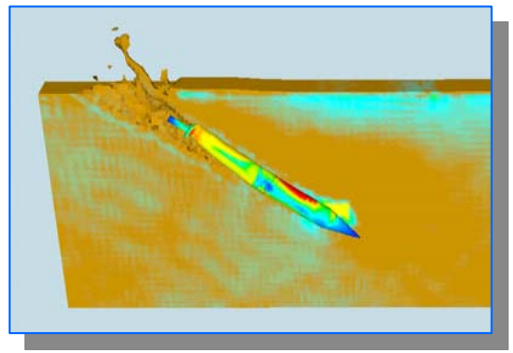
Optimal Design of Complex Systems Using the Entero Code System



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Topics in Presentation

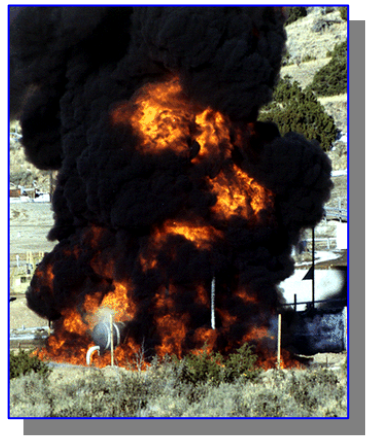
- Introduction
- Goal of the Entero Project
- Status of Project
- The Entero Earth Penetrator Toolkit (EPT)
- Optimization and Uncertainty in Entero using Dakota
- The Sampll Computer Code
- Some Example Problems
- Summary

Introduction

- The design of complex systems may involve optimization of critical system parameters or performance with constraints imposed by design requirements or the environment.
- Also, there may be uncertainties in the design due to tolerances in system features or knowledge of the environment.
- Engineers often lack an integrated framework to perform the analyses needed for designing such systems.

Goal of the Entero Project

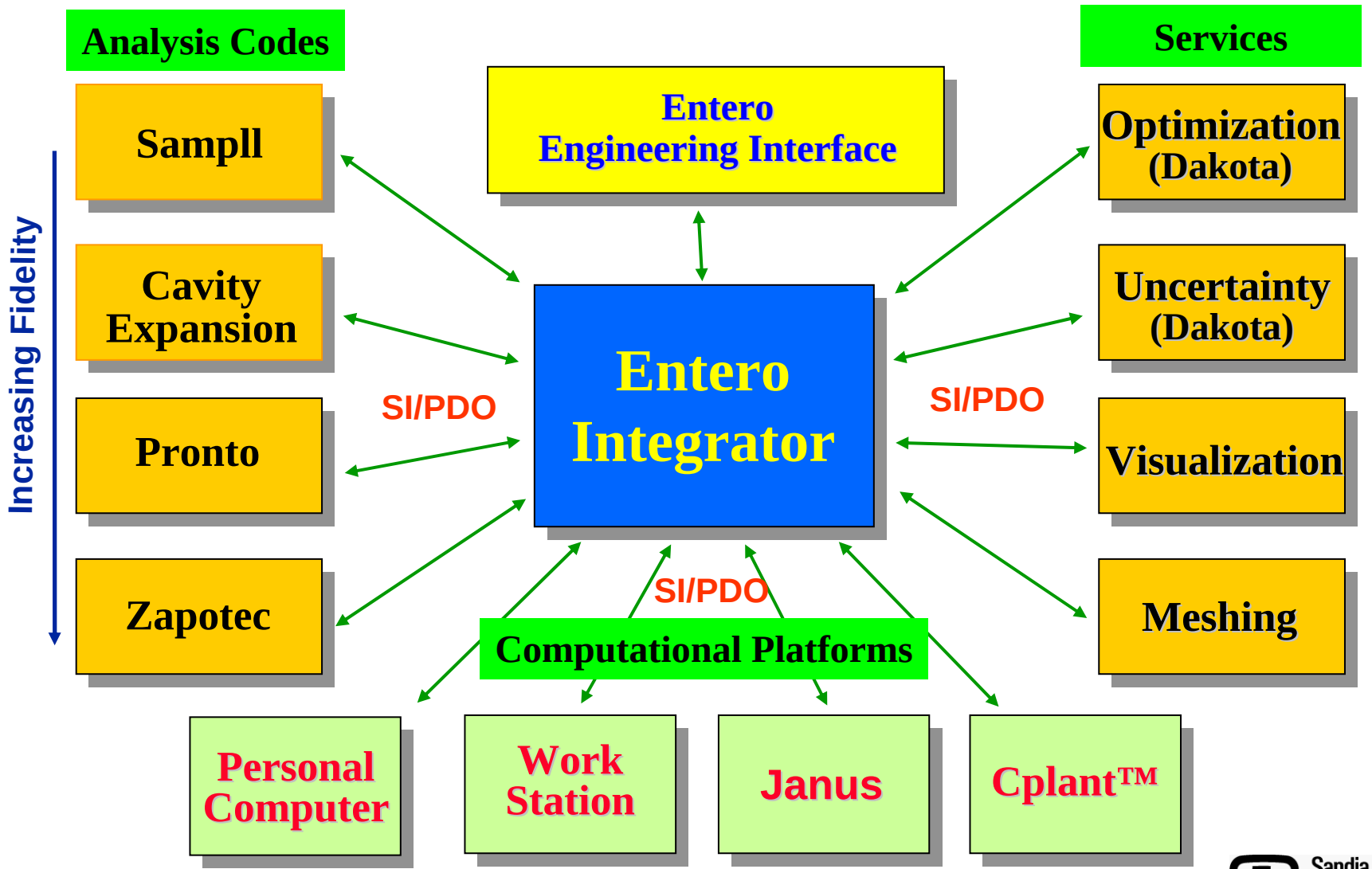
To develop a flexible environment for the design and analysis of complex systems in diverse environments from a system-oriented, module-oriented point of view using models with varying degrees of fidelity and accessed by means of a web-like user interface.



Status of Project

- **Architecture designed and being implemented**
  - Discussed elsewhere
- **Thermal analysis prototype tool for safety analysis developed**
  - Multifidelity capability
    - detailed 3D and lumped parameter in same simulation
- **Earth penetrator toolkit prototype developed**
  - Includes optimization and uncertainty analysis
  - Focus of presentation as illustration of methods

The Entero
Earth Penetrator Toolkit (EPT)



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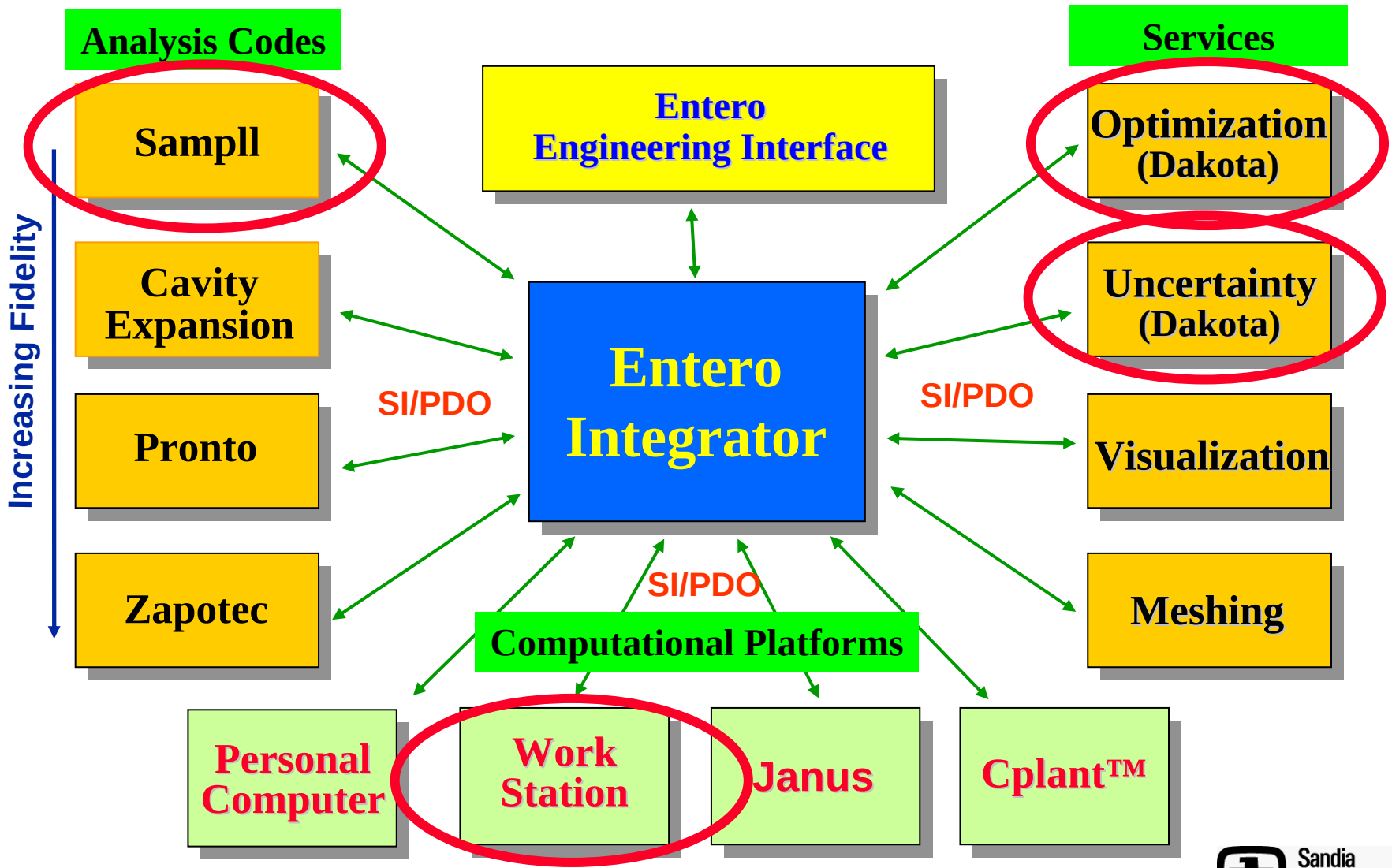
Focus of Presentation



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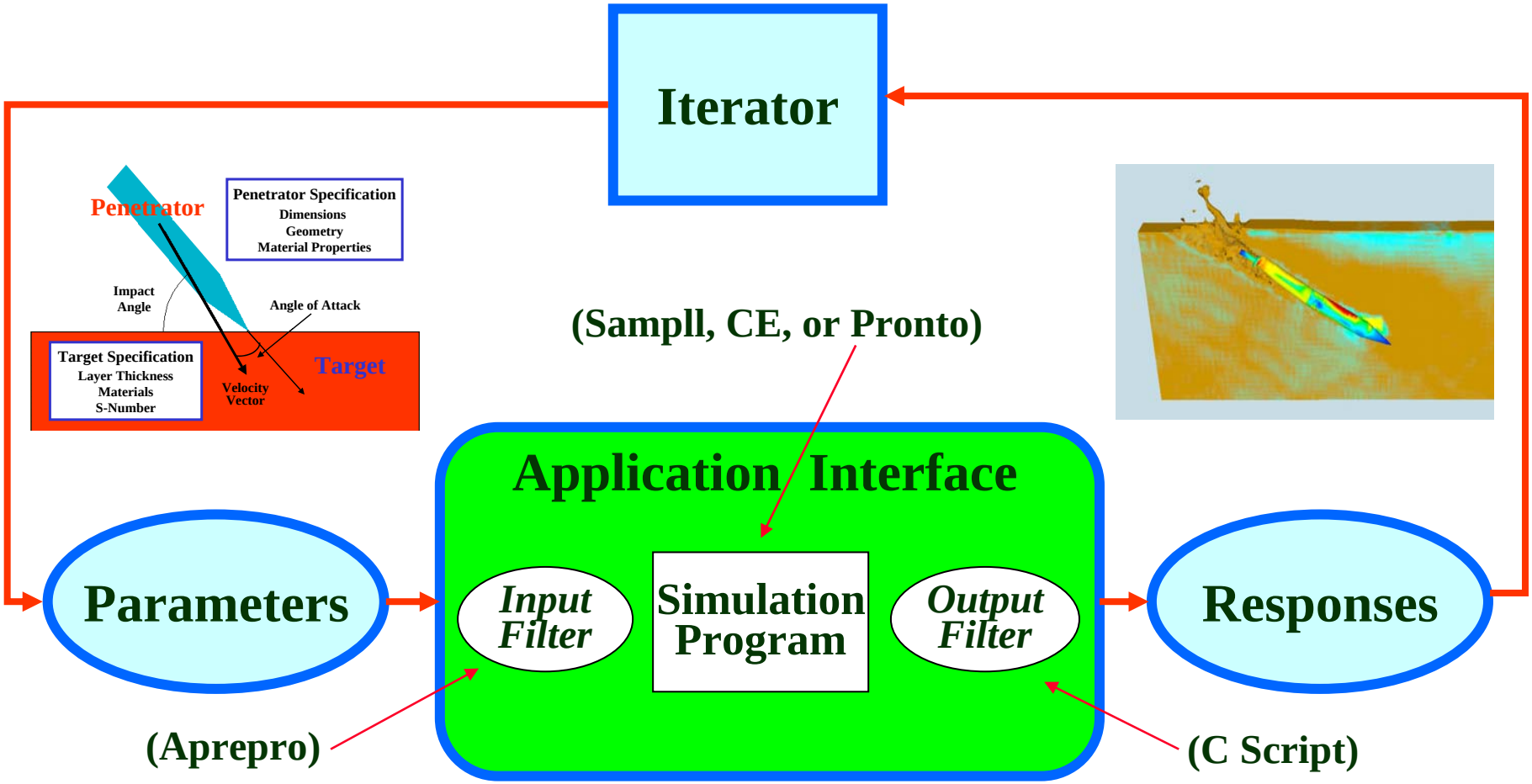
Optimization and Uncertainty in the Entero EPT Using Dakota



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The Sampll Computer Code

- **The simplest analysis code used in the EPT is the *Sampll* (Simplified Analytical Model of Penetration with Lateral Loading) computer code**
- **Empirically based and widely used**
  - Modified failure criterion and opened output file appropriate to optimization analyses.
- **Simple description of penetrator and target**

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
Length		Material	soil
Segment 1	2.5 ft	S-number	5
Segment 2	3.7 ft		
Density	733 lb/ft^3	**Impact Conditions**	
Wall Thickness	0.5 in	Impact Speed	1400 ft/s
Wall Weight	400 lb.	Impact Angle	73°
Type of Nose	ogive	Attack Angle	0

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Some Example Problems

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
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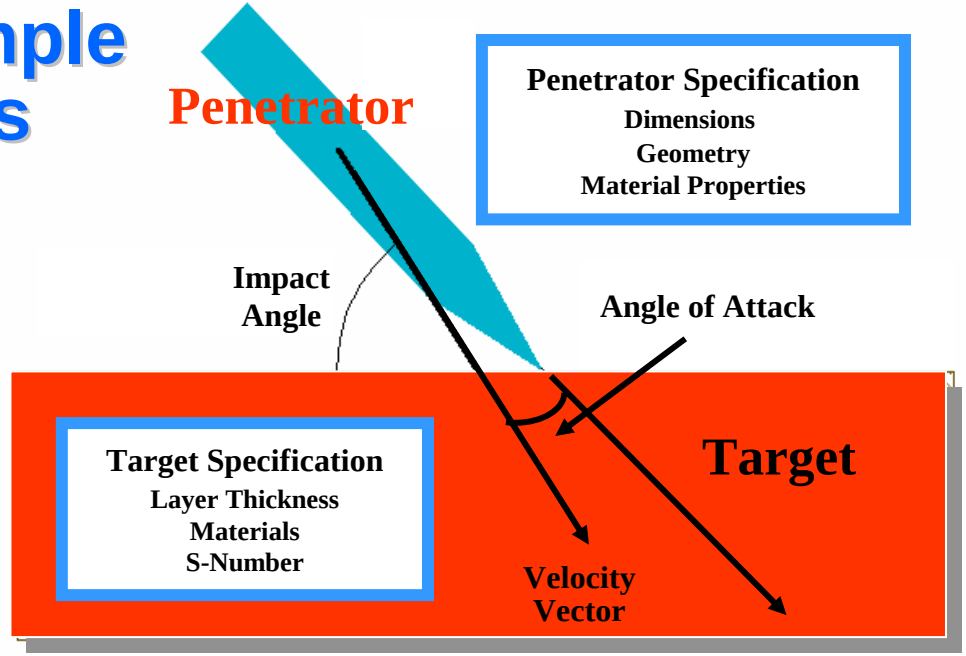

Problem 1: Determine the impact angle at which the penetration depth is a maximum.

Problem 2: Suppose that constraints on the payload of the penetrator restrict the wall thickness to be less than 0.72 in. Determine the maximum penetration depth.

Problem 3: Determine variability in penetration depth given the following. All variables are normally distributed. The means are the penetrator's wall thickness from *Problem 2*, its default strength properties, and the failure criterion, impact speed, impact and attack angles, and the target's S-number that are listed in table. The standard deviations are 10% except for attack angle, which has a standard deviation of 2°.

Problem 4: Suppose that the penetrator must reach a depth of at least 10 ft to accomplish its mission. Determine the minimum wall thickness needed to accomplish its mission.

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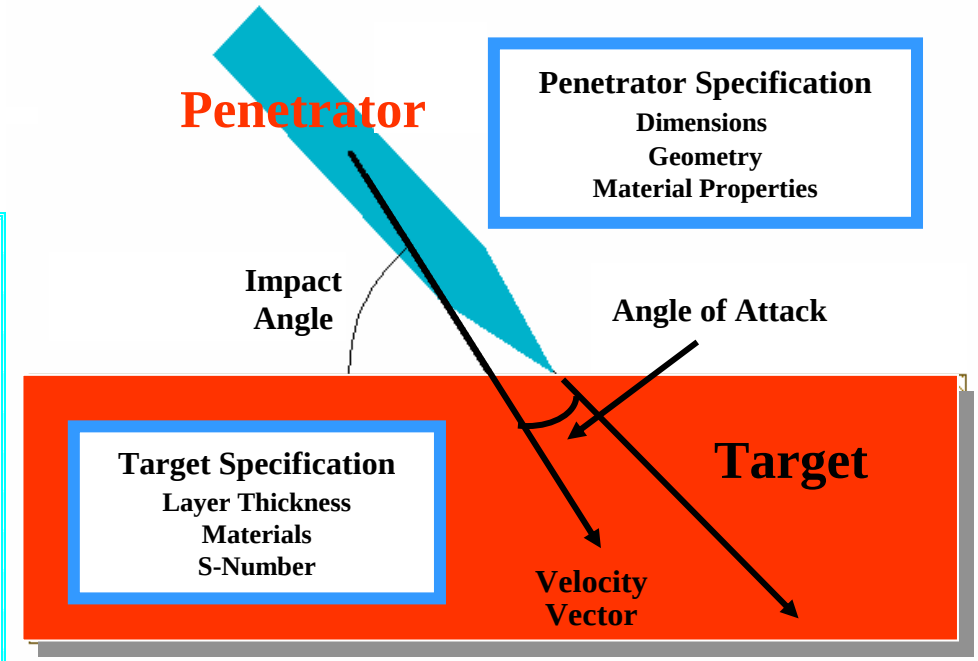
Problem 1

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
Length		Material	soil
Segment 1	2.5 ft	S-number	5
Segment 2	3.7 ft		
Density	733 lb/ft^3	**Impact Conditions**	
Wall Thickness	0.5 in	Impact Speed	1400 ft/s
Wall Weight	400 lb.	Impact Angle	TBD
Type of Nose	ogive	Attack Angle	0



- **Determine the impact angle at which the penetration depth is a maximum.**
  - This simple problem is valuable since the answer is known and obtaining the correct answer provides some confidence in the method.
  - Input was appropriate to determine a solution between 0° and 100° using a genetic optimization algorithm.
  - Solution obtained is 90°.
    - Penetrator does not fail when impacting the target at this angle and reaches a depth of 32.2 ft.

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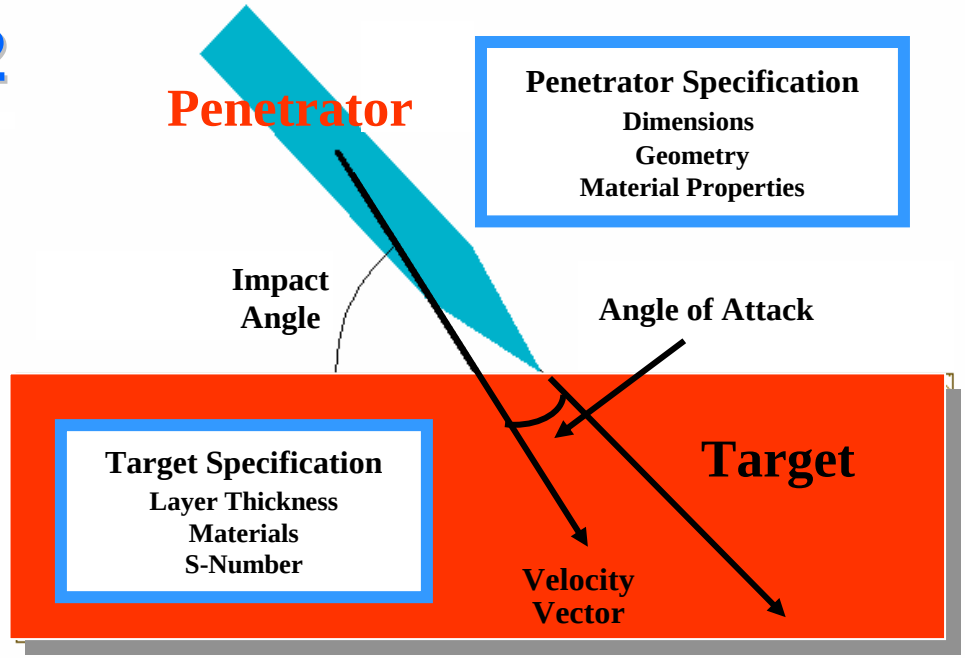
Problem 2

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
Length		Material	soil
Segment 1	2.5 ft	S-number	5
Segment 2	3.7 ft		
Density	733 lb/ft^3	**Impact Conditions**	
Wall Thickness	TBD	Impact Speed	1400 ft/s
Wall Weight	400 lb.	Impact Angle	73°
Type of Nose	ogive	Attack Angle	0



- **Suppose that constraints on the payload of the penetrator restrict the wall thickness to be less than 0.72 in. Determine the maximum penetration depth.**
  - Input was appropriate to determine a solution for wall thickness between 0.48 in and 0.72 in. using a genetic optimization algorithm.
  - Solution obtained is 36.6 ft.
    - This solution is obtained for a wall thickness of 0.71 in.

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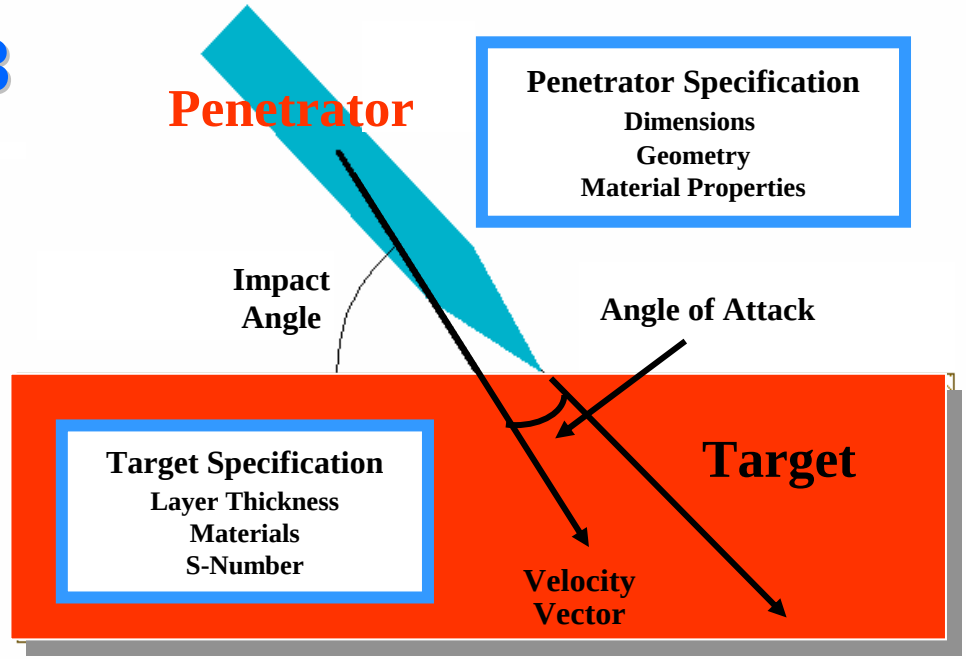
Problem 3

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
Length		Material	soil
Segment 1	2.5 ft	S-number	5
Segment 2	3.7 ft		
Density	733 lb/ft^3	**Impact Conditions**	
Wall Thickness	0.72 in	Impact Speed	1400 ft/s
Wall Weight	400 lb.	Impact Angle	73°
Type of Nose	ogive	Attack Angle	0



- **Determine variability in penetration depth given the following. Variables are normally distributed. Means are the penetrator's wall thickness from *Problem 2*, default strength properties, and failure criterion, impact speed, impact and attack angles, and the target's S-number that are listed in table. Standard deviations are 10% except for attack angle, whose standard deviation is 2°.**
  - Input was appropriate to perform an uncertainty calculation using Latin hypercube sampling.
  - Mean value for penetration depth is 19.4 ft and the standard deviation is 1.6 ft.
    - For the 100 sample cases, there are 52 failures, indicating that the stated variations are unacceptably large for a penetrator design or that the design is not robust.

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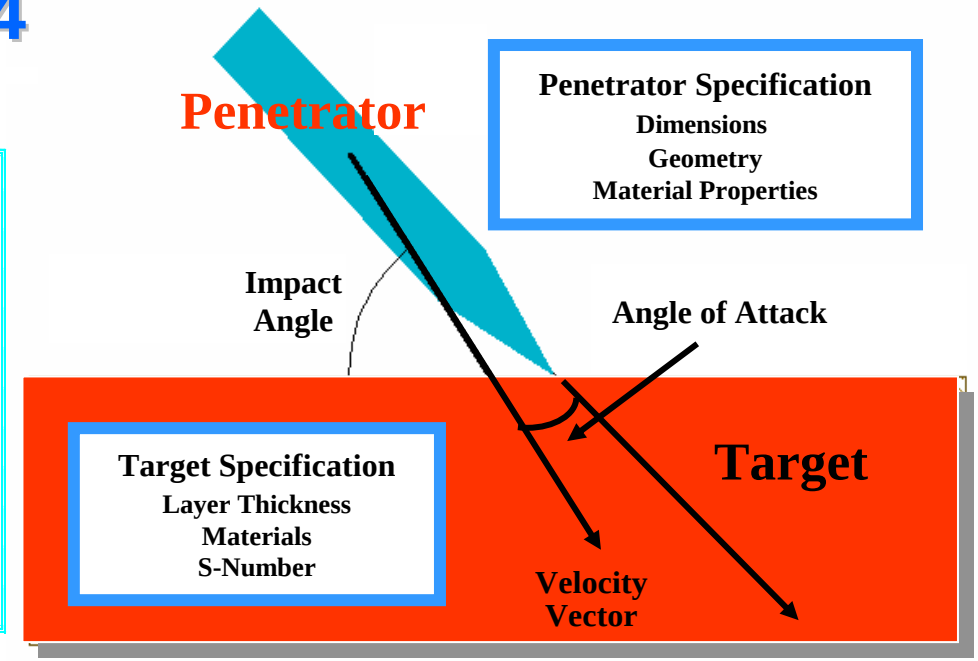
Problem 4

Penetrator Data			
Total Weight	591 lb.	Failure Criterion	1000 g
Length	6.2 ft		
Number Segment	2	**Target Data**	
Diameter	13.3 in	Target Layers	1
Length		Material	soil
Segment 1	2.5 ft	S-number	5
Segment 2	3.7 ft		
Density	733 lb/ft^3	**Impact Conditions**	
Wall Thickness	TBD	Impact Speed	1400 ft/s
Wall Weight	400 lb.	Impact Angle	73°
Type of Nose	ogive	Attack Angle	0



- **Suppose that the penetrator must reach a depth of at least 10 ft to accomplish its mission. Determine the minimum wall thickness needed to accomplish its mission.**
  - Input was appropriate to determine a minimum wall thickness subject to the constraint that the penetrator reaches a depth of at least 10 ft using a Newton optimization algorithm.
  - Solution is 0.539 in.
    - Penetration depth is 32.2 ft.
    - Solution is extremely sensitive to wall thickness.

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Summary

- **Completed a top-level design of the Entero EPT**
  - Summarizes vision of the mature toolkit
- **Developed a Web-based prototype for critique by targeted users**
- **Developed methodology for integration of penetrator analysis codes with Dakota**
- **Modified Sampll code for integration in the EPT**
  - Includes damage criterion used by designers
- **Illustrated methodology with example problems**
- **Work is summarized in paper for this conference, *Optimal Design of Complex Systems Using the Entero Code System***

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