Adaptive Sensitivity Testing in Armaments: A Case Study

Zach Krogstad
Nick Tashjian
Chris Drake
Doug Ray

NDIA

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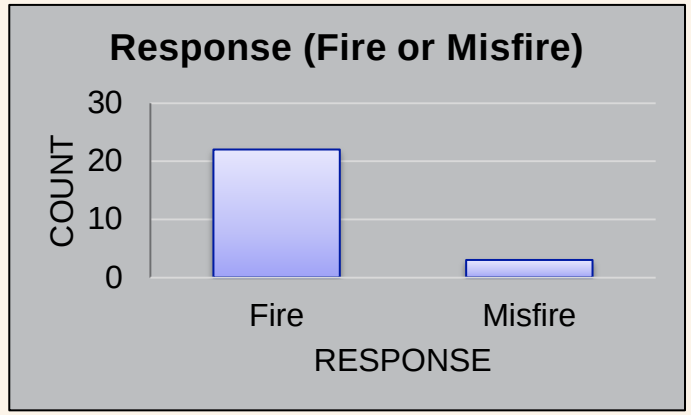
BACKGROUND

Modern statistical computing has enabled sensitivity test data to be collected in a more efficient manner



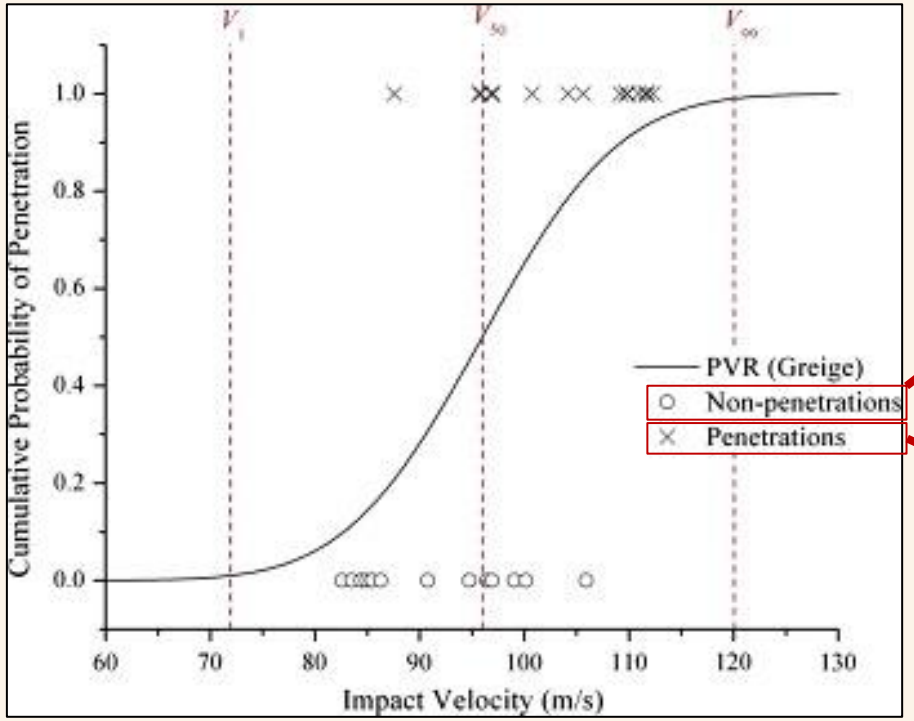
This is applicable to all armament tests where the response is binary

A case study involving small caliber primer testing will be presented

- 200,000+ primers tested per year at LCAAP
- 300 - 600 primers per test
- **Modern methods can reduce this by an order of magnitude**

SENSITIVITY TESTING

A common example: armor penetration/perforation

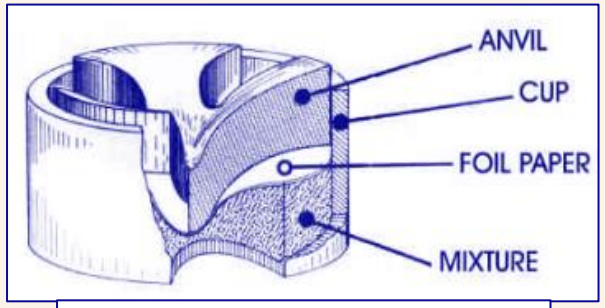


Note: Data are not linked as shown. Graph for illustrative purposes only.[1]

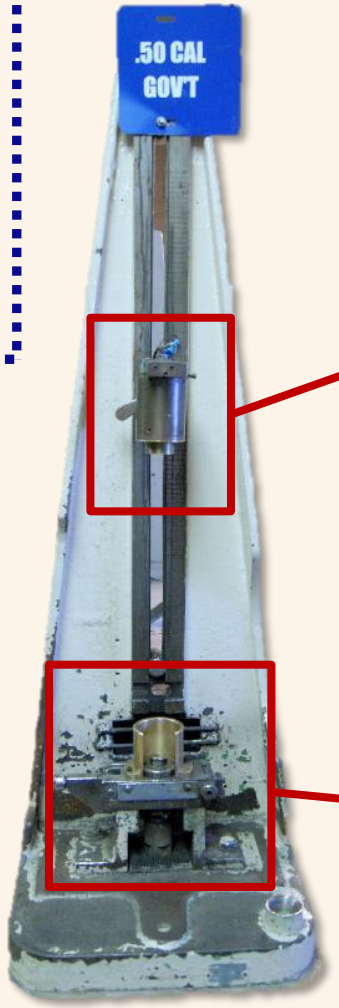
Impact velocity = LOW

Impact velocity = HIGH

PRIMER SENSITIVITY



Small caliber primer



A steel sphere (not pictured) is held in place by a magnet

(size varies per caliber)

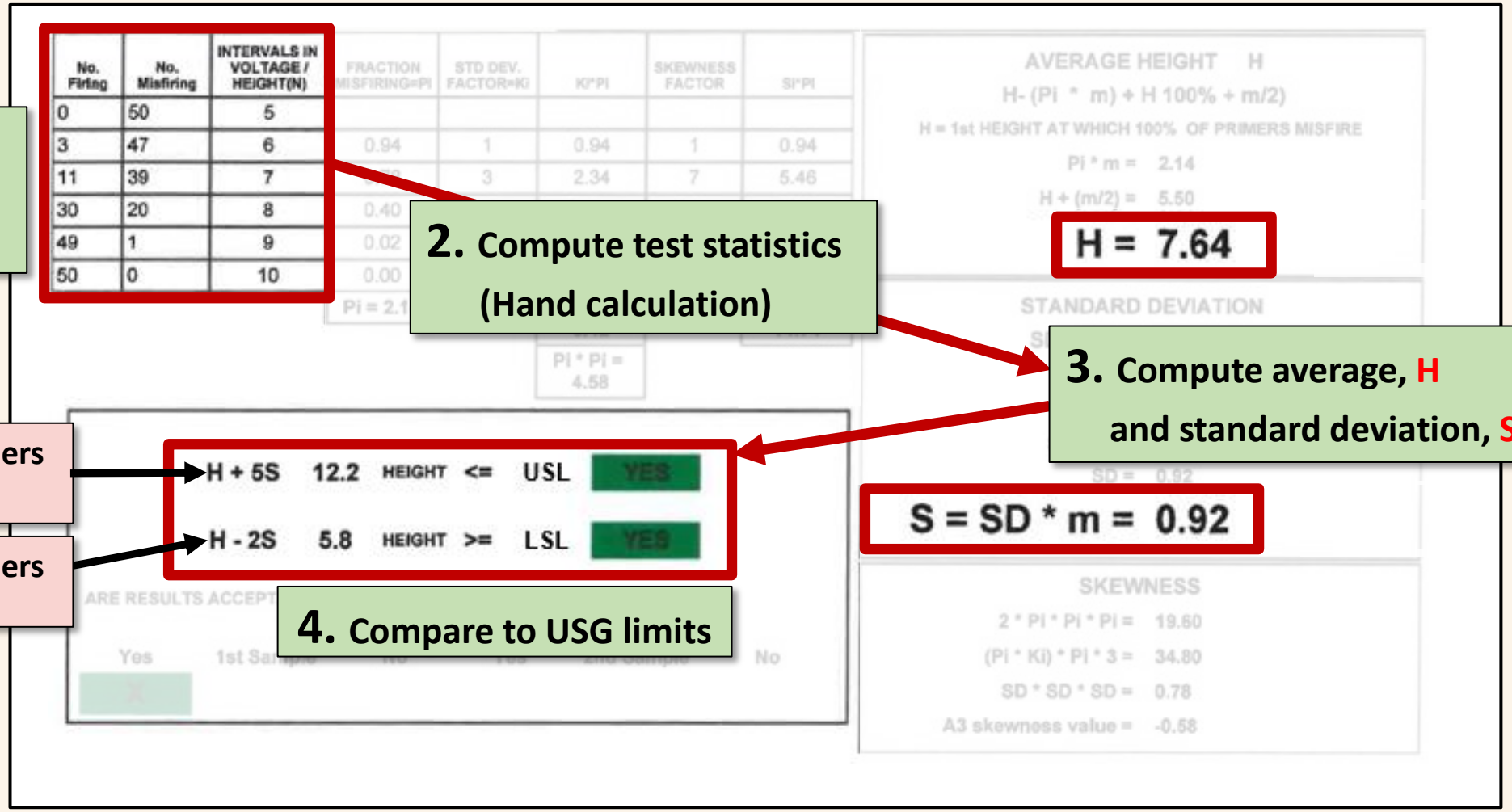
Primed cases are placed in the test apparatus

Pseudo firing pin rests on top of primed case in fixture

The sphere is dropped at 1” intervals to generate a range of impact energies

THE RUNDOWN METHOD*

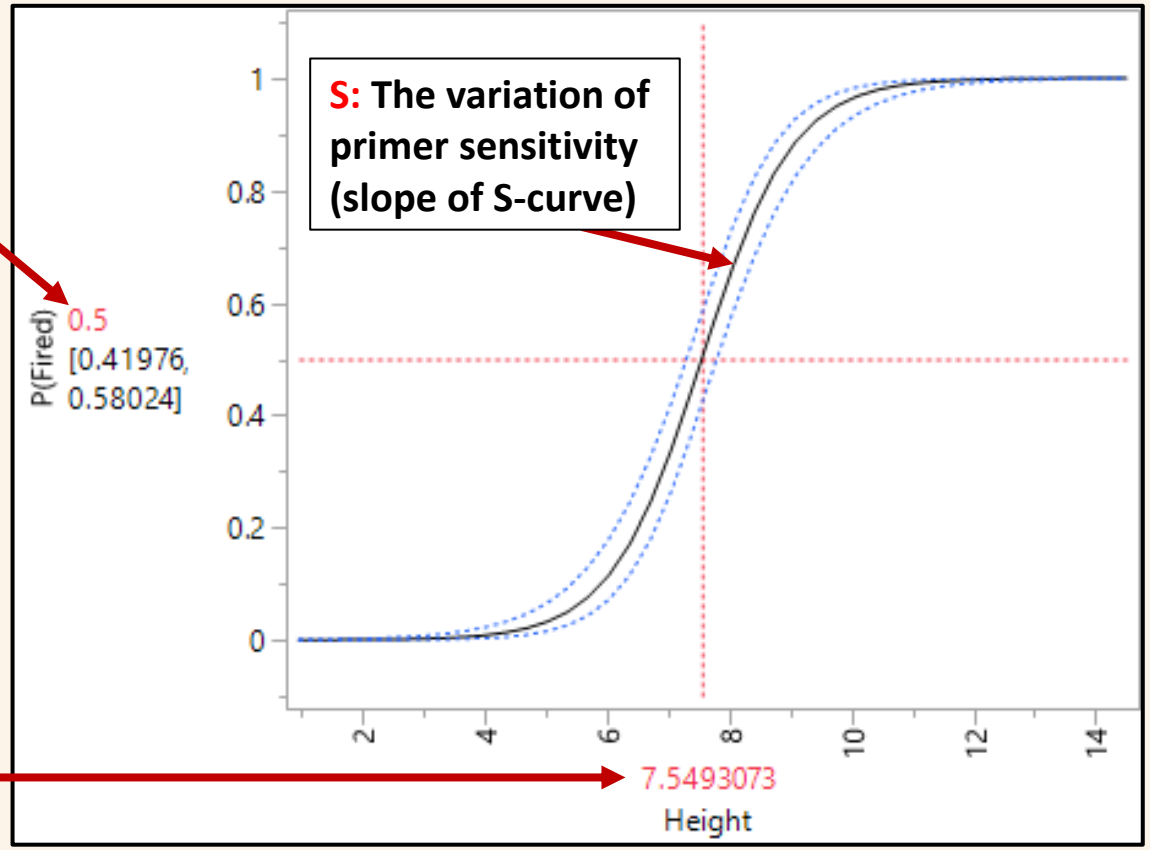
*Technically considered an application of the sigmoid dosage-mortality curve (Bliss, 1935)

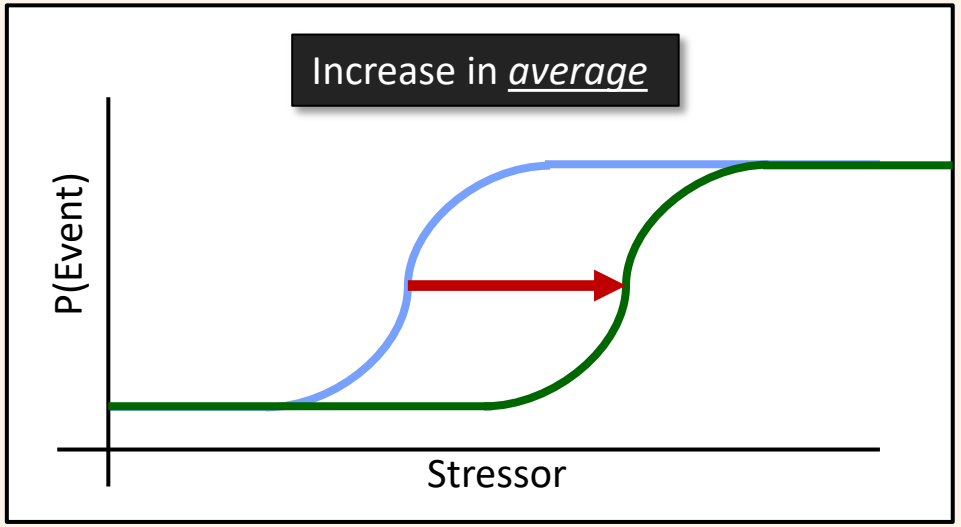


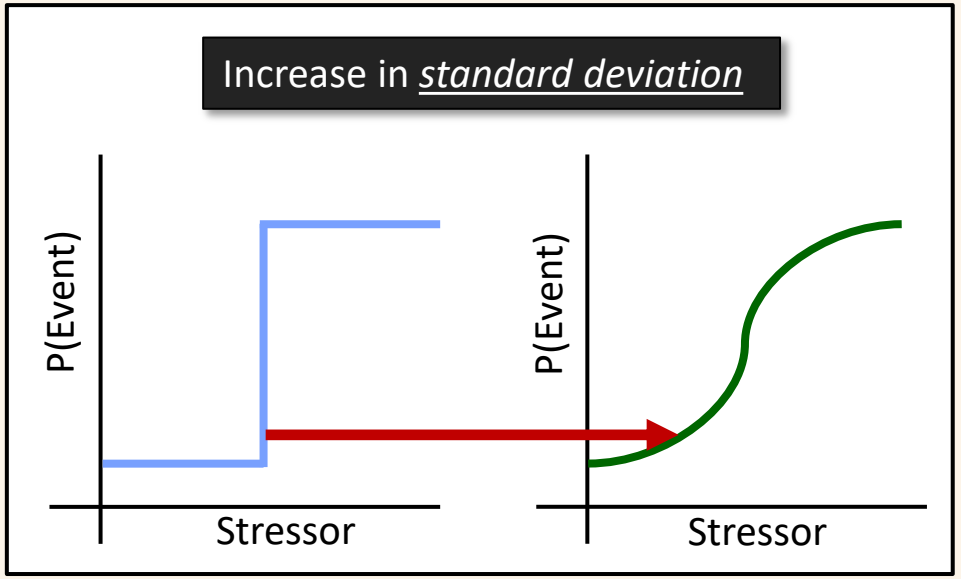
S-CURVES

H: The height at which **50%** of primers are expected to fire (center of S-curve)

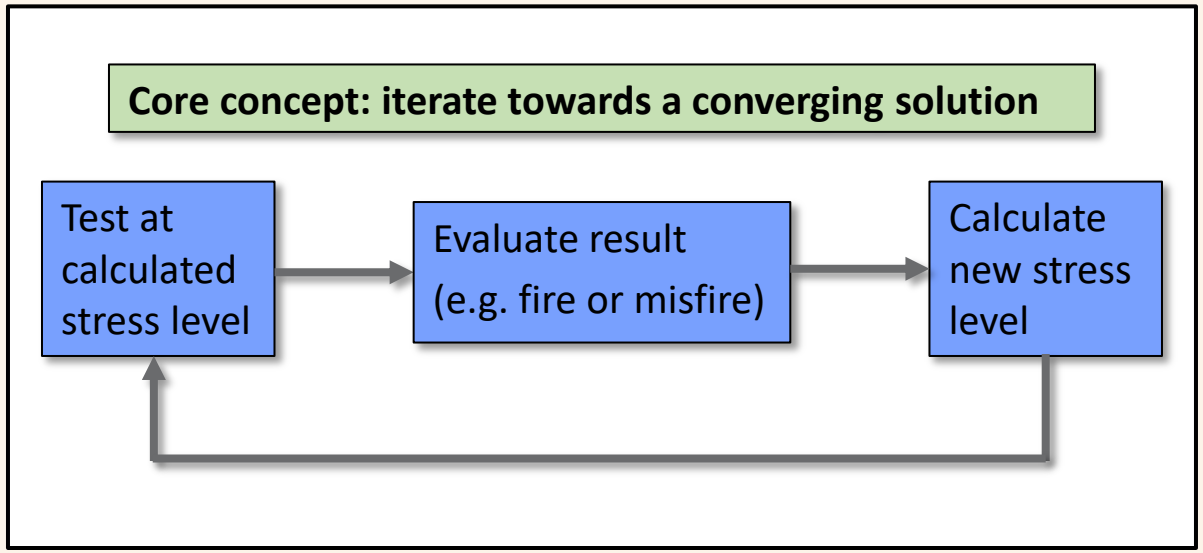
S: The variation of primer sensitivity (slope of S-curve)





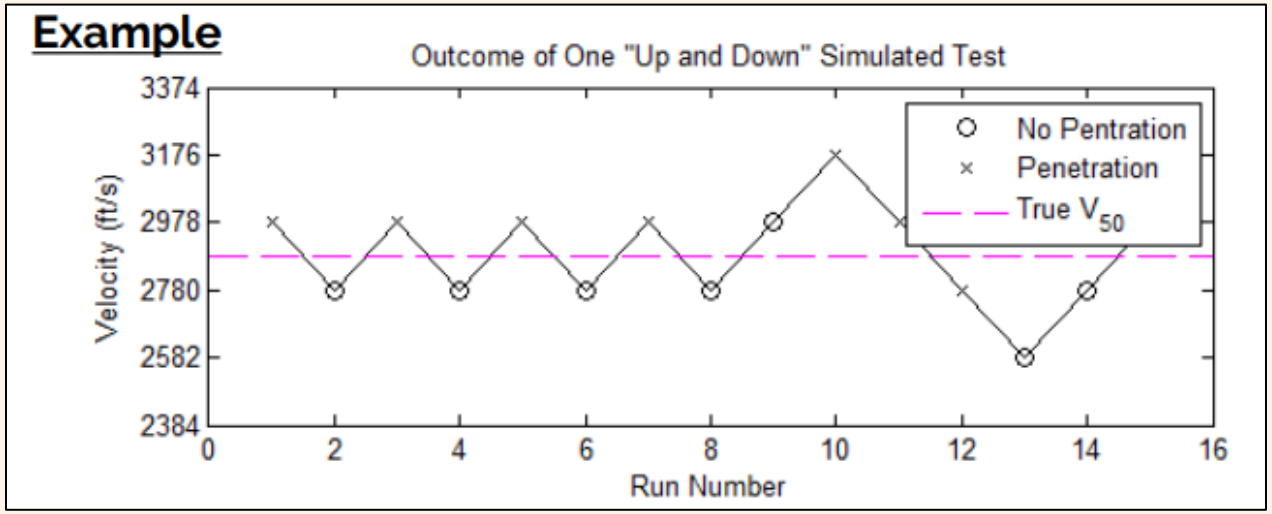


Adaptive Sensitivity Test Methods



Examples of adaptive sensitivity test methods:

- **Bruceton or Up-Down (1948)**
- **Langlie (1962)**
- **Neyer D-Optimal (1994)**
- **Robbins-Monro-Joseph (2004)**
- **3POD (2014)**



Example of Up-Down method[2]

3 Phase Optimal Design (3POD)

- Most recent adaptive method developed by Wu and Tian (2014)
- Conducted in 3 phases, as follows:

I. Search: *Identify a reasonable experimental range*

1. Obtain one event of each type (e.g. 1 fire, 1 misfire)
2. Find "overlapping region" or "zone of mixed results" (expected a fire, got a misfire, or vice versa)
3. Refine "zone of mixed results"

II. Estimate: *Optimize the parameter estimation in the assumed model*

- Utilizes D-optimal design criterion to place design points
- "Where can I test next to gain the most amount of information?"

III. Approximate: *Gain more information about a percentile of interest*

- Converges on 50th percentile by default
- What if we wanted to know V_{10}? V_{90}?

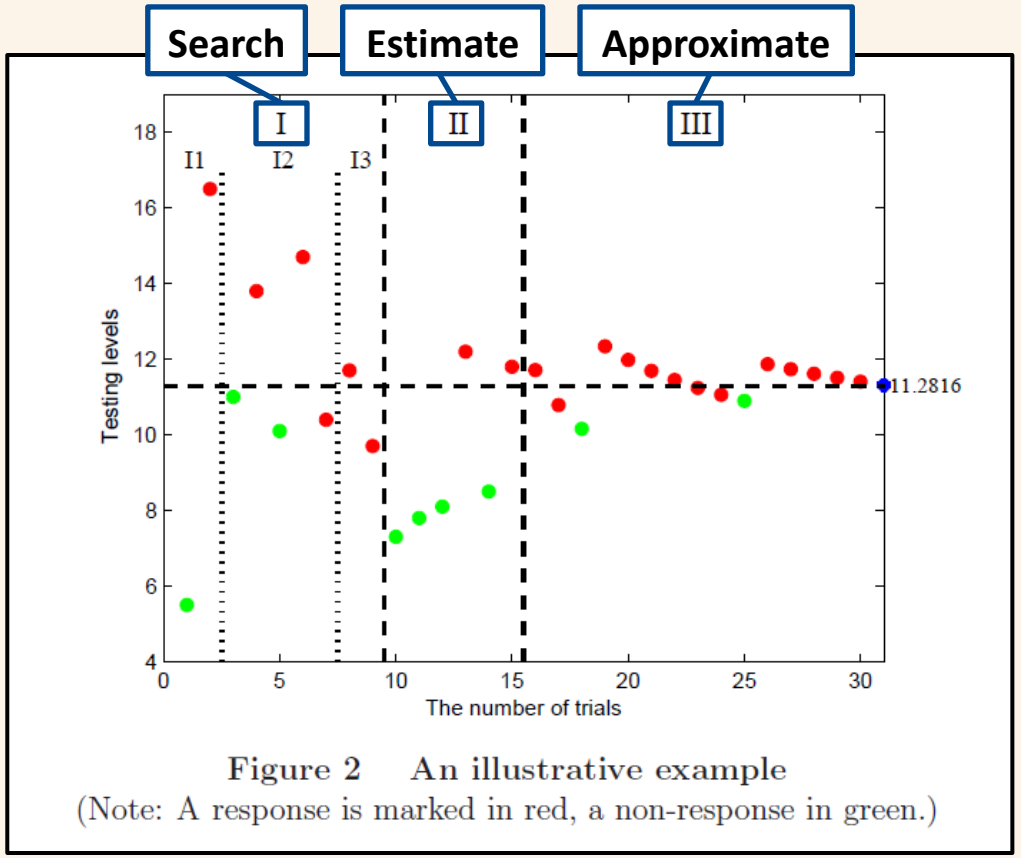
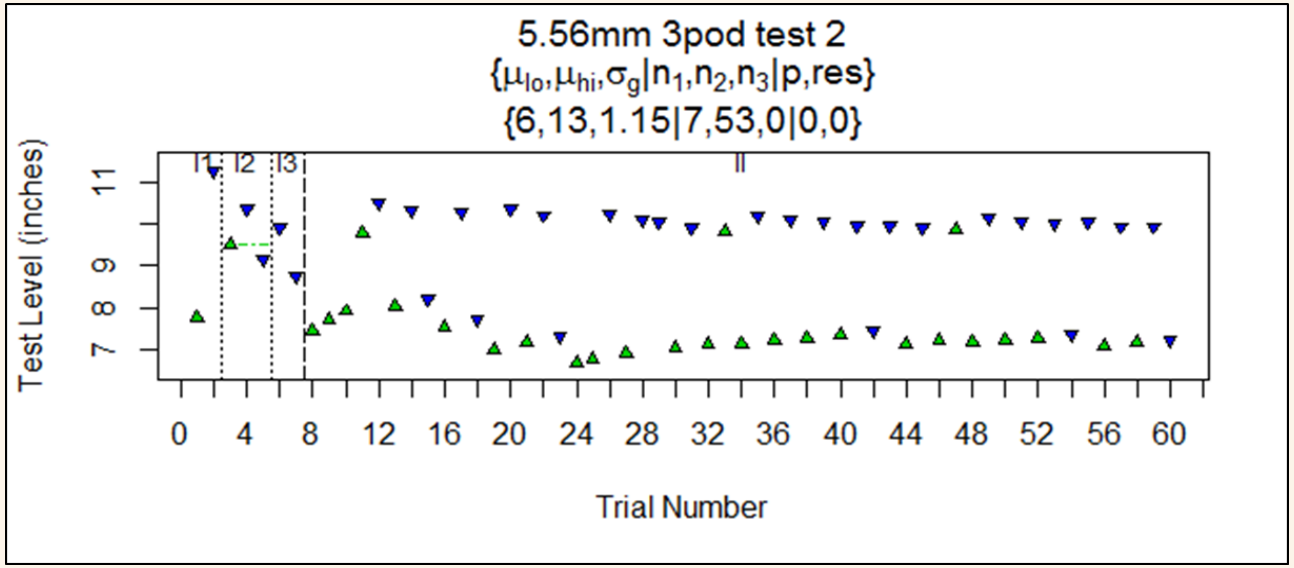


Figure 2 An illustrative example
(Note: A response is marked in red, a non-response in green.)

Example of 3POD method[3]

3POD PRIMER SENSITIVITY

- **ARDEC engineers and statisticians have conducted testing at Picatinny Arsenal and the LCAAP to evaluate efficacy of 3POD**
  - 5.56mm and 7.62mm, .50 cal in progress
- **Only Phases 1 and 2 conducted**
  - Phase 3 not necessary in this application for evaluating H_{50}
- **Most recent tests used linear position transducer to accurately measure drop height**



SUMMARY

Current Method: Rundown

- **300-600** primed cases required per test
  - Time and labor intensive
- Utilizes **antiquated hand-calculation** to analyze sensitivity data
  - Dosage-mortality curve (1935)
- Uses **1" rods** to adjust drop height

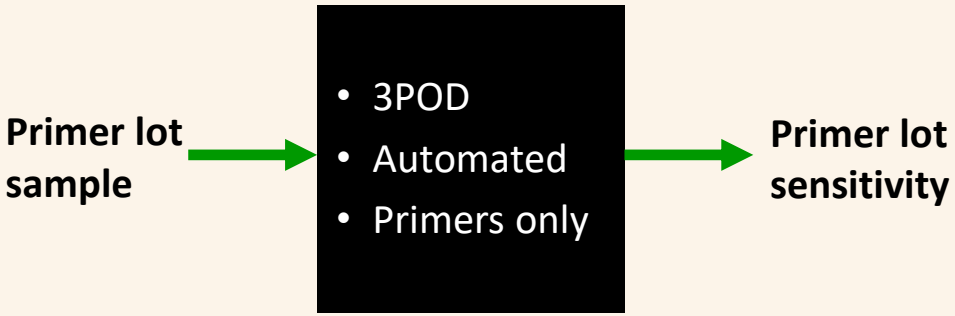
New Method: 3POD

- **30-60** primed cases required per test
- Utilizes **cutting-edge statistical techniques**
  - 3POD (2014) → Regression analysis
- **No limit** to location of drop height within test range

Current Challenges

- New methods would **require modernized equipment**
  - An accurate drop height measurement system
    - E.g. linear position transducer, etc.
  - Computer access during testing
- Uncertainty in **alpha** and **beta** risks
  - **Growth in confidence intervals** resulting from fewer drops
  - Is a binary regression model a **better fit**?

"The Black Box Solution"



Further Reading and References

Further Reading:

- 3POD tool “Gonogo”
  - https://www2.isye.gatech.edu/~jeffwu
- “Adaptive Testing of DoD Systems with Binary Response”
  - https://www.tandfonline.com/doi/pdf/10.1080/09332480.2018.1467632?needAccess=true
- 3POD paper: “Three-phase sequential design for sensitivity experiments”
  - https://www2.isye.gatech.edu/~jeffwu/~3pod/optimal_design.pdf
- D-optimal design criteria
  - https://www.itl.nist.gov/div898/handbook/pri/section5/pri521.htm
- “Test Strategies for Experiments with a Binary Response and Single Stress Factor Best Practice”
  - https://www.afit.edu/stat/statcoe_files/Test_strategy_experiments_Binary_response_single_stress_factor_final_.pdf

References:

- [1] “Tutorial on Sensitivity Testing in Live Fire Test and Evaluation”, (Johnson et al.)
  - https://www.ida.org/idamedia/Corporate/Files/Publications/IDA_Documents/OED/2016/D-5829.ashx
- [2] “Three-phase sequential design for sensitivity experiments”, (Wu, Tian)
  - https://www2.isye.gatech.edu/~jeffwu/~3pod/optimal_design.pdf
- [3] “Experimental investigation of the role of frictional yarn pull-out and windowing on the probabilistic impact response of kevlar fabrics”, (Nilakantan et al.)
  - https://doi.org/10.1016/j.compositesb.2014.08.033