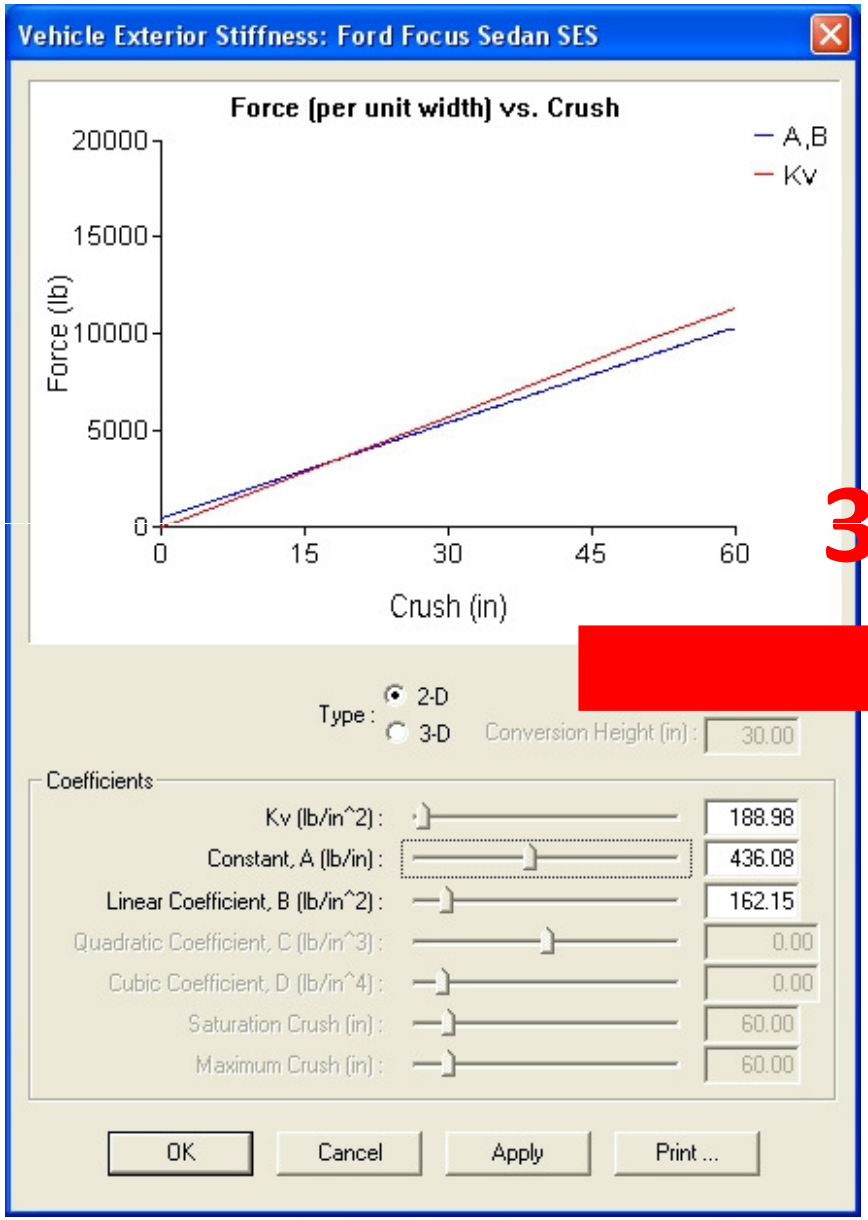
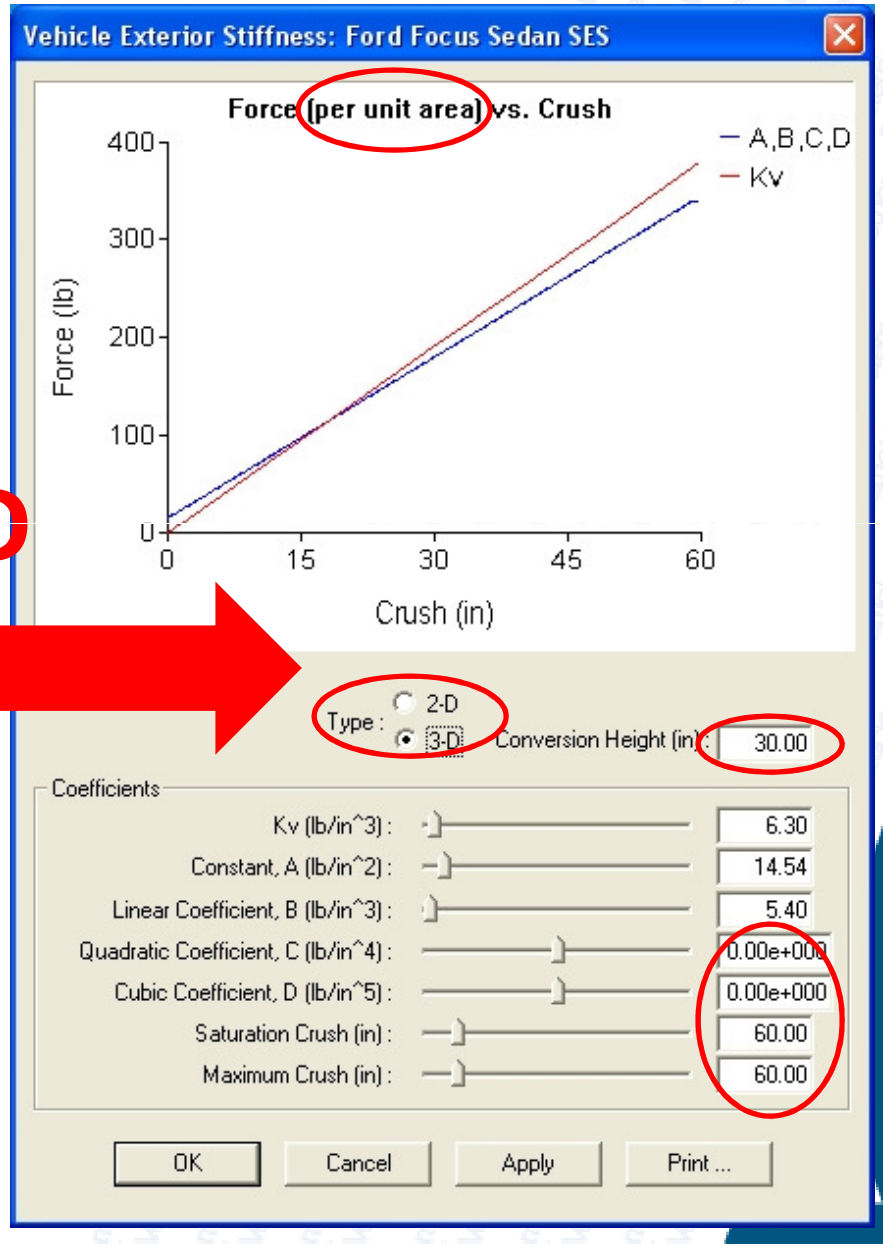
A Method to Determine Non-Linear Crush for Use in HVE

Brian Gilbert, Ron Jadischke and Joe McCarthy
Vehiclemetrics Inc.
McCarthy Engineering Inc.

Current Crush Coefficients



3-D



Calculation of Crush Coefficients

Linear Stiffness Coefficients

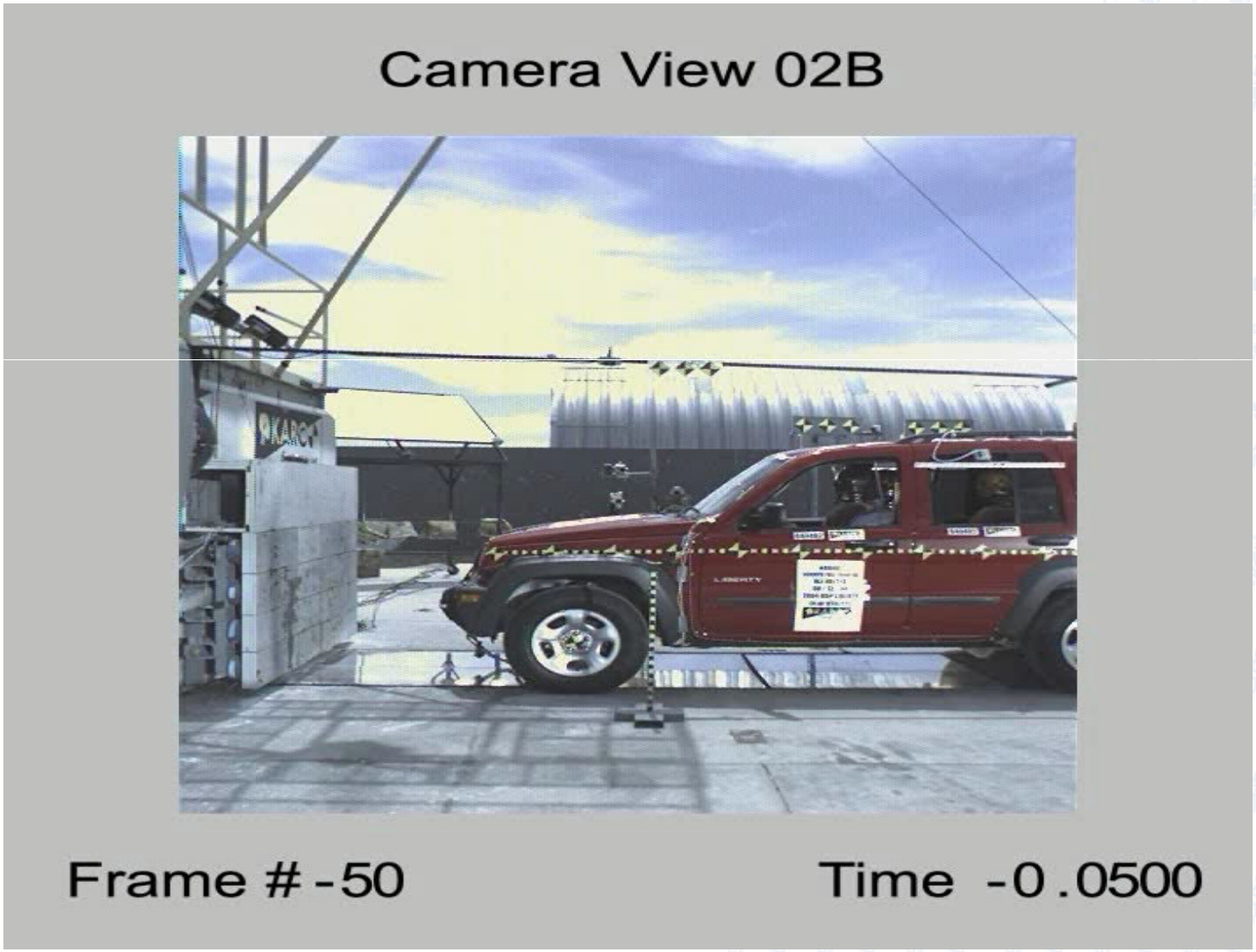
- Inputs:
  - b0 = 5 mph, Restitution = 10%
  - Average Crush, Weight, Damage Length, Impact Speed
- Result:
  - A, B, G, kv
- Example:
  - A = 269.7 lb/in
  - B = 94.1 lb/in^2
  - For the Conversion Height of Default 30 in:
    - A = 8.9911 lb/in^2
    - B = 3.1365 lb/in^3

Non-Linear Stiffness Coefficients

Purpose

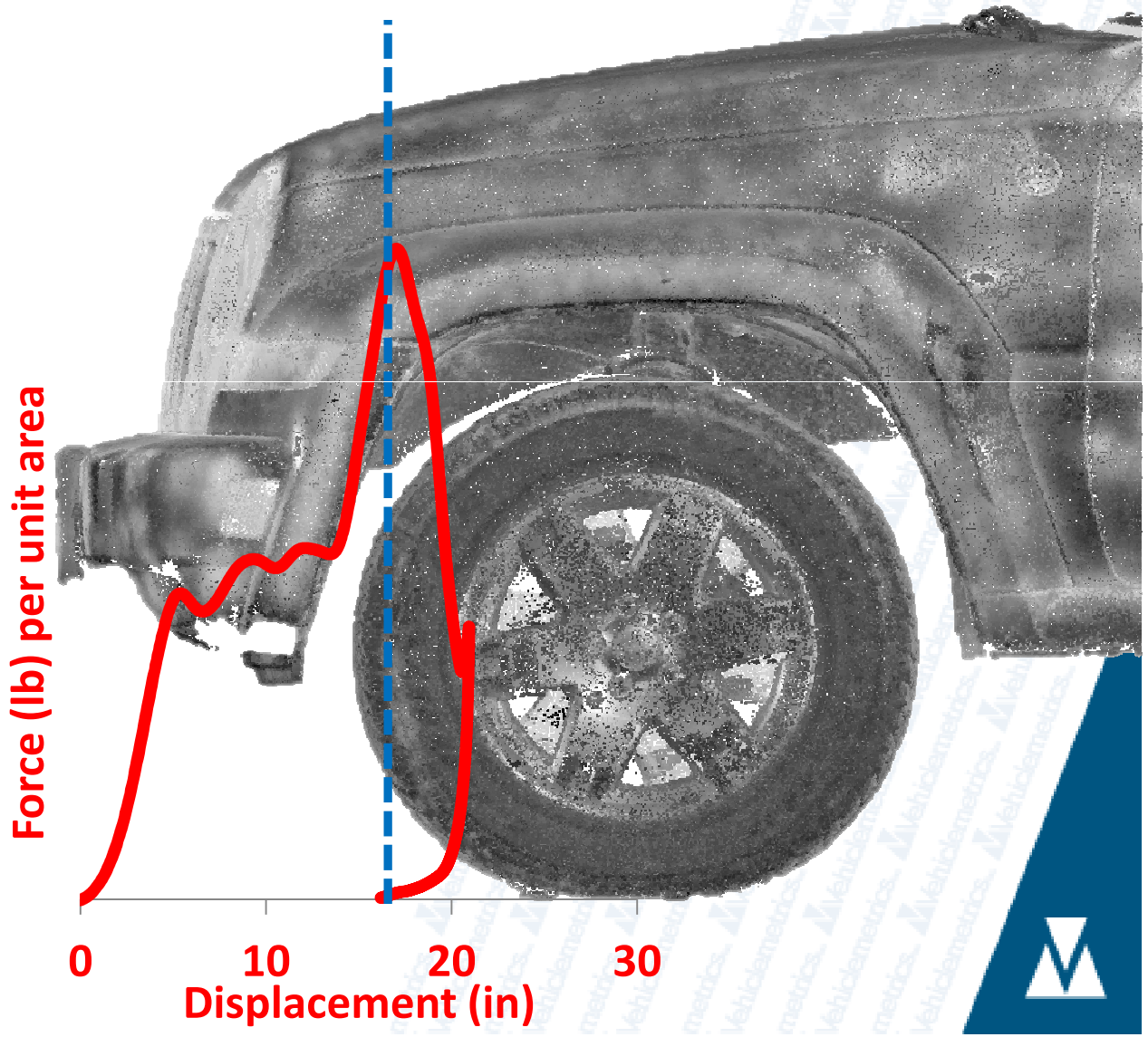
- Develop a method to calculate the A,B,C and D Coefficients
- Discuss a method to calculate vehicle specific conversion heights
  - Two methods studied
    - Use a weighted conversion height based on actual vehicle
    - Potentially eliminate conversion height
- Presented as a case study on a single vehicle
  - 2002-2007 Jeep Liberty

Potential Advantages of Non-linear Crush Coefficients



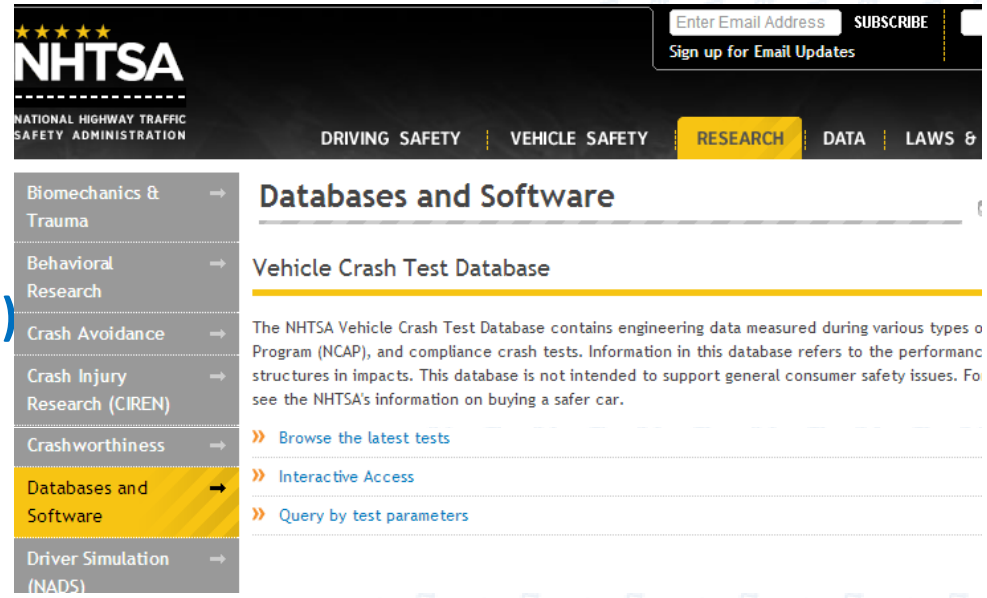
Potential Advantages of Non-linear Crush Coefficients

1. Ability to model vehicle structural changes
2. Improved accuracy over a range of crush depths



Materials: Crash Test Data

- **Materials:**
  - **NHTSA Database**
    - To develop stiffness curve (Force versus displacement)
    - Load Cell Barrier (LCB) crash tests (typically 35 mph)
  - **NHTSA Signal Software**
  - **Vehicle Geometry**
    - To measure conversion height
    - Laser scan data or an accurate model

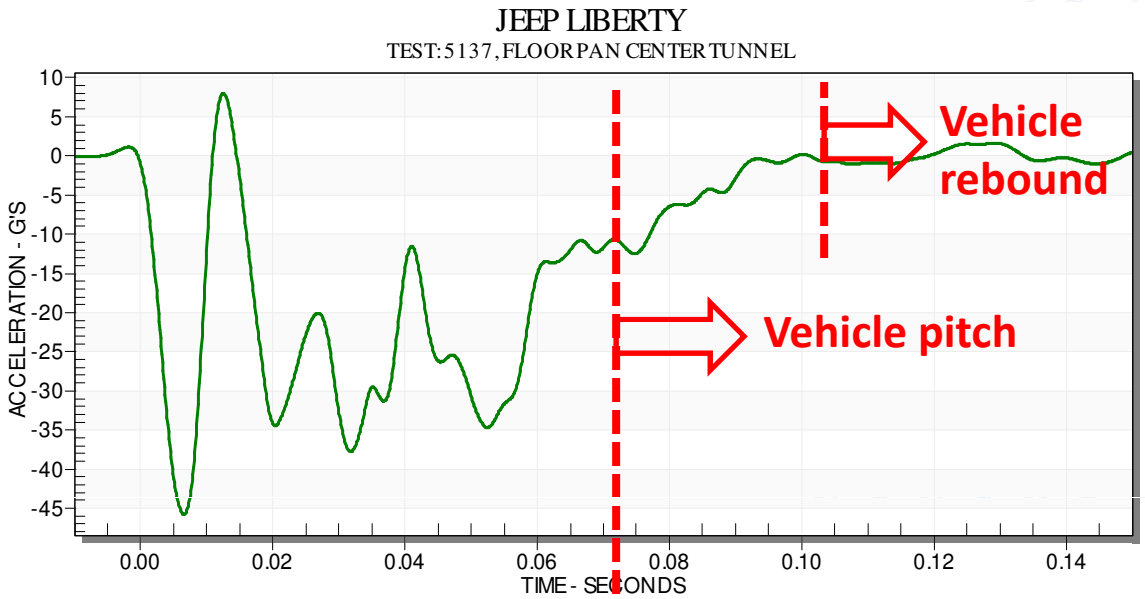


Methods: Stiffness Curve Model

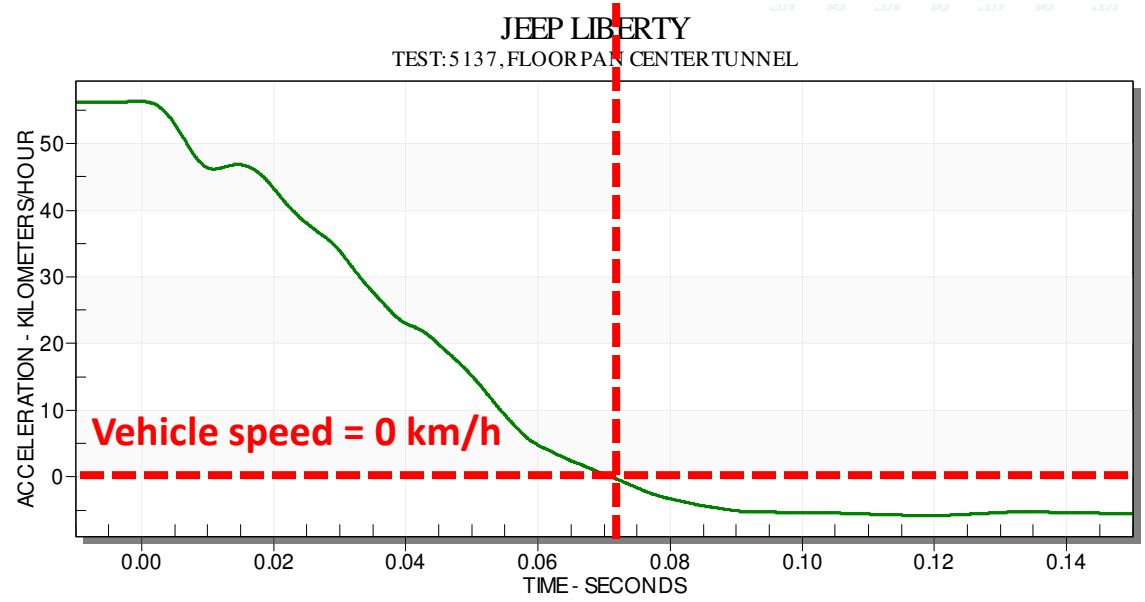
- Methods
  1. Select accelerometer trace
  2. Filter and integrate to calculate velocity
     - Filter data per SAE standards
  3. Integrate to calculate displacement
  4. Sum load cell data from Load Cell Barrier
  5. Combine Data to create Force vs. Displacement Curve
  6. Divide by width and conversion height to generate curve for HVE

Methods: Acceleration and Velocity

Acceleration Curve

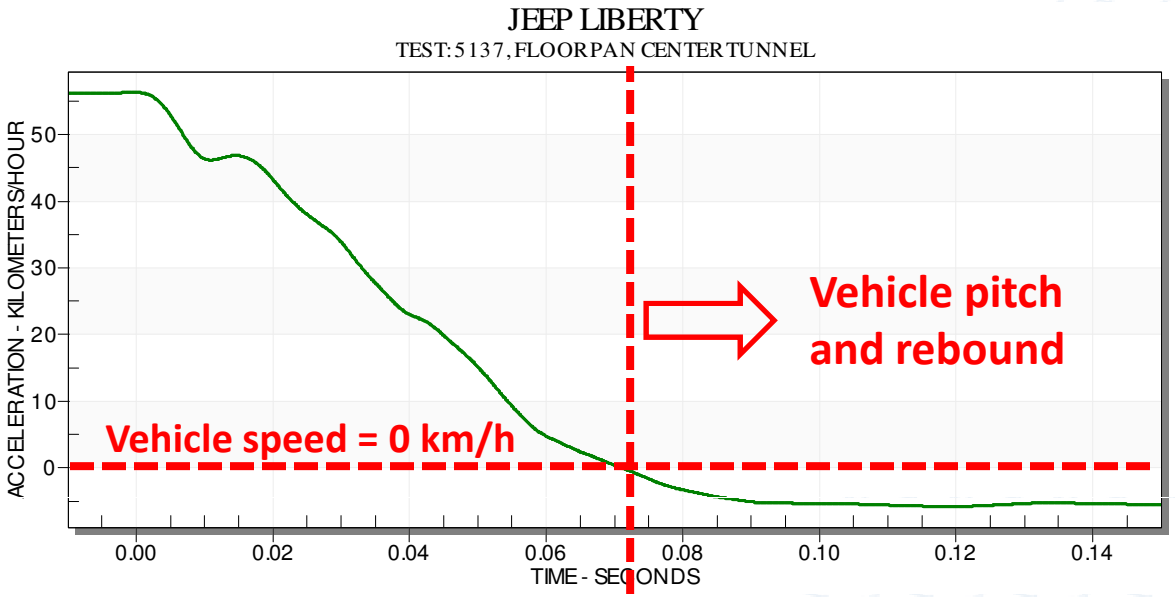


Velocity Curve

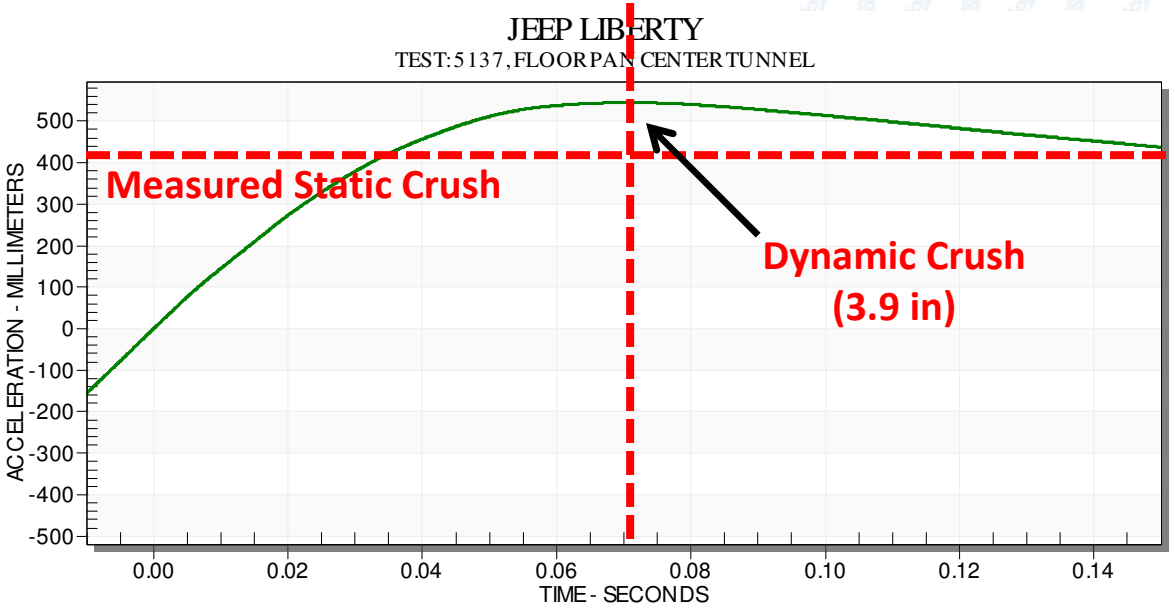


Methods: Velocity and Displacement

Velocity Curve

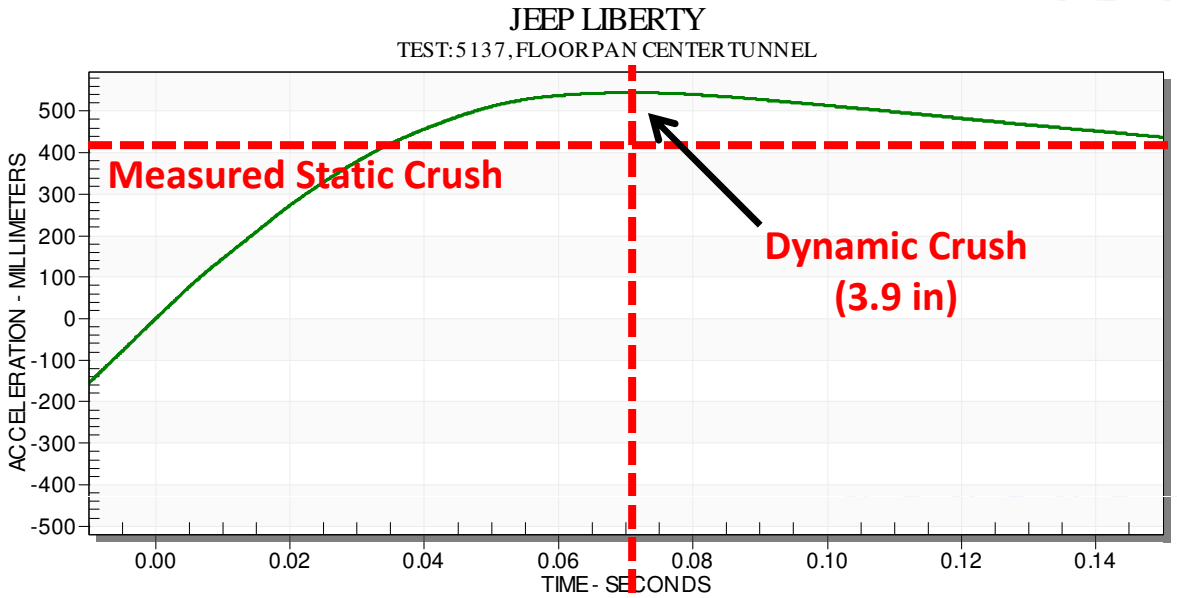


Displacement Curve (integrated from velocity curve)

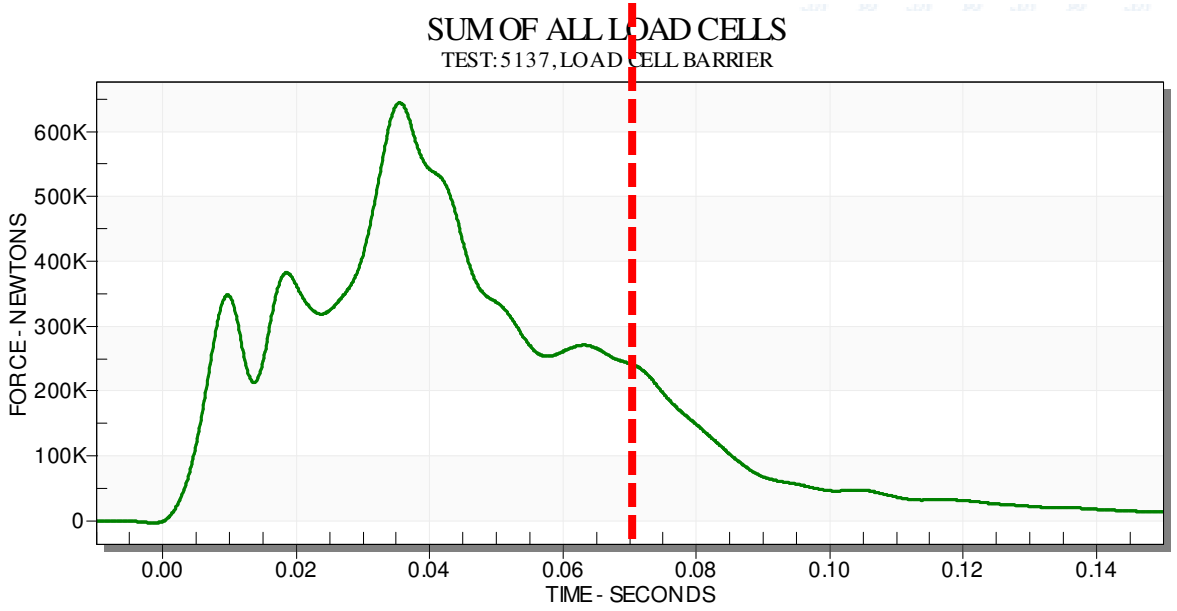


Methods: Displacement and Force

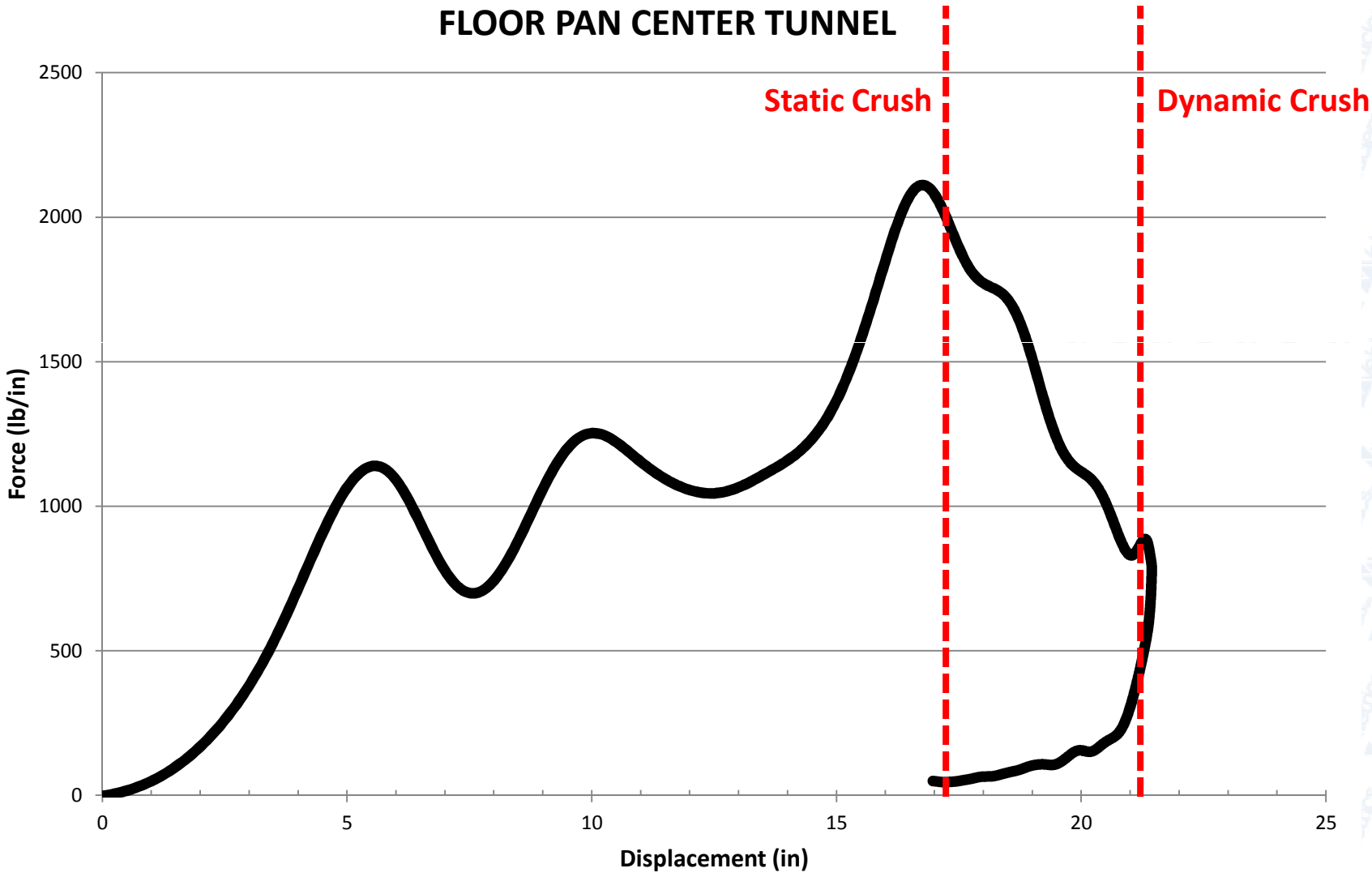
Displacement Curve (integrated from velocity curve)



Total Force Curve (Sum of all Load cells in barrier)

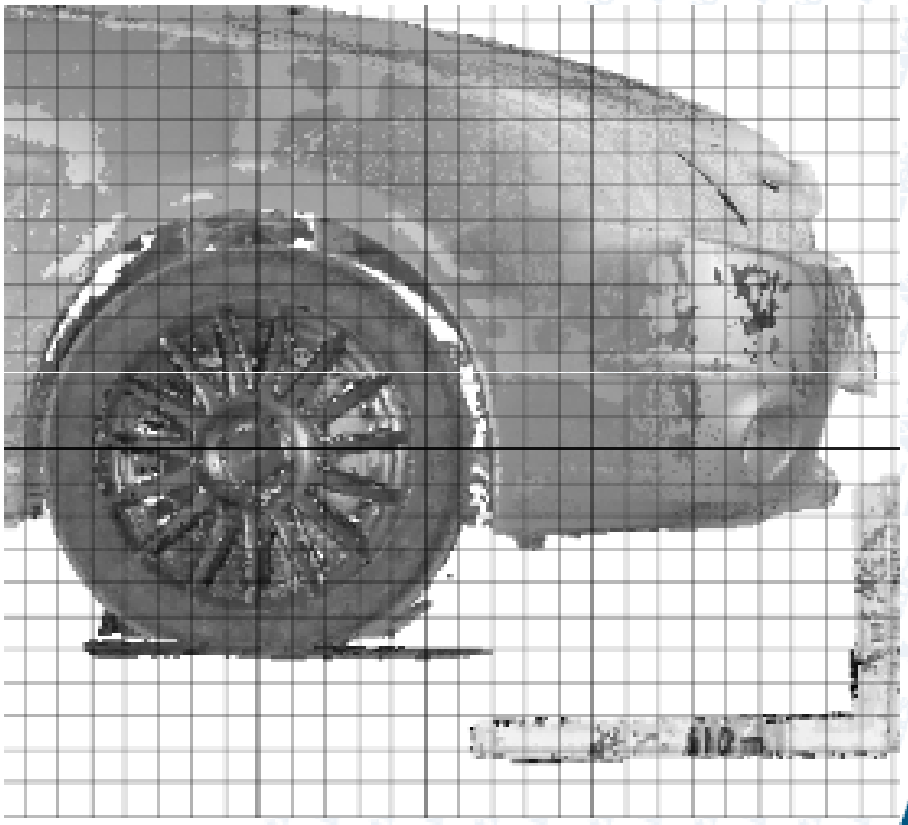


Combining Displacement and Force (per unit width)



Method 1 - Conversion Height

- **To convert to "3-D" notation, a Conversion Height must be determined**
- **We used Laser Scan of vehicle**
  - **Weighted conversion height = 23.6"**

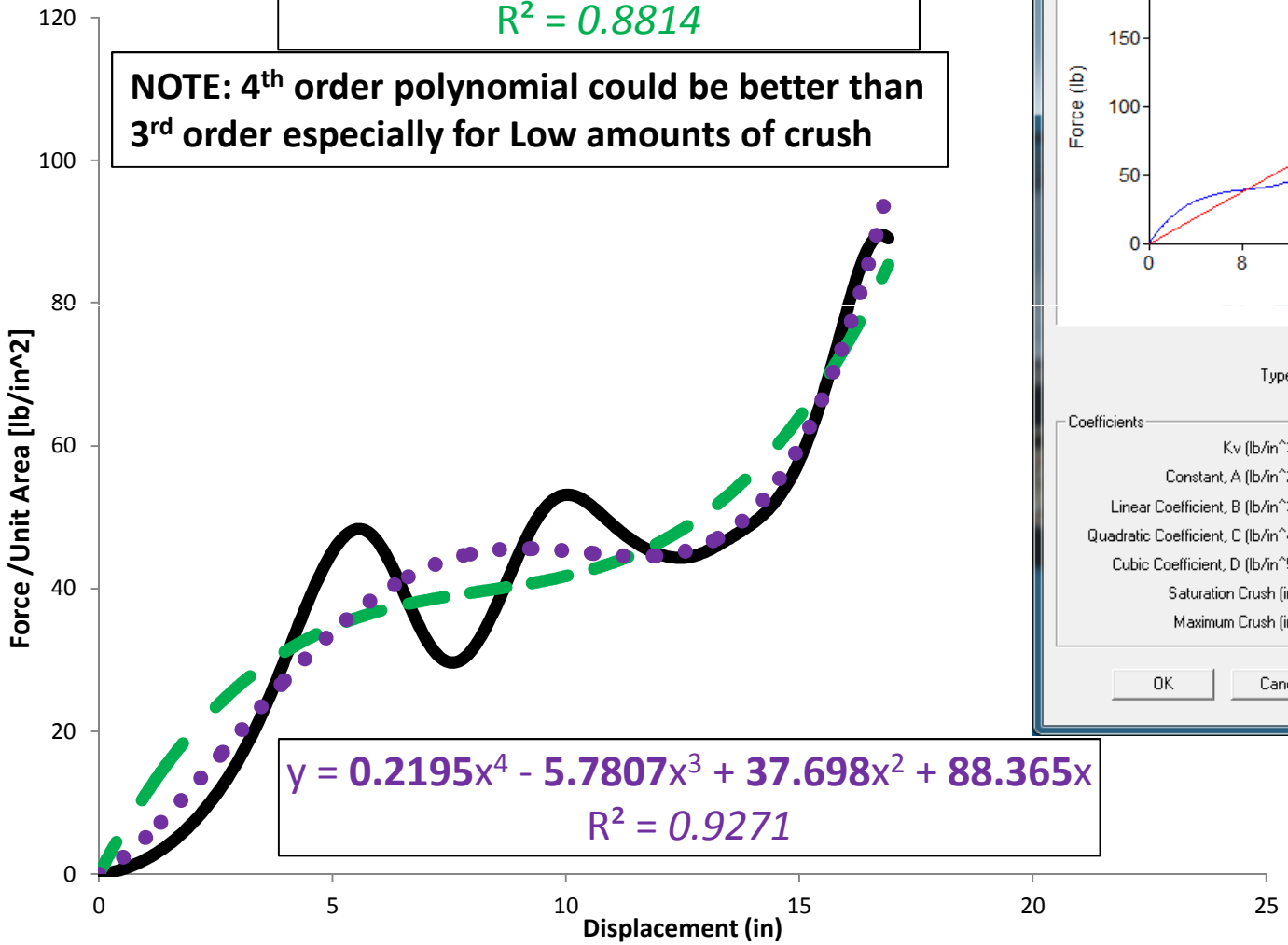


Method 1 - Force (per unit area) vs Displacement

$y = 0.0567x^3 - 1.3988x^2 + 12.4941x$

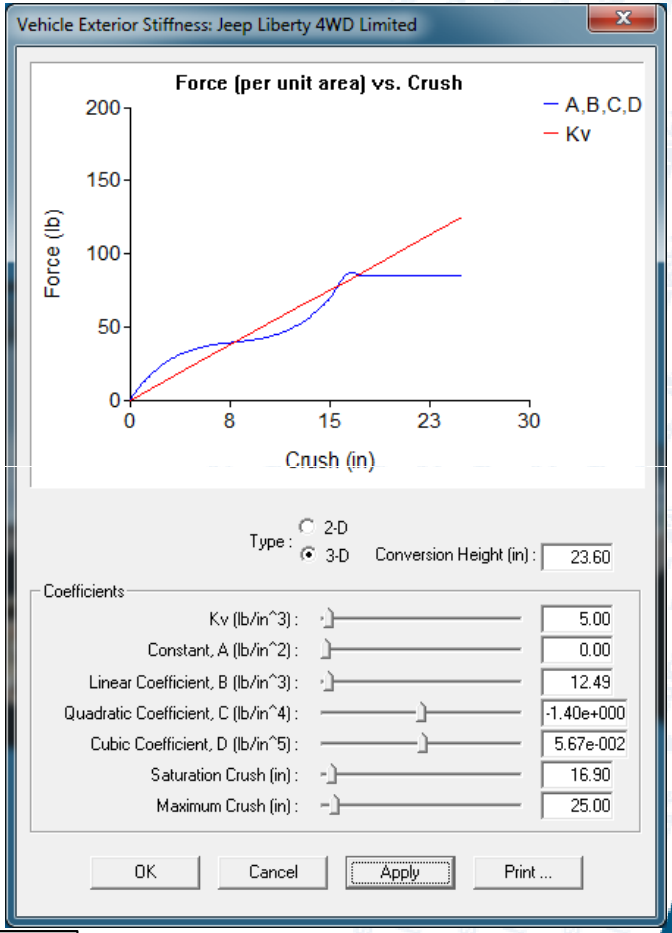
$R^2 = 0.8814$

NOTE: 4th order polynomial could be better than 3rd order especially for Low amounts of crush



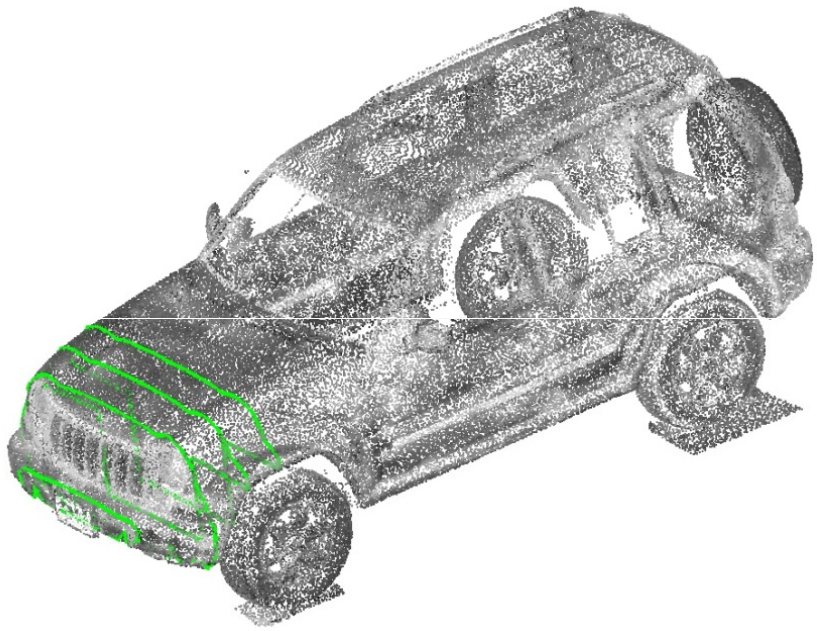
$y = 0.2195x^4 - 5.7807x^3 + 37.698x^2 + 88.365x$

$R^2 = 0.9271$

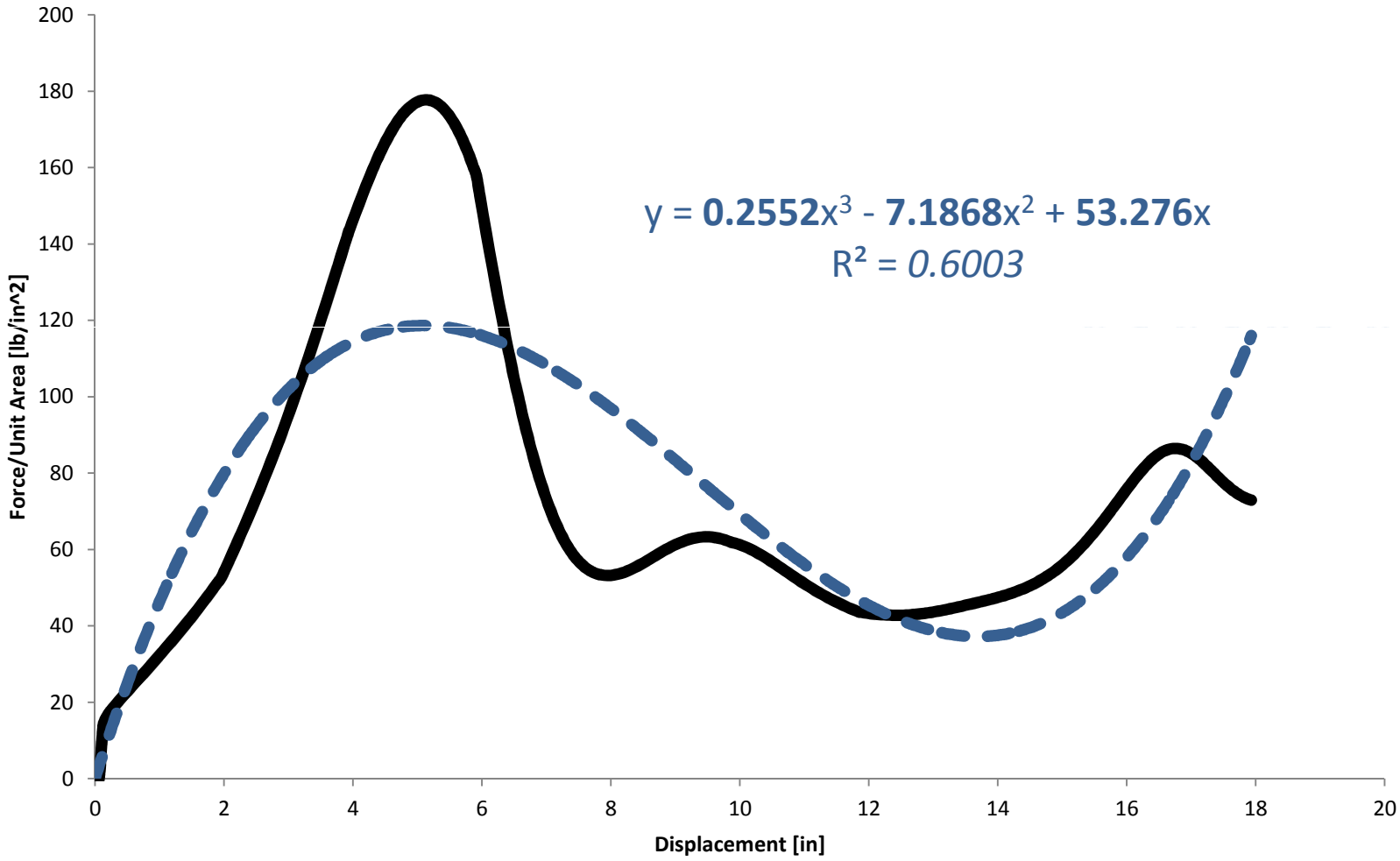


Method 2 – No Conversion Height

- To convert to “3-D” notation
  - Calculate area at various locations
  - Divide F by calculated area
- We used Laser Scan of vehicle
  - Sections cut in 2 in (5 cm) intervals and area calculated
  - Interpolated area in between



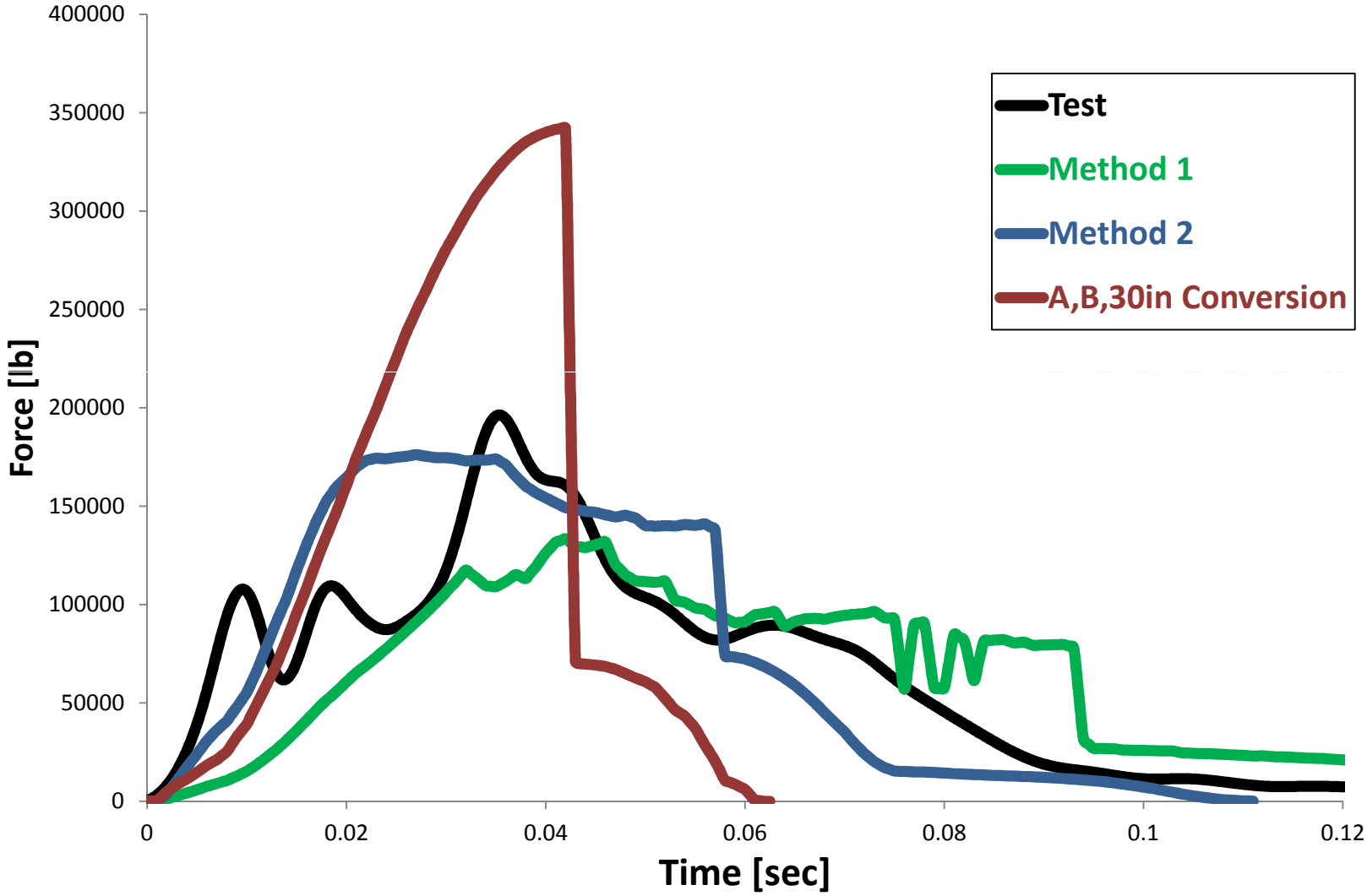
Method 2 - Force (per unit area) vs Displacement



Simulation Comparison

- **Compared 3 different Methods**
  - **Method 1**
    - **Incorporates a vehicle specific "Conversion Height" (23.6 in)**
    - **Uses polynomial curve fit to generate F v d Curve (A,B,C and D)**
      - **(0.00** lb/in^2**, 12.49** lb/in^3**, -1.40** lb/in^4**, 0.0567** lb/in^5**)**
    - **Does not account for area differences since conversion height is fixed**
  - **Method 2**
    - **Incorporates vehicle specific cross-sectional areas**
    - **Uses polynomial curve fit to generate F v d Curve (A,B,C and D)**
      - **(0.00** lb/in^2**, 53.28** lb/in^3**, -7.19** lb/in^4**, 0.255** lb/in^5**)**
  - **Method 3**
    - **Uses A, B coefficients only**
      - **Calculated with b0 = 5 mph and Restitution at 10%**
      - **(734.55 lb/in, 321.61 lb/in^2 in2D)**
    - **30 in "Conversion Height"**
      - **(24.49 lb/in^2, 10.72 lb/in^3, 0.00 lb/in^4, 0.00 lb/in^5 in 3D)**

Simulation Comparison



Simulation Comparison

Test	56 km/h (34.8 mph)			
	NHTSA 5137	Method 1 – Weighted Conversion Height	Method 2 – Use actual area from vehicle	A, B Only and 30 inch Conversion Height
Peak Acceleration	45.6 g	28.7 g	39.1 g	74.7 g
Time to Rebound	0.07 sec	0.22 sec	0.09 sec	0.06 sec
Peak Force	190,900 lb	133,863 lb	180,314 lb	342,126 lb
Delta V	38.56 mph	42.7 mph	39.0 mph	38.7 mph
Max Crush (static)	17.2 in	19.0 in	17.2 in	16.6 in

Note: All simulations have relaxation length set to 0.05.

Observations

- Developed an empirical method of calculating A,B,C and D
  - Curve fit of actual crash test data
  - Crash data should be inspected to assure no measurements were dropped
- Using vehicle specific cross-sectional areas (*Method #2*) provided the best overall results
- When setting the "Saturation Crush" it limited the amount of crush that occurred
  - Example – If set to 7 in the Jeep only crushed approximately 8 in
- We will extend this research to include more vehicles
  - Also researching underride stiffness values of vehicles based on load cell grid positions

Questions?

www.vehiclemetrics.com
bgilbert@vehiclemetrics.com