Evaluation of System Effectiveness of Guided Projectiles

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ARROW TECH
If you Can't Get a Bigger Target...

Typical Application

- **The Problem:**
  - Assess the system effectiveness of a notional guided projectile (performance metrics = CEP).
- **Givens:**
  - The basic projectile shape is known and the control mechanism (scheme) has been defined.
  - The aerodynamics are unknown.
  - The G, N, & C system has not yet been developed / defined. (e.g. “on” time, control force magnitude, etc.)
- **Output:**
  - **Calculate the CEP for a number of zones, ranges and atmospheric conditions….**
  - **Delivery: one week!!!**

Guided System Simulation: Overview

Typical Monte Carlo Trajectory Simulation except:

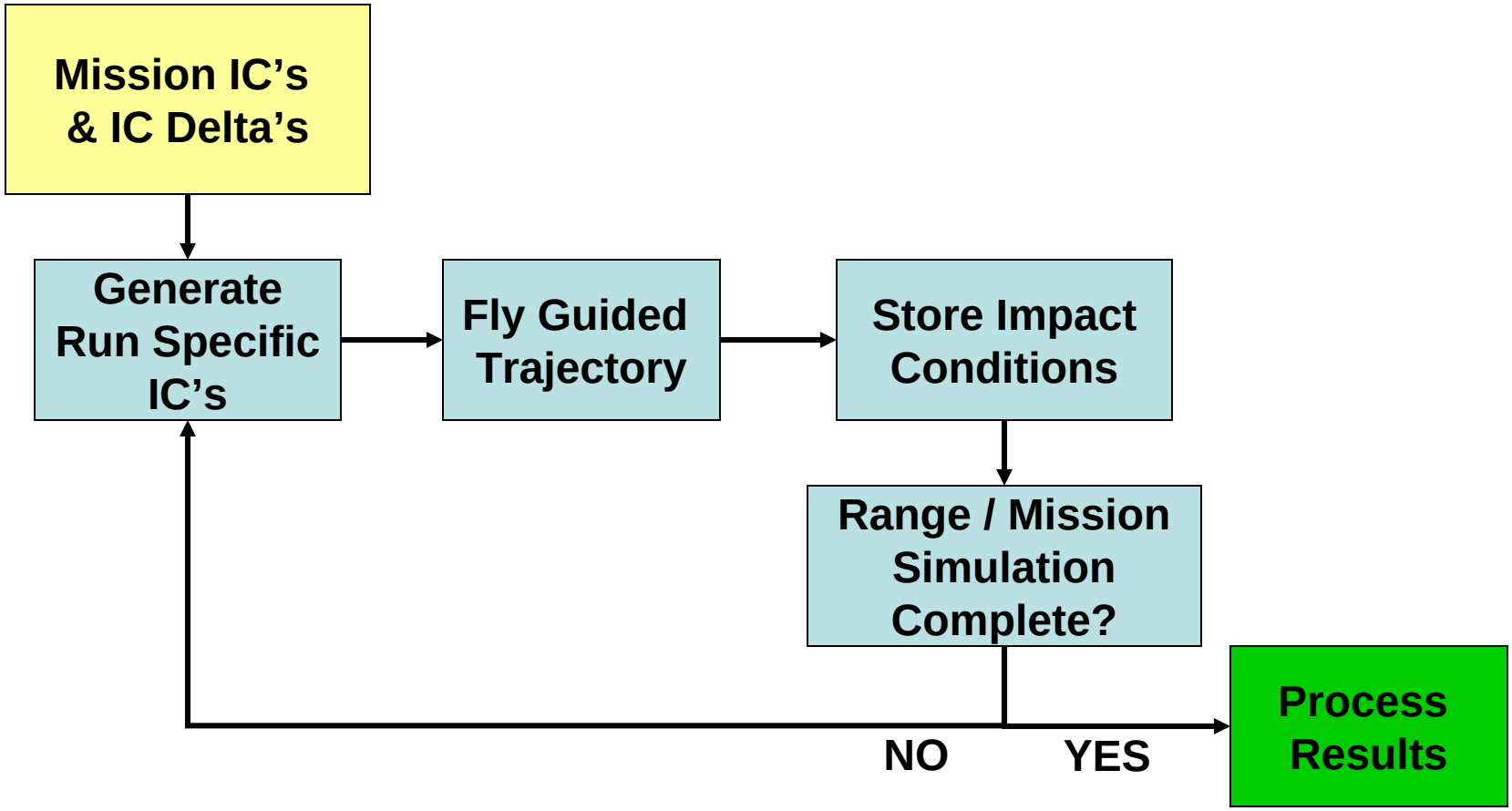
- Want to refine guidance algorithms
- Compare Guided versus Unguided
- Do initial G,N, & C trades w/o “true” random draws

- **Preprocessor module: develops a set of initial condition deltas from the error model**

- **Initial conditions “set” can be used repeatedly to isolate the influence of flight control system modifications**

- **IC “set” is expressed as deltas, applied to varying nominal cases (e.g. different zones or QE)**

Guided System Simulation: Overview

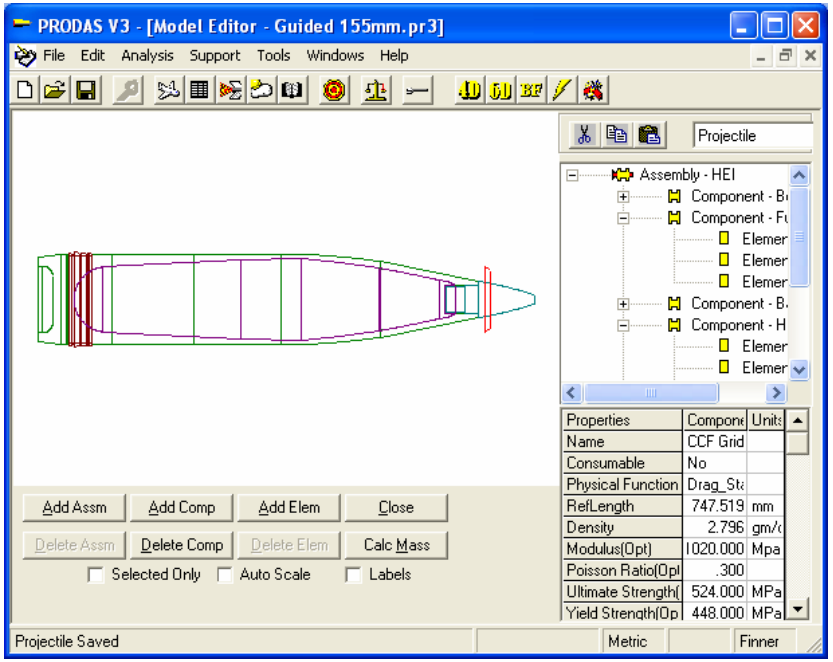


Arrow Tech Approach

1. Build (or import) a model into PRODAS.
2. Estimate aerodynamics using one (or more) of the ***PRODAS Aero Predictor*** codes
3. Design the control system using the ***PRODAS GN&C Prototype Tool***
4. Define an error budget and create a set of initial conditions deltas using ***PRODAS Initial Conditions Generator.***
5. Define all of the nominal firing conditions, use ***PRODAS Firing Table*** module to solve for req'd QE and azimuth
6. Use the ***PRODAS Macro language*** to simulate thousands of firings with and w/o guidance.
7. Process the results in spreadsheet.

Step 1 – Build a Model

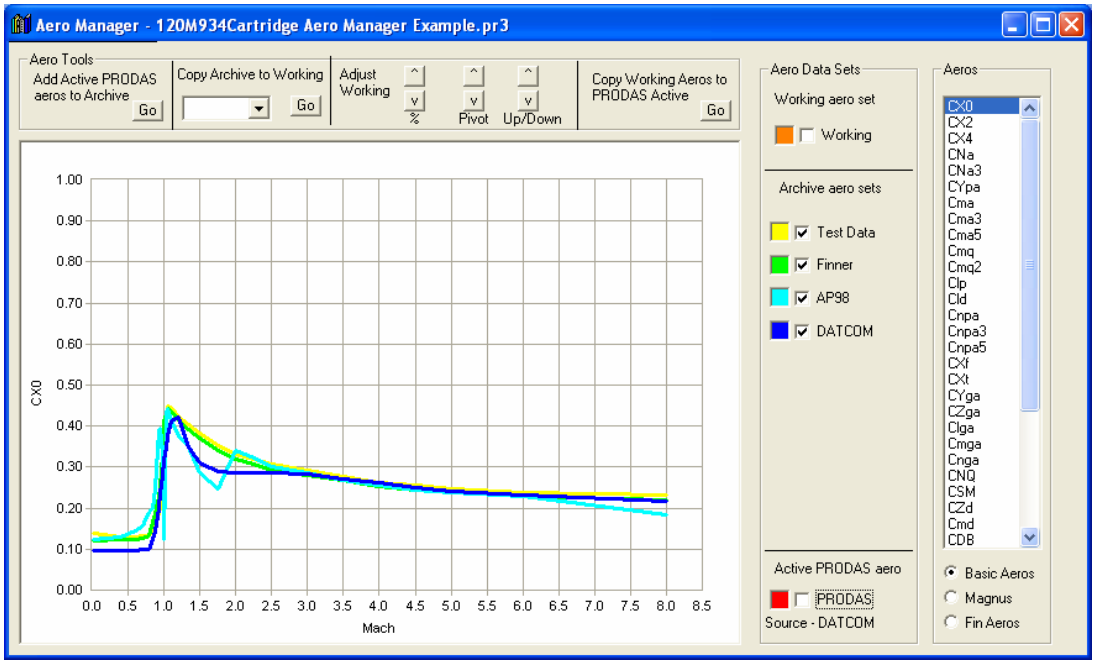
- **There are multiple ways to build a model**
  - Use the PRODAS Model Editor
  - Import either DXF or IGES files
  - Point and click on a bitmap of an existing projectile with the PRODAS Tracing Tool
  - Modify one of the existing models



- **The model then becomes the basis for all of the subsequent analyses**

Step 2 – Estimate the Aerodynamics

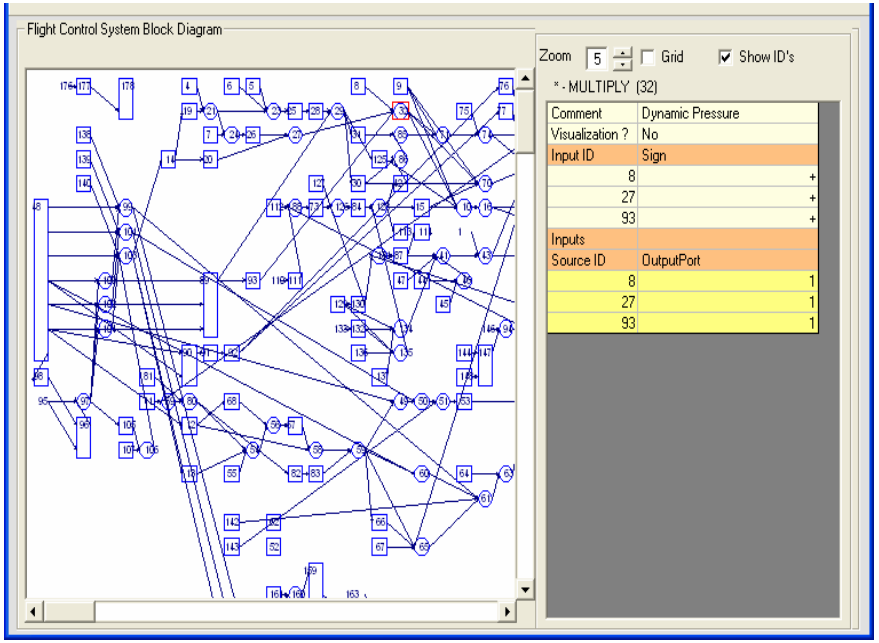
- **Use one or more of PRODAS' *Aero Prediction* codes**
  - *Spinner2000*
  - *Finner2000*
  - *AP98*
  - *Missile DATCOM*
  - *NEAR MISL3 (coming soon)*



- **If multiple codes are applicable, use the *Aero Manager* to help sort them out.**

Step 3a – Develop a Control System

- **The *PRODAS GN&C Prototype Tool***
  - Fully integrated 6 DOF Trajectory and GN&C Simulation
  - Short learning curve w/ drag and drop control builder
  - Large library of control element building blocks, including typical sensors
  - Executes much faster than real time, depending on the size of the control system
  - Control with canards, squibs or generic forces and moments



Step 3b – Build the GN&C System

- **Iteration 1**
  - Clean sheet design using projectile state variables
  - No sensor errors
  - Evaluate guidance algorithms and control loops
  - Establish initial gains within the controller

- **Iteration 2**
  - Add realistic sensors with errors
  - Work around sensor limitations (GPS slow updates)
  - System tuning

- **Test and tune with multiple nominal trajectories prior to Monte Carlo simulations**

Step 4a – Develop an Error Budget

- **Develop an error budget for the system**
  - Mission to Mission
  - Weapon to Weapon
  - Round to Round

Error Source	Level of Application		
	Mission-to-Mission	Weapon-to-Weapon	Round-to-Round
Gun Lay/Pointing/Aiming		X	
Gun/Weapon Dynamics		X	X
Muzzle Velocity	X	X	X
Ammunition / Projectile	X	X	X
MET Staleness	X		
Weapon Location		X	
Fire Control	X		
GPS	Bias		Random

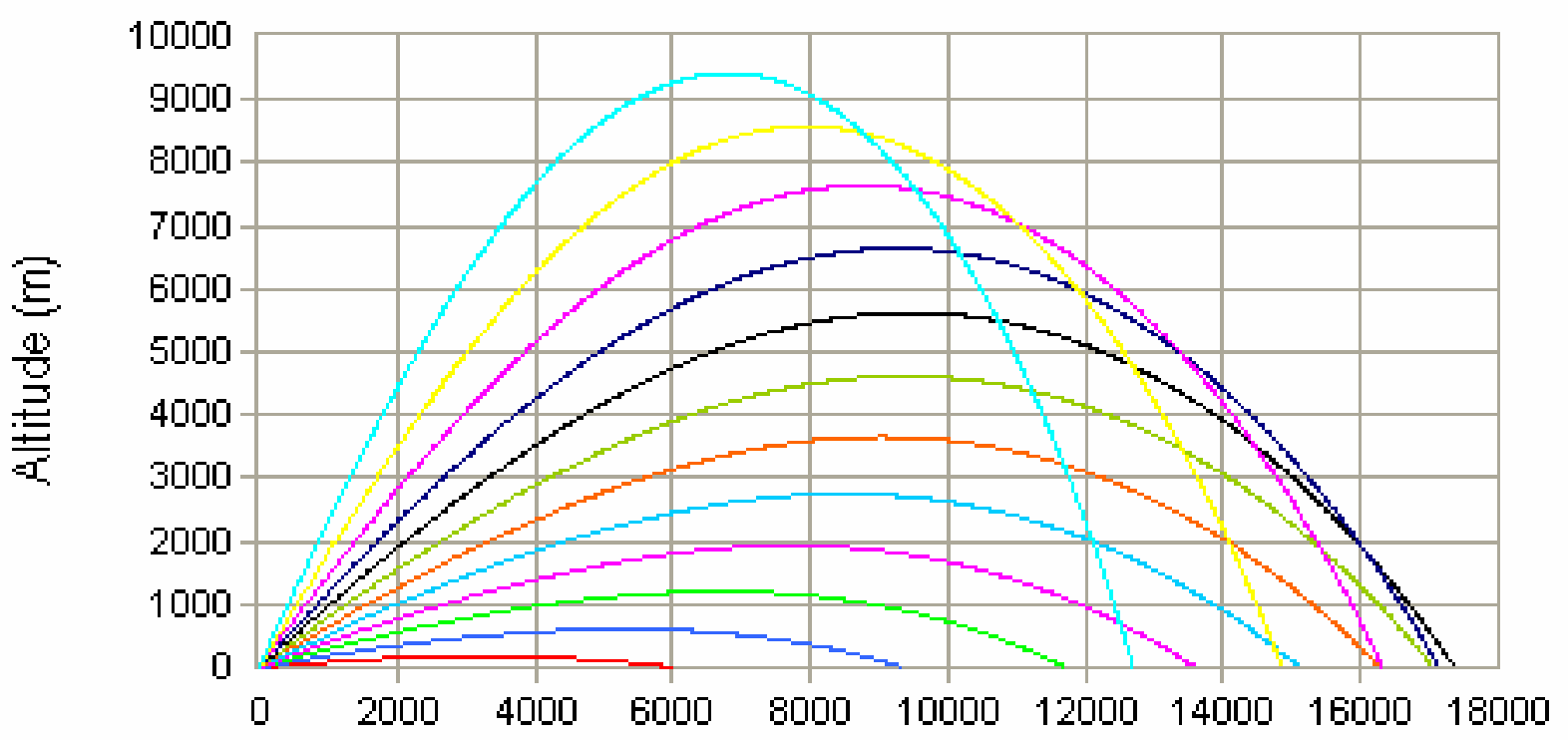
- **Error Budget "Tuned" to match FT / "Real" World**

Step 4b – Generate a Set of Initial Conditions Deltas

- **Using the error budget and the *PRODAS Initial Conditions Generator*, generate error deltas for:**
  - Muzzle Velocity
  - Angular Rates
  - Gun Pointing (QE and Azimuth)
  - Drag and Lift
  - GPS bias errors
  - Met variability
- **These deltas are applied to a set of nominal values to provide IC's all of the subsequent runs.**

Step 5 – Define Gun Nominal Conditions

- Need the firing solutions for multiple ranges and zones
- Easiest way: run ***PRODAS Artillery Firing Tables***



Step 6a - Build the macros

- **PRODAS Macro language facilitates automation of just about anything a user can do.**
  - Open a projectile file
  - Set the initial values for analysis
  - Run an analysis
  - Save a projectile file
  - Produce cross plots
  - Save results to a text file

- **Or, use the *PRODAS Analysis Bot* to create the macro, which can be modified later if req'd.**

Step 6a' - Test the Macro

Step 6b – Run the Macro

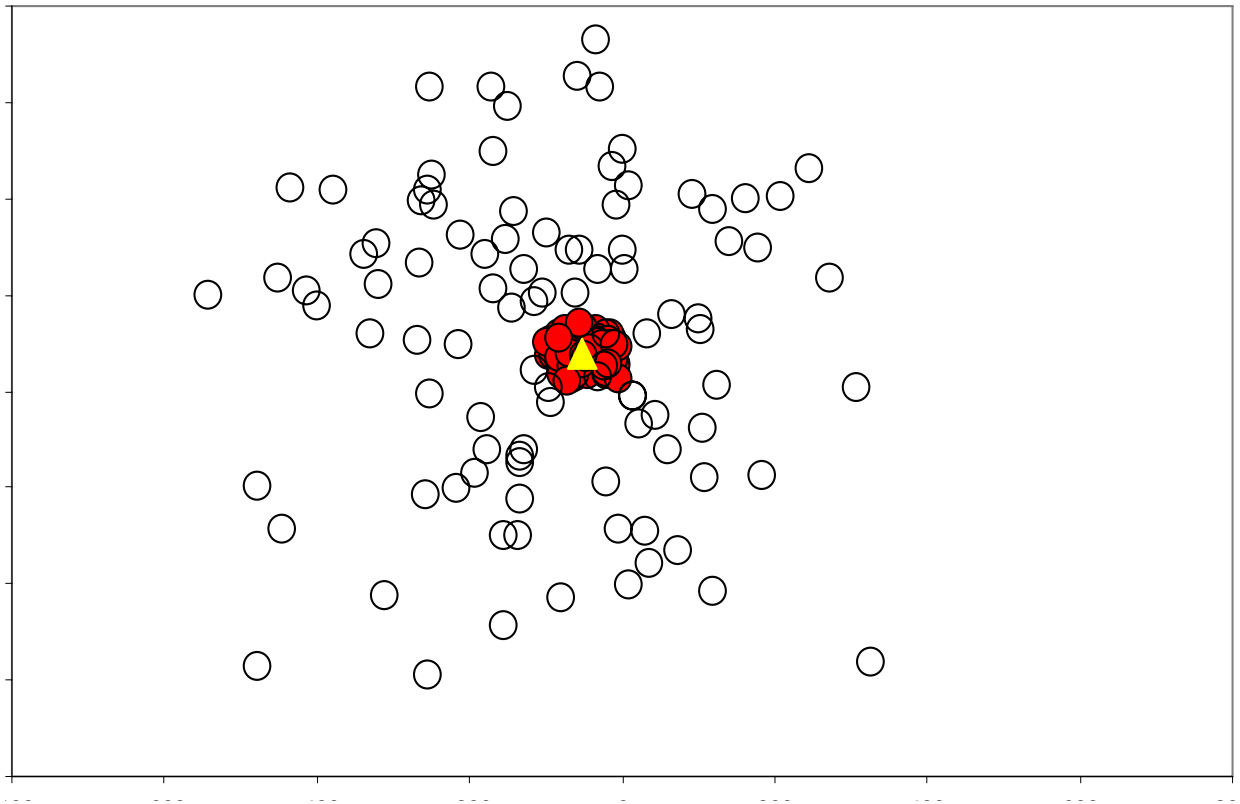
- **For system simulations, we use a macro with two loops**
  - **The "inner" loop**
    - Opens files
    - Runs guided 6 DOF Trajectories with random initial conditions
    - Collects Impact Data
  - **The "outer" loop**
    - Allows running "batches" of guided 6 DOF Trajectories with varying scenarios (e.g., zone, QE, Met, etc.)
    - Build equations into the results file to calculate CEP

Typical Guided Projectile Flight Behavior

Step 7 - Post Process the Results

- **All results are written to files for further processing / plotting.**
  - **Impact location and conditions, and initial conditions are recorded.**
  - **Intermediate data / states can be recorded.**

Example Outputs



- **(Typical) 100 Shots with and w/o guidance**
- **CEP with & w/o guidance as a function of range**

Observations

- Guidance for artillery projectiles: Range & Az. Error, ~ 30-50m, range & proj. dependent
- Range Extension dependent on control scheme & mechanization
- CEP Effectiveness at short ranges dependent on maneuver authority, signal acquisition & active time
- CEP as a percent of range shrinks for guided projectiles at longer ranges, up to max maneuver authority

Conclusions

- Integrated, all inclusive analyses (e.g. PRODAS) is the most efficient way to conduct trades
  - Eliminates hand-off / translation problems
  - Macro Language is powerful & flexible
  - Macros used for all types of trade studies
- System effectiveness comparisons of configuration changes (aero's, algorithms, duration, etc.) can be quickly generated & an optimum scheme selected
- Guided projectile performance (e.g. CEP) can be evaluated in a timely manner, using readily available tools.