CIBX Ground Impact Assessment

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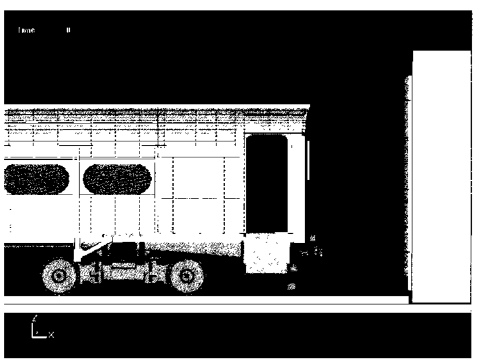
Introduction

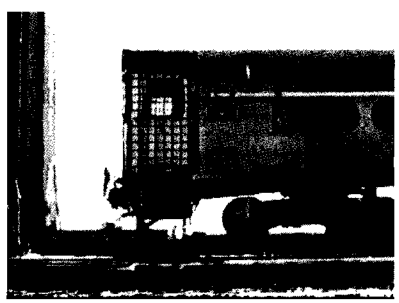
- Objective
  - Estimate the acceleration experience by CIBX payload at ground impact
- Outline
  - LS-DYNA Overview
  - CIBX Model
  - Soil Model
  - LS-DYNA Model
  - Results
  - Model Check
  - Summary

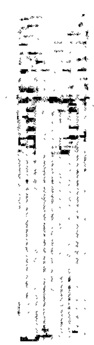
LS-DYNA Overview

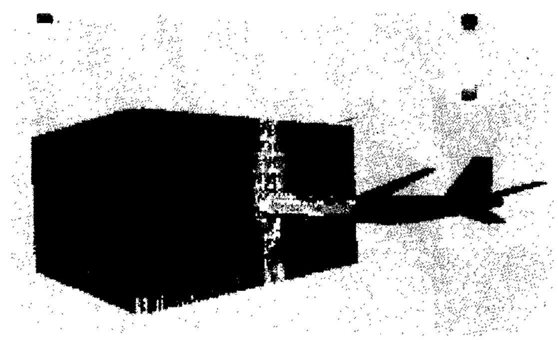
TO VIEW ANIMATION, POWERPOINT MUST BE IN FULL SCREEN "SLIDE SHOW" MODE

- LS-DYNA is a powerful time consistent transient dynamic finite element program
- LS-DYNA utilizes physics, material behavior, and contact interaction to simulate actual or potential real world events analytically
- Some LS-DYNA in industry examples:
  - Human Survivability & Structual Tolerance
  - Automotive Crash Modeling
  - Explosion/Industrial Accidents
  - Armor Capability
  - Kinetic Weapons
  - Hypervelocity Impacts
  - Product Testing
  - Forensic Engineering
  - CFD: Fluid-Structure Interaction, Sloshing
  - September 11
    - WTC/Pentagon Crash Simulations
    - Building Collapse & collateral Damage



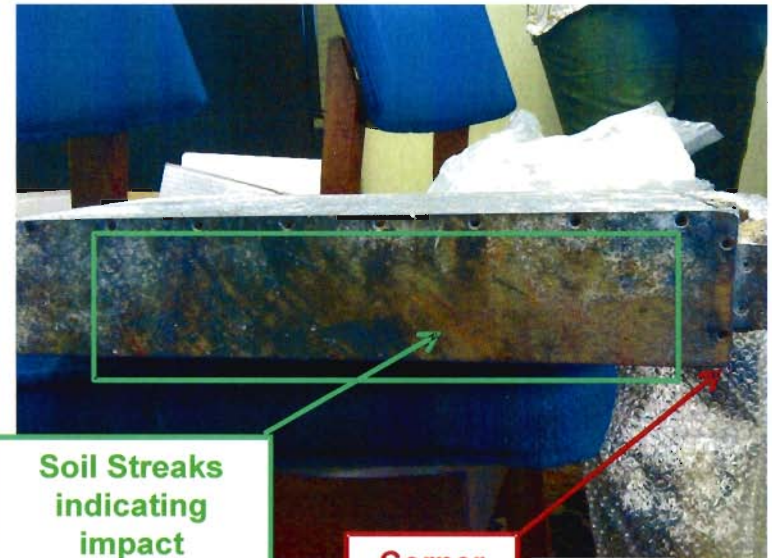


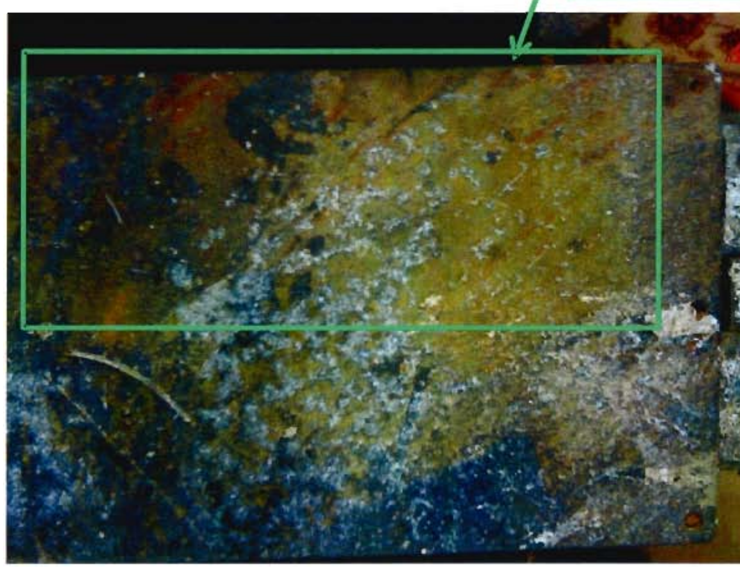


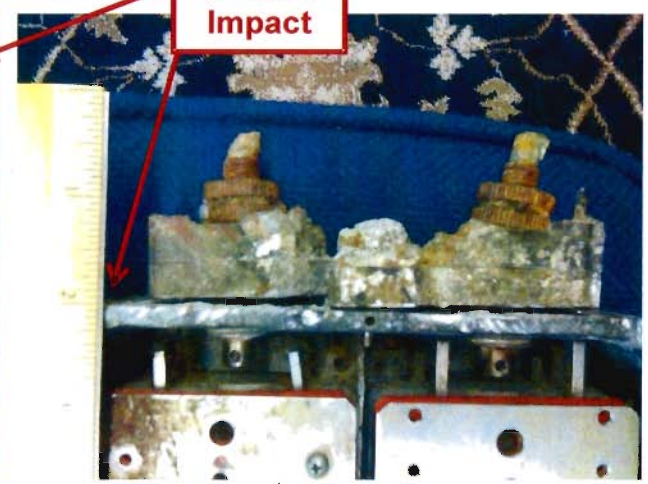


CIBX Model

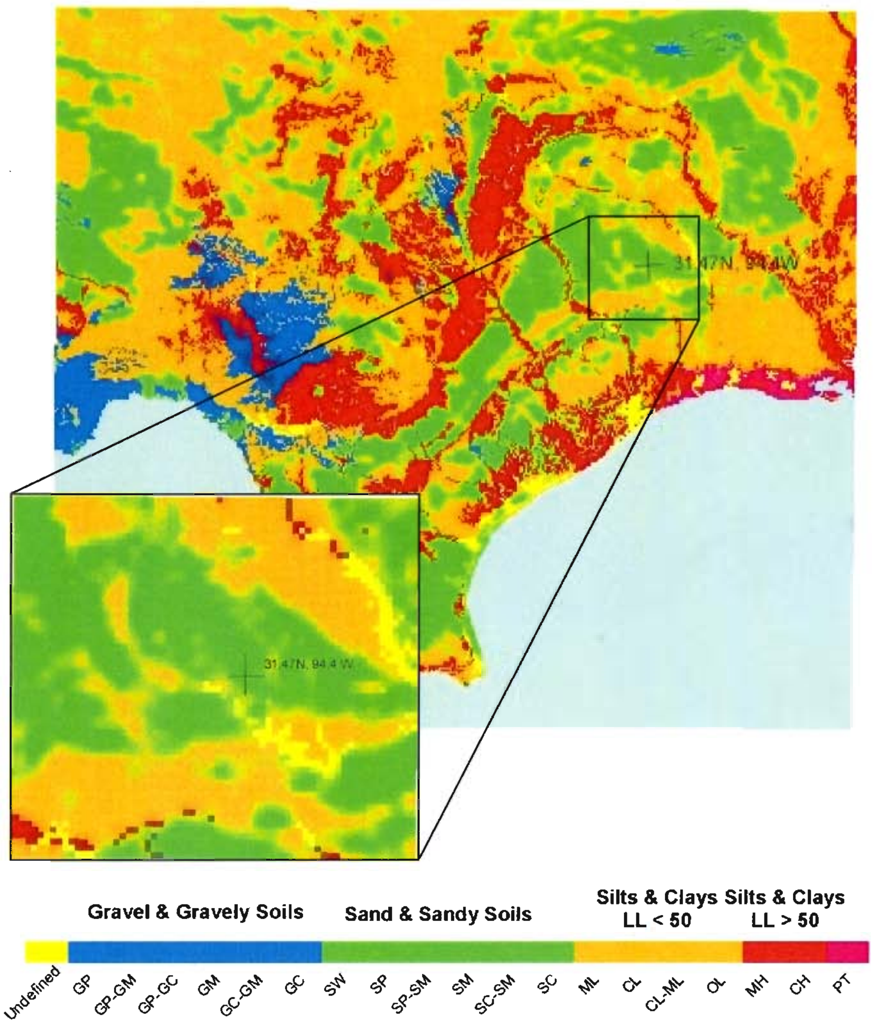
- Orientation
  - Soil streaks (approximately 45 deg) on two sides indicate orientation
- Rigid body acceleration
  - Box was modeled rigidly, as overall box accelerations are desired
- Velocities
  - Orientation indicates the box was not trimmed at impact
    - Tumbling velocity (per NASA/EG aero analysis) used as best estimate
    - Maximum aero (min impact velocity) also assessed for a lower bound
- Mass of 4.2 kg at impact







Soil Model



- In support of the Orion land landing effort, NASA/LARC was tasked to characterize and model many soil types with varying "hardness" and moisture content
  - Applied Research Associates was contracted with developing a soil map that spanned the United States
  - LARC performed extensive soil testing including a penetrometer drop test to determine impact attenuation properties
  - LARC used this test data to develop 8 soil models corresponding to these soil types
- Soil type at impact location (Soil Model A)
  - "Open Box" retrieved at 31.47N, 94.4 W
  - Area is "sandy soil"; It is similar in soil type to the area around the KSC launch pad pictured below
- Bounding the soil uncertainty (Soil Model B)
  - There is some variation within soil types due to the local soil contents and moisture
  - A minimum acceleration case was created utilizing a "softer" soil type of higher moisture content and less sand that is expected to provide a confident lower bound of the accelerations

LS-DYNA Model

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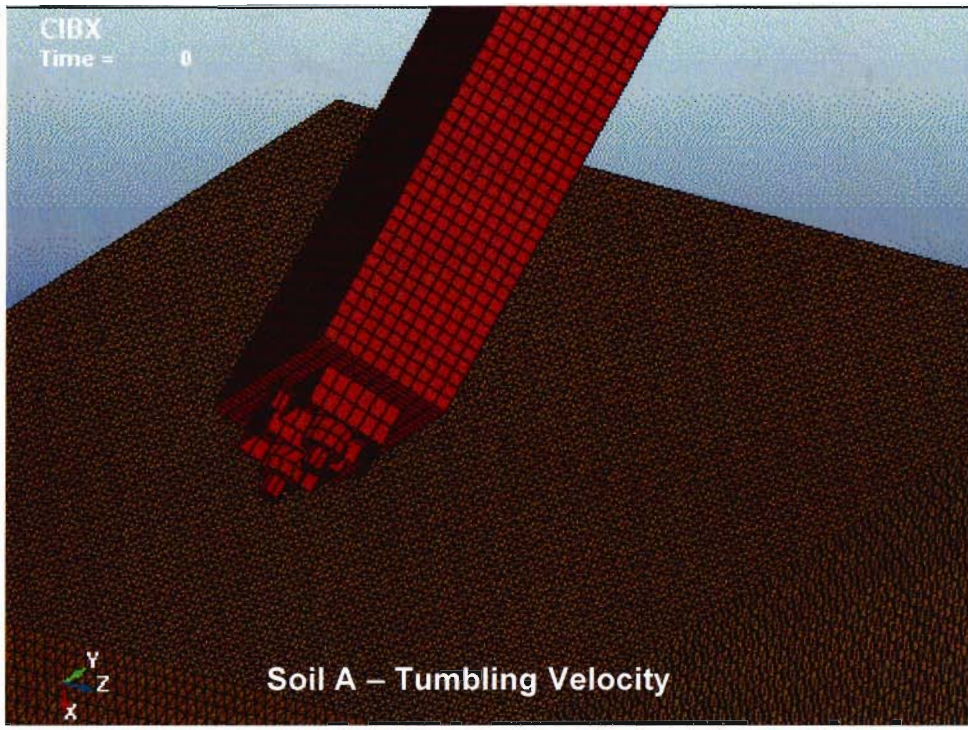
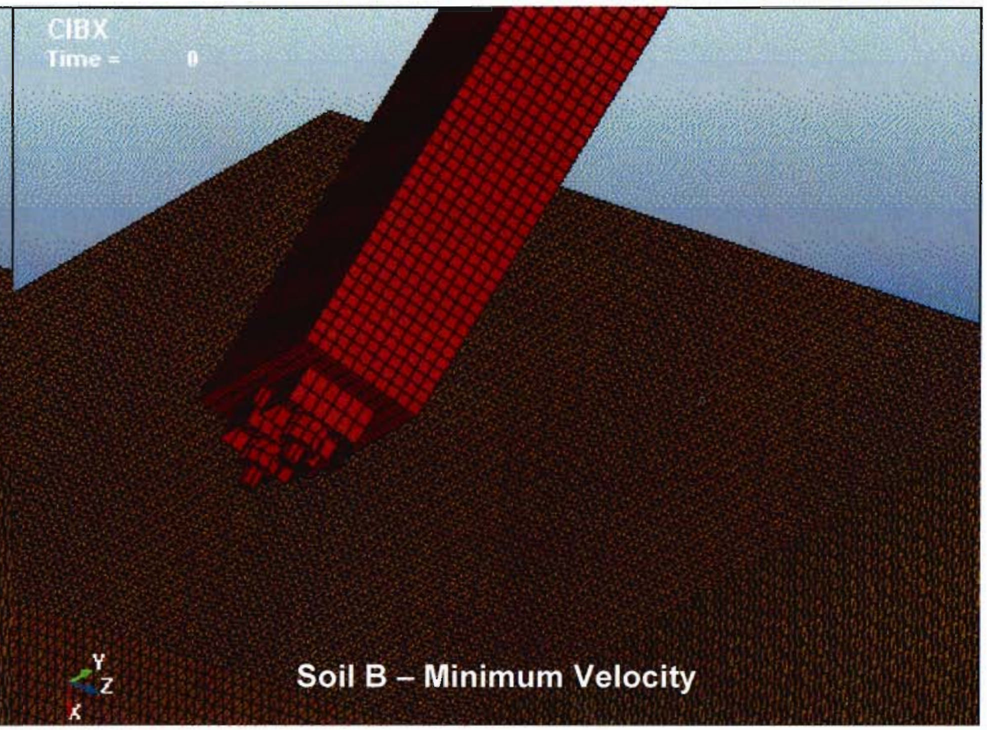
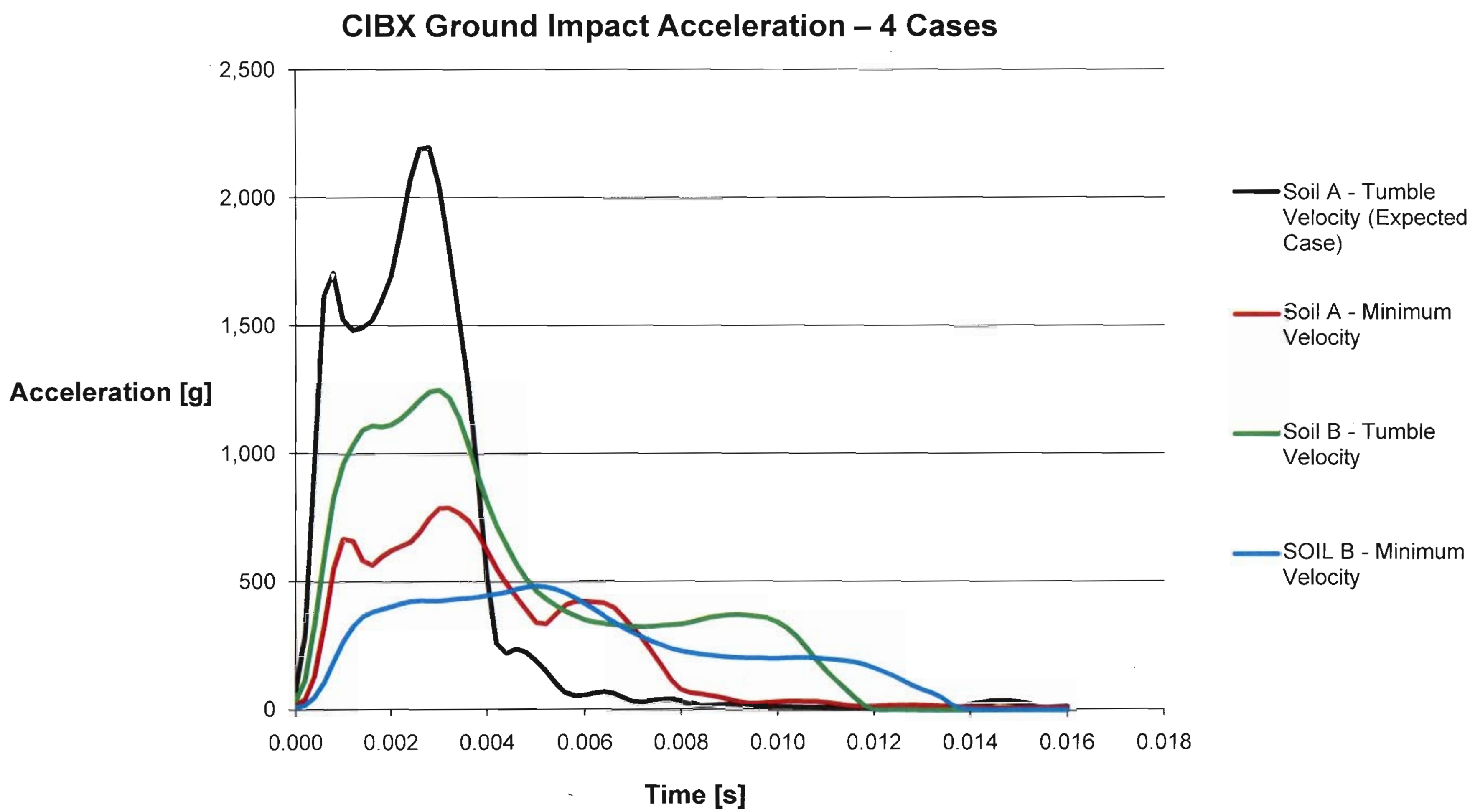
- Model checks:
  - Soil mesh density study was performed to check the results were not sensitive to soil mesh size
  - Soil container study was performed to check the results were not sensitive to amount of soil in the model
- 4 CASES:
  - Soil A – Tumbling Velocity (Expected Case)
  - Soil B – Minimum Velocity (Lower Bound Acceleration Case)
  - Soil B – Tumbling Velocity
  - Soil A - Minimum Velocity
- The 2 cases on the right are useful to show sensitivity of results to Soil Type and Velocity





Results


CIBX Ground Impact Acceleration – 4 Cases
Acceleration [g]
2,500
2,000
1,500
1,000
500
0
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
Time [s]
Soil A - Tumble Velocity (Expected Case)
Soil A - Minimum Velocity
Soil B - Tumble Velocity
SOIL B - Minimum Velocity

Model Check

- We can use physics equations to determine the estimate accelerations as a simple model check
- Note: This method assumes a constant acceleration, which is not applicable, so findings are only ballpark estimates
- Equation relating Velocity change to acceleration and position traveled:

$$v_f^2 - v_0^2 = 2ad \quad (v_f \to 0)$$

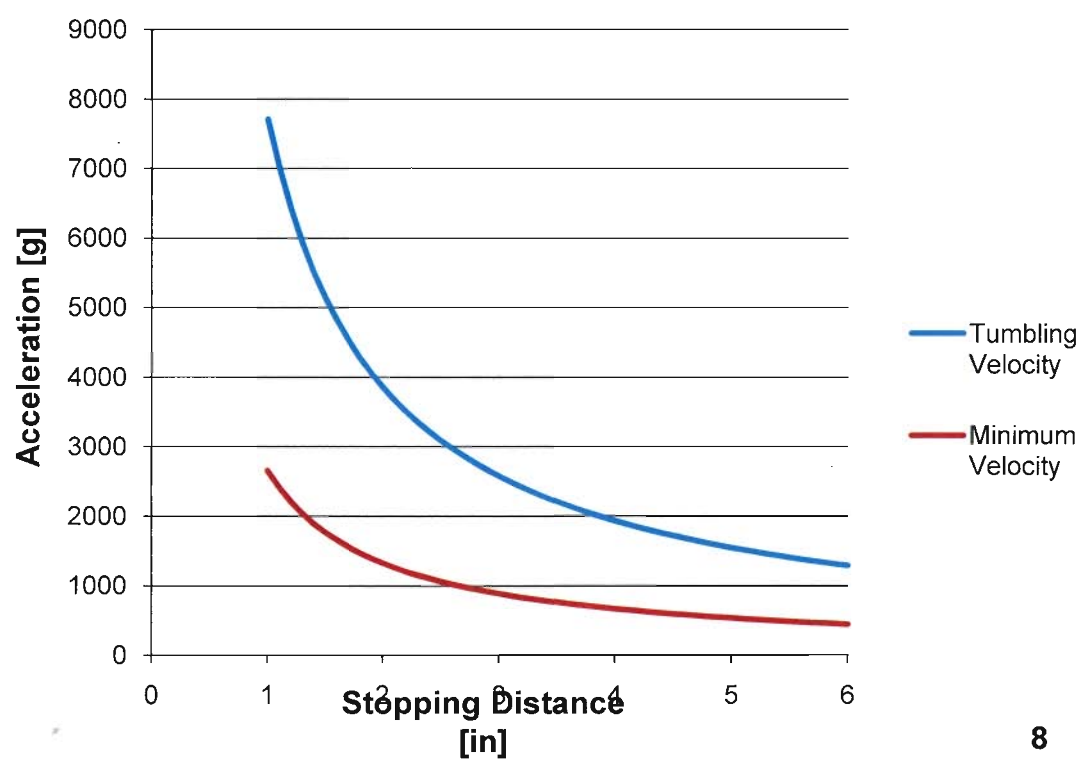
$$a = \frac{v_0^2}{2d}$$

$$v_{0_{tumbling}} = 2442 \quad \textbf{in/s}$$

$$v_{0_{minimum}} = 1433 \quad \textbf{in/s}$$

d	Displacement or change in position
v_o	Original velocity, the velocity at the start of the acceleration
v_f	Final velocity, the velocity at the end of the acceleration.
a	Acceleration, this is a constant acceleration

- With the given velocities, we can see the distances required to stop an object under constant acceleration



Summary

- "Open Box" most likely impacted at 45 deg inclination at corner based on soil streaks seen on box
- Model Checks
  - Hand calculations show results in expected range for velocities/displacement
  - Sensitivity studies were performed to check appropriateness of soil mesh density and soil dimensions
- Best estimate for peak impact acceleration: 2190 g's
  - Based on tumbling aero velocity and best approximate soil model
- Lower bound peak acceleration 484 g's
  - Based on minimum velocity and least conservative soil type