model in augmenting live testing, determine the need for additional testing, and determine the range of applicability for data augmentation relative to inherent system variation.
The purpose is to inform the SE process, particularly physical decomposition, concept selection, system design, build, and test with richer M&S-based prediction.

Data & Analysis

Case Study

- Anonymized munition example
- Key performance parameter: long-range target engagement capability
- Engineering team executes pre-prototype M&S of various subsystems:
  - Aero, structural, interior ballistics, lethality, MBSE/functional architecture, etc

Aero Study Background

- 6-DoF Aeroballistics model is developed to verify that tentative airframe design performs as intended across trajectory
- What happens to our ability to meet KPP (long-range target engagement capability, in terms of impact errors in the x- and y-directions and velocity) when we vary initial velocity, launch disturbances in the x- and y-axis, and spin rate of the munition (Hz); given tentative design (canard/fin geometry, projectile geometry, CG, etc)?
  - Resulting Velocity (velocity decay)
  - Other unintended consequences to the system (pressures required to achieve velocity/range, and impact of those pressures on system reliability / parts fatigue)

Approach

- Objective: Study the impact of varying Aero inputs on the outputs, then explore tradespace to determine aero solution which minimizes x- and y-dispersion errors, and maximizes downrange velocity retention
- How: Simulate the model in various scenarios to support a DOE-based model emulator/surrogate model
  - Can use emulator to rapidly execute what-if analysis, sensitivity analysis, optimization and robustness analysis

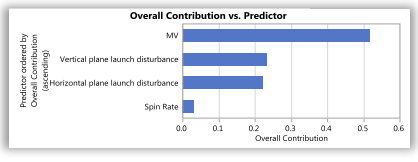
Analysis

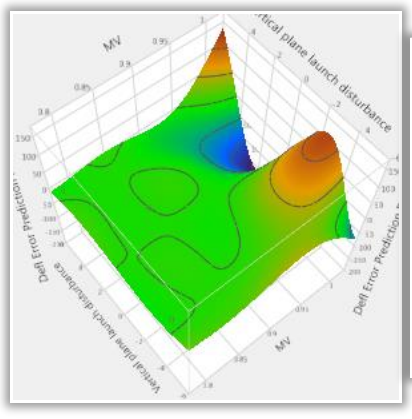
- Simulation DOE
  - MaxPro Latin Hypercube Space-Filling Design

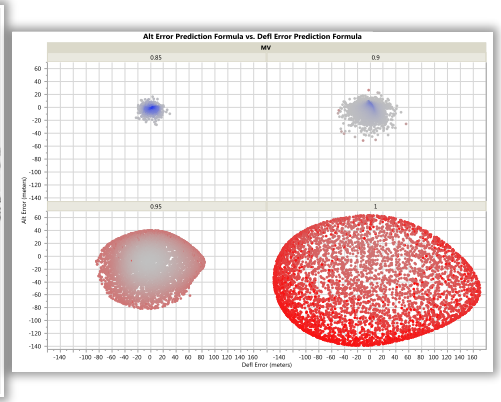
Input Variable	Factor	Units	Low	High
x1	MV	--	0.8	1.0
x2	Vert Launch Dist	Rad/sec	-6	6
x3	Horz Launch Dist	Rad/sec	-6	6
x4	Spin Rate	Hz	20	60

Output Variable	Response
y1	Delta Vel
y2	Final Vel
y3	Deflection Error (X)
y4	Altitude Error (Y)

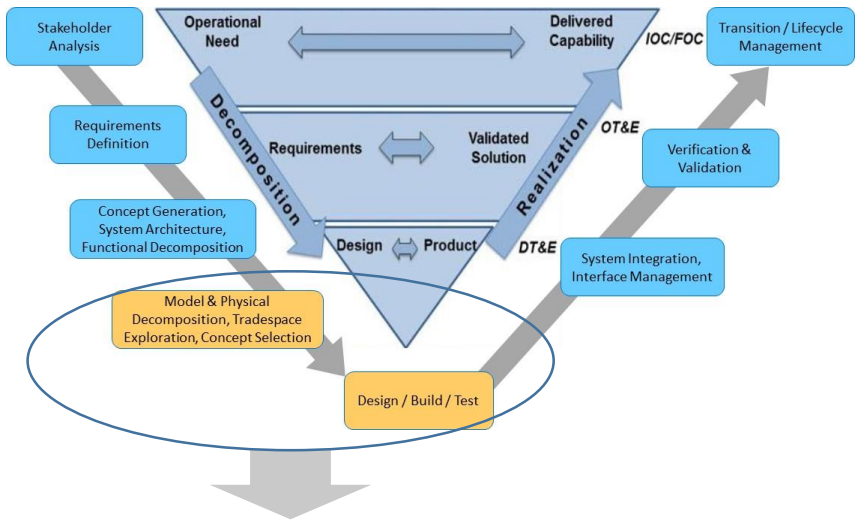
- Emulation / Empirical Model Fitting
  - Gaussian Process Modeling with model crossvalidation
- Numerical Optimization & Propagation of Error
- Monte-Carlo Simulation, Sensitivity Analysis & KPP validation

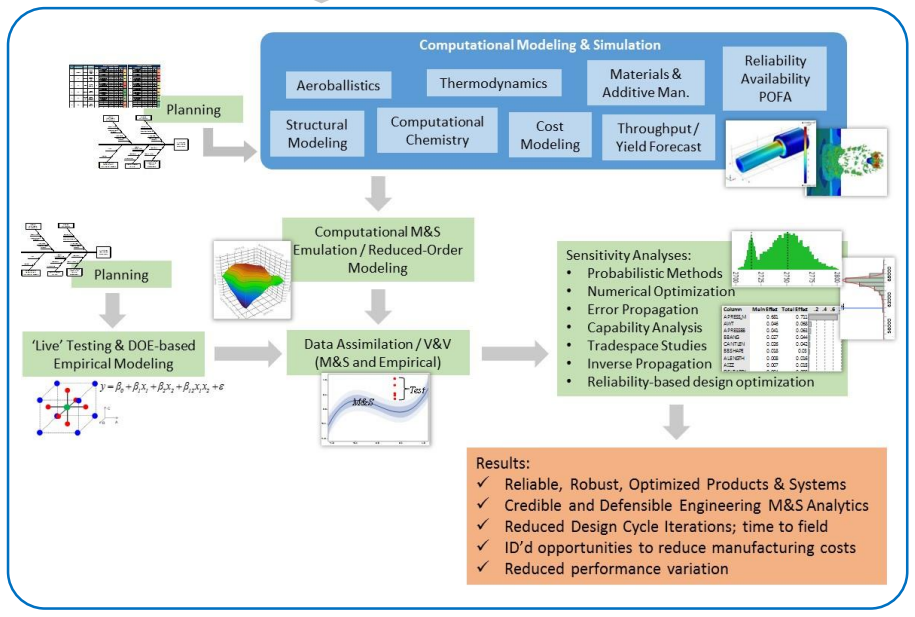






Methodology





Future Research

Future research will seek to:

- Refine the M&S and UQ workflows within the DoD's Systems Engineering Process
- Adapt to wider variety of DoD cases
- Develop visualization-based approach for data assimilation
- Develop new sampling criteria for M&S evaluations for integration with field data

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POC: Douglas Ray, douglas.m.ray.civ@mail.mil