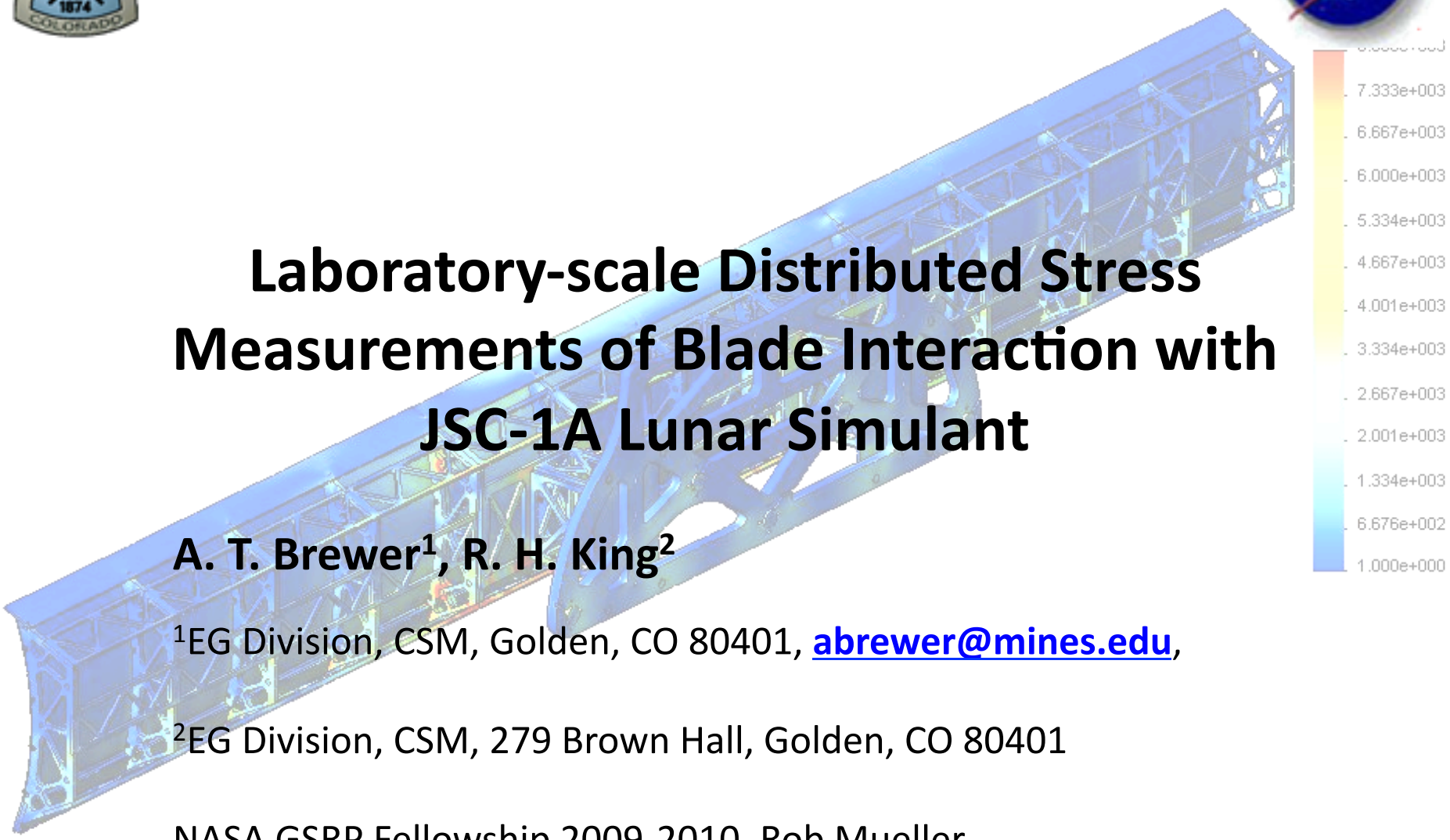

Laboratory-scale Distributed Stress Measurements of Blade Interaction with JSC-1A Lunar Simulant

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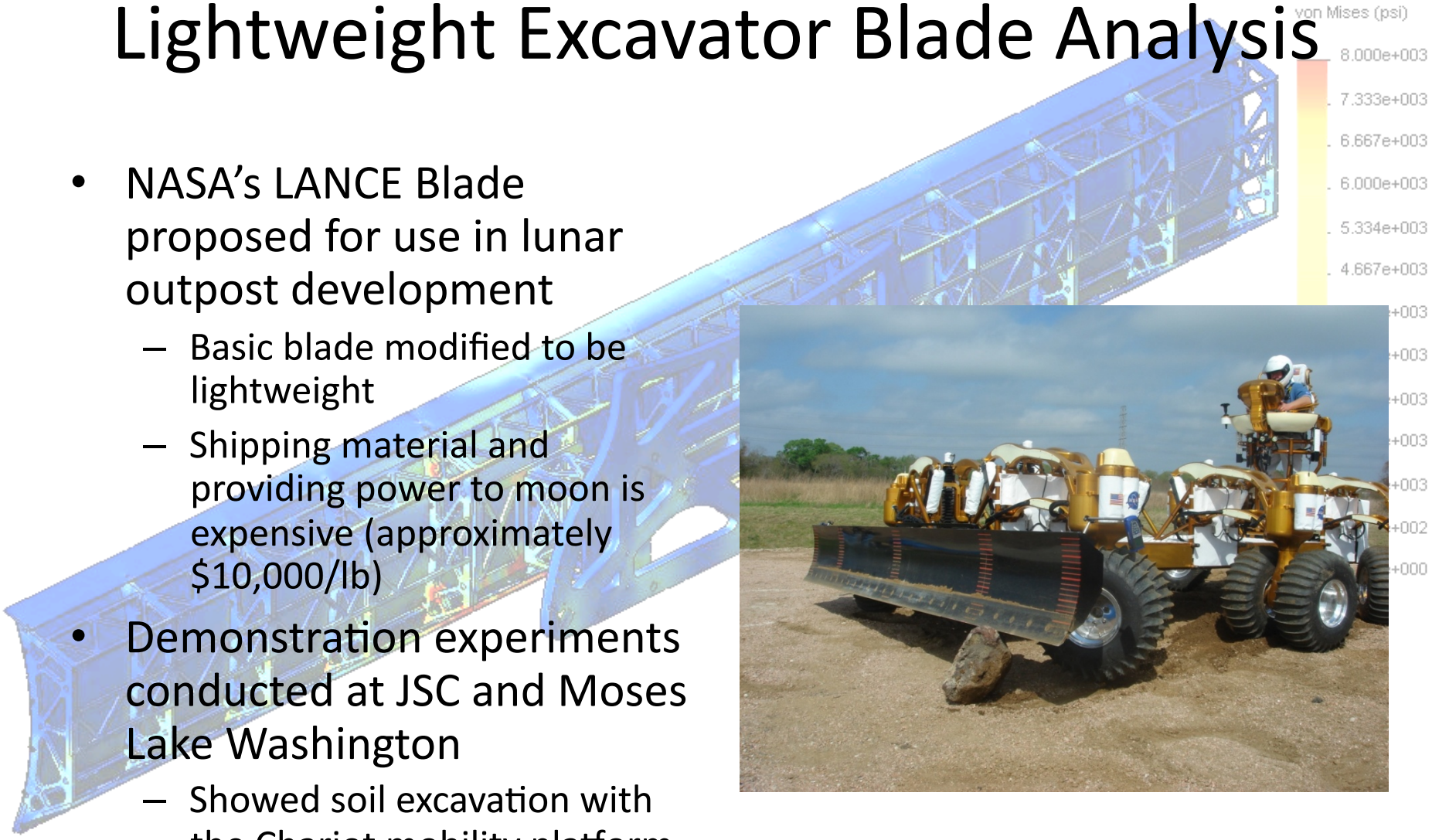
NASA GSRP Fellowship 2009-2010, Rob Mueller

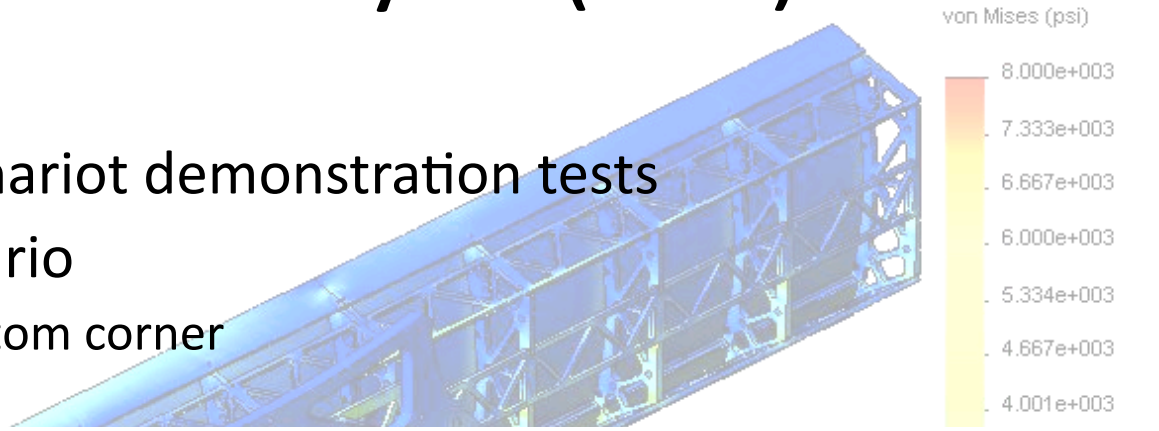
Lightweight Excavator Blade Analysis

- NASA's LANCE Blade proposed for use in lunar outpost development
  - Basic blade modified to be lightweight
  - Shipping material and providing power to moon is expensive (approximately $10,000/lb)
- Demonstration experiments conducted at JSC and Moses Lake Washington
  - Showed soil excavation with the Chariot mobility platform
  - Force data collected



Carrier III, W. D., G. R. Olhoeft, W. Mendell, Physical Properties of the Lunar Surface, Chapter 9, The Lunar Sourcebook, 1991.

Finite Element Analysis (FEA)

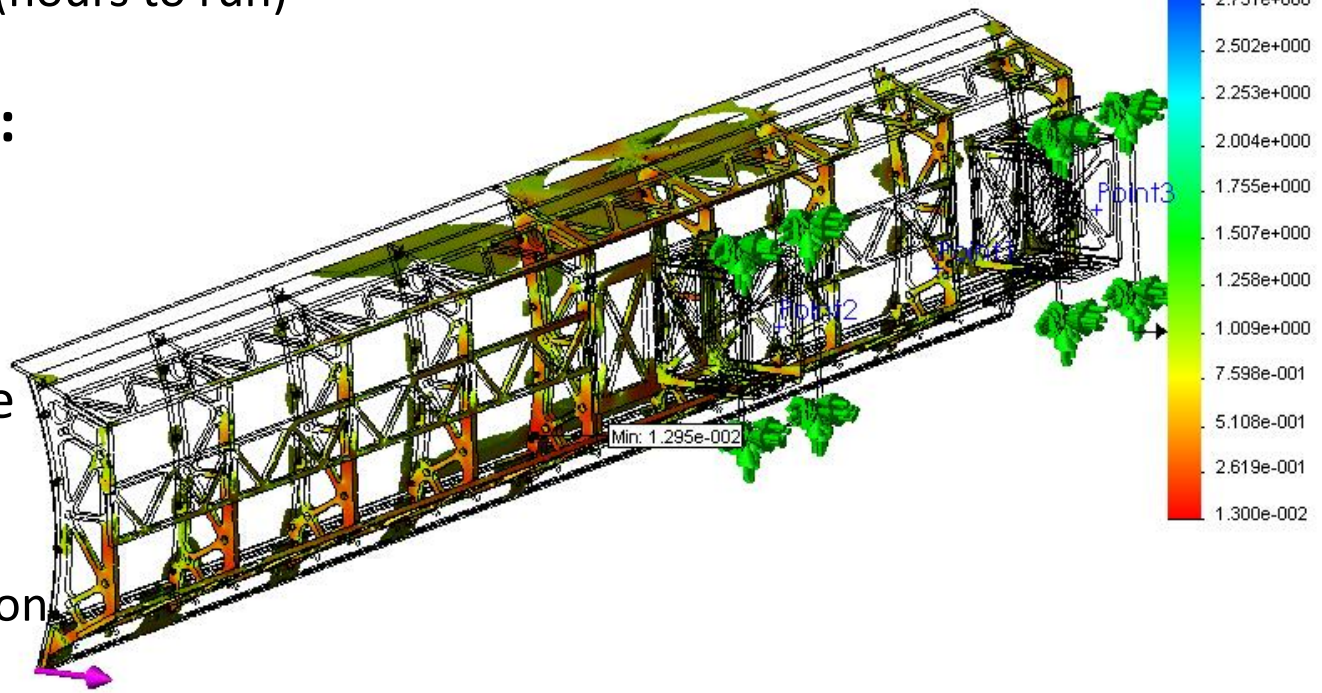


Purpose of FEA:

- Replicate Lance Blade/Chariot demonstration tests
- Analyze worst case scenario
  - 5000 lb point force at bottom corner
- Each test analyzed twice
  - Bolted assembly (days to run)
  - Bonded assembly (hours to run)

FEA initial conditions:

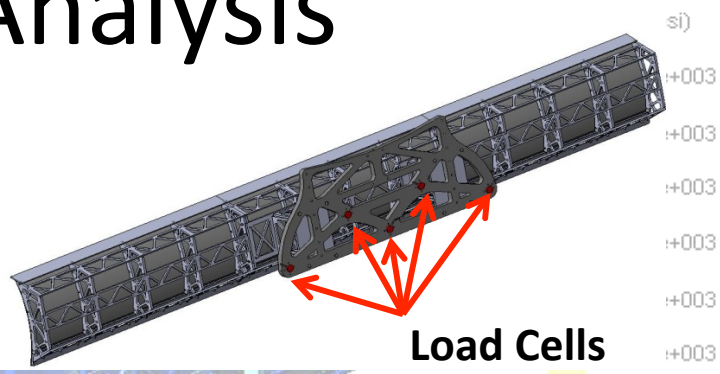
- Geometry
  - NASA CAD files
- Material
  - Al not composite
- Applied load
  - Point force
  - pressure distribution
- Restraints

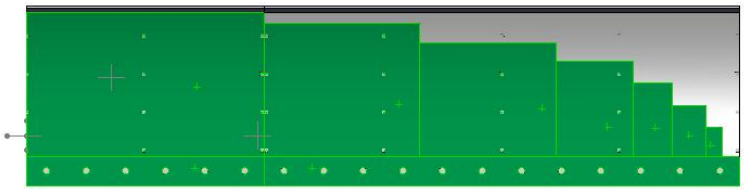


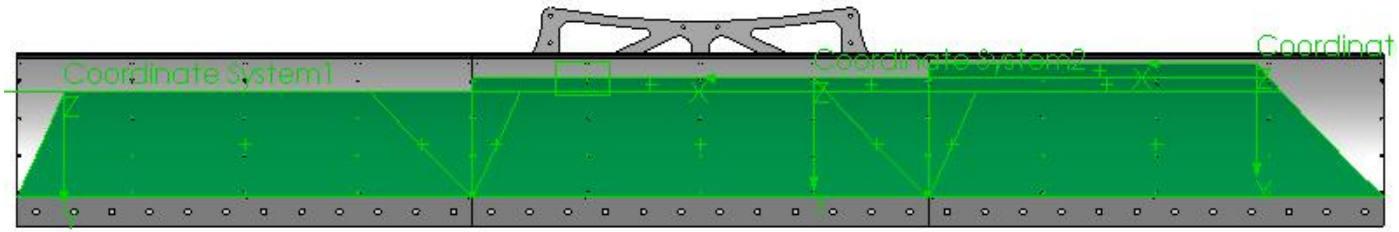
Finite Element Analysis

- Simple force model developed for each demonstration test
  - Load cell data from tests
  - Video footage of tests
  - All models of the form

    $p = (A\ y^2 + B\ y)$ psi.
- Thanks to Brian Dreiling



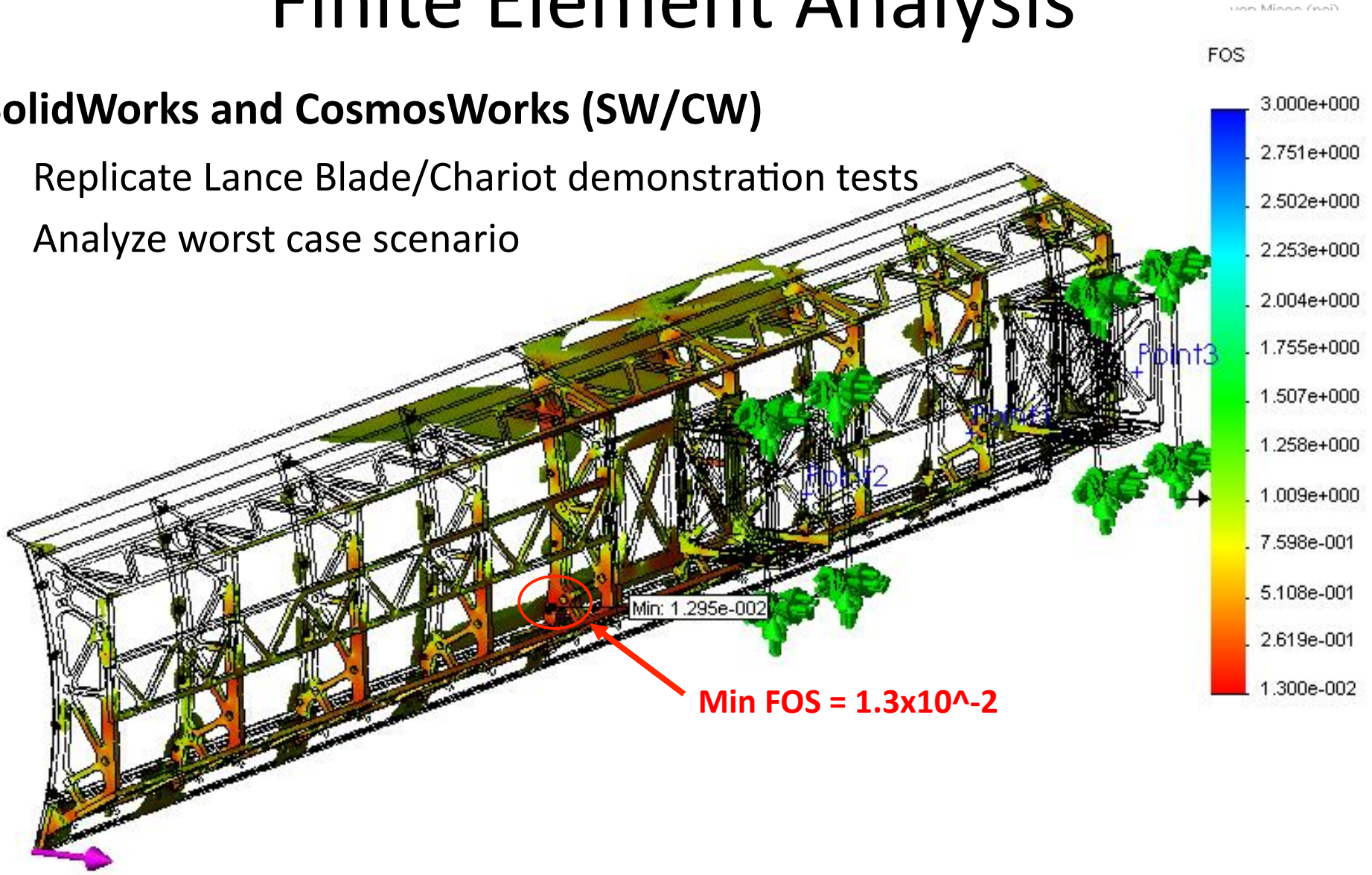




Finite Element Analysis

SolidWorks and CosmosWorks (SW/CW)

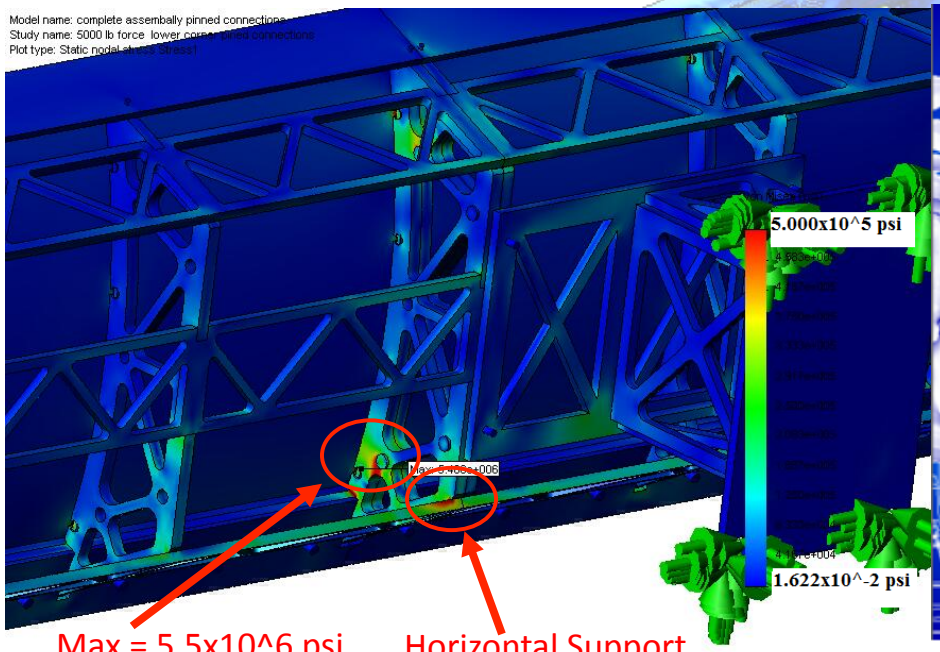
- Replicate Lance Blade/Chariot demonstration tests
- Analyze worst case scenario



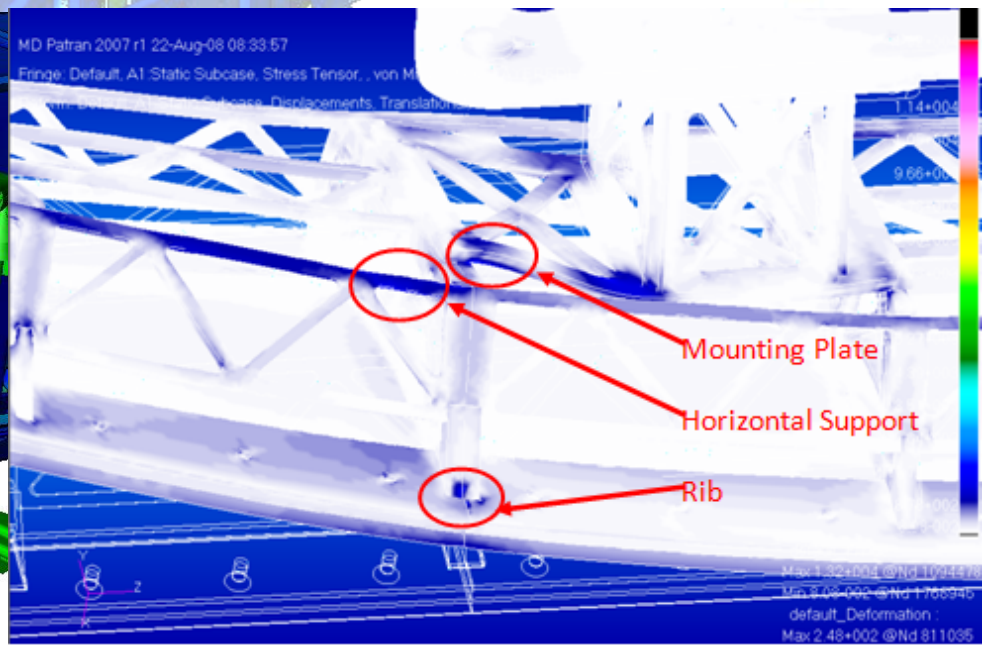
Finite Element Analysis

Patran and Nastran (P/N)

- Analyze worst case scenario for comparison with SW/CW analysis
  - Both results show the highest stresses occur in the same area
  - Both resulted in high stress in the horizontal support



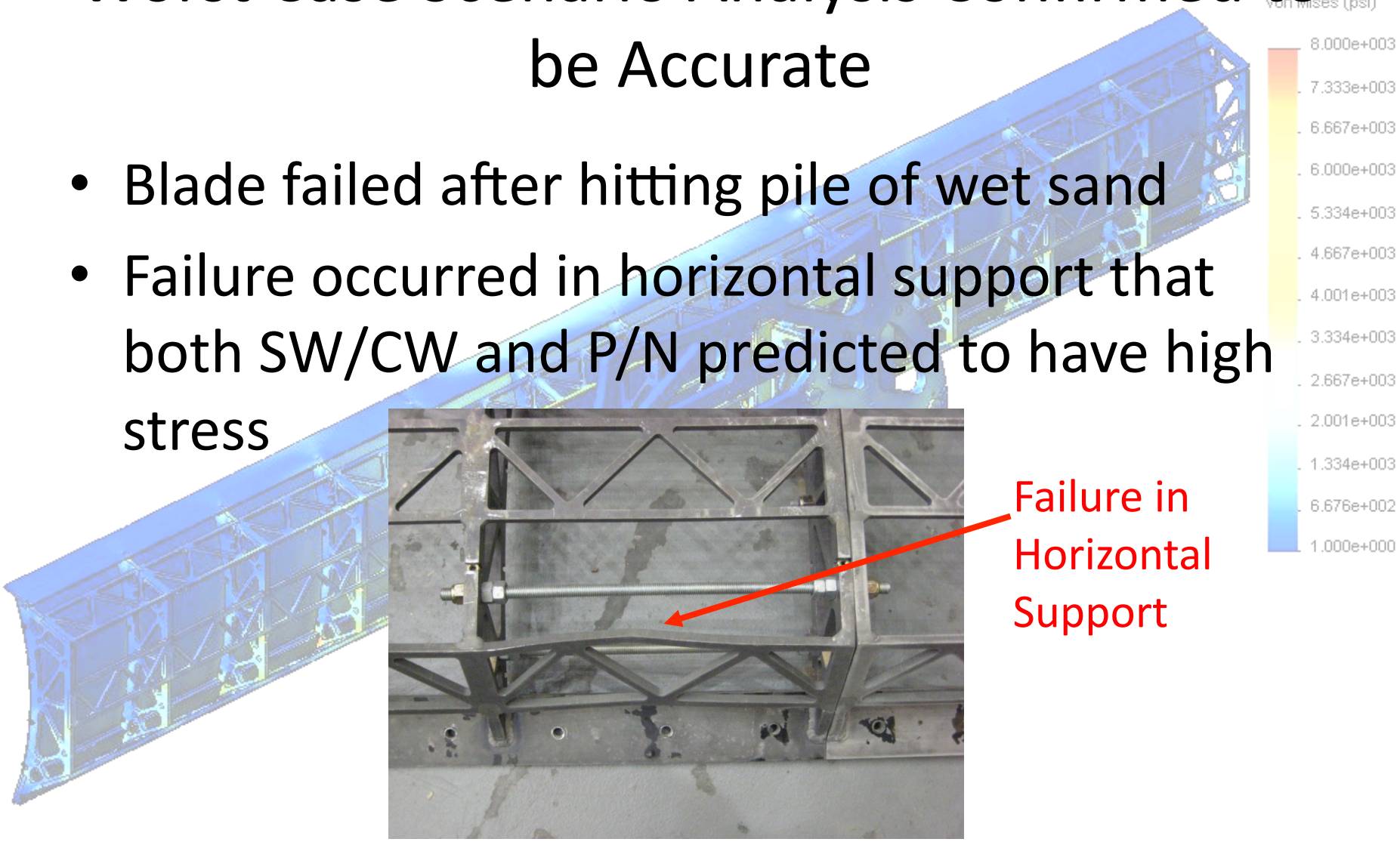
SW/CW



P/N

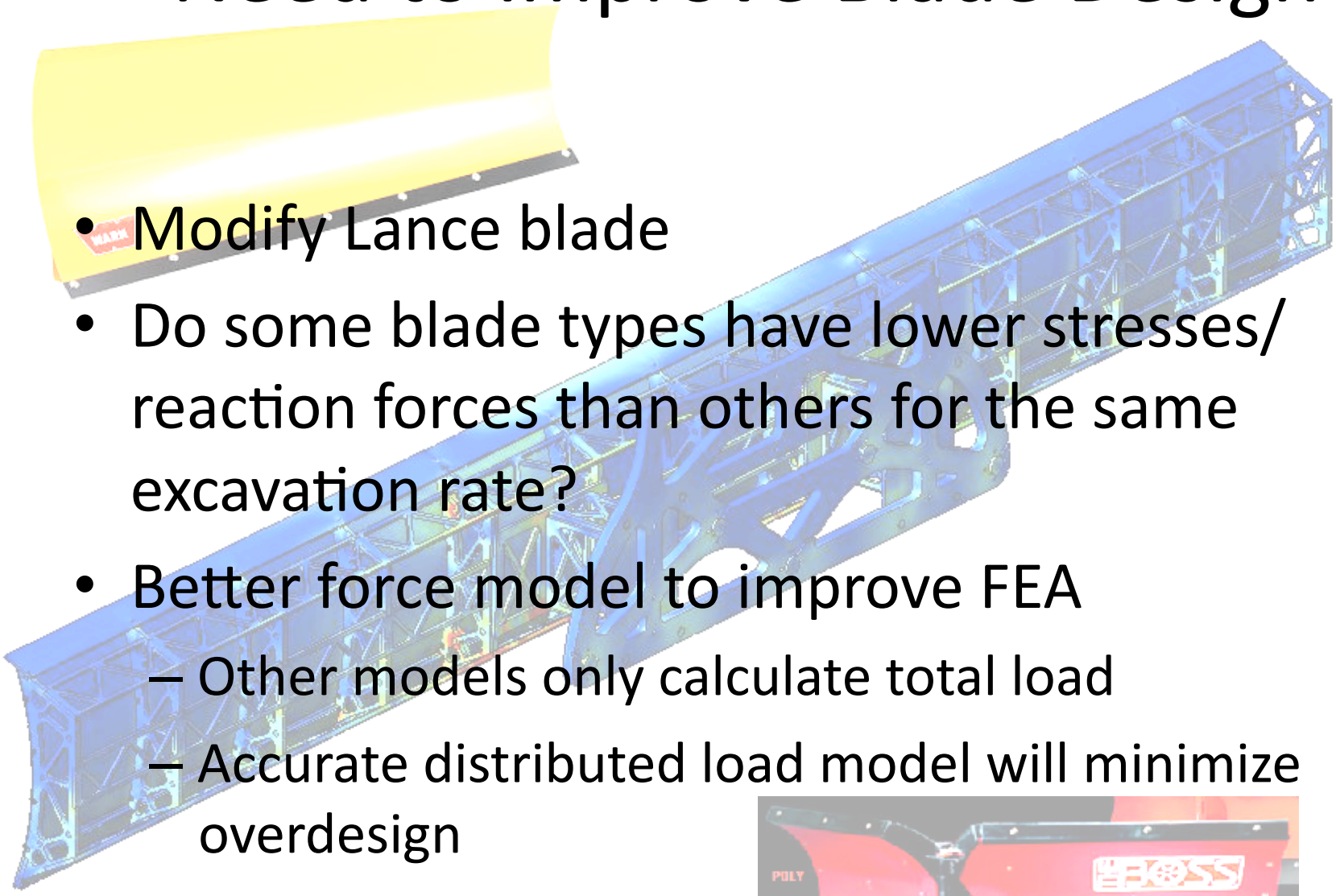
Worst Case Scenario Analysis Confirmed to be Accurate

- Blade failed after hitting pile of wet sand
- Failure occurred in horizontal support that both SW/CW and P/N predicted to have high stress



- SW/CW analyses are valid for blade evaluation

Need to Improve Blade Design



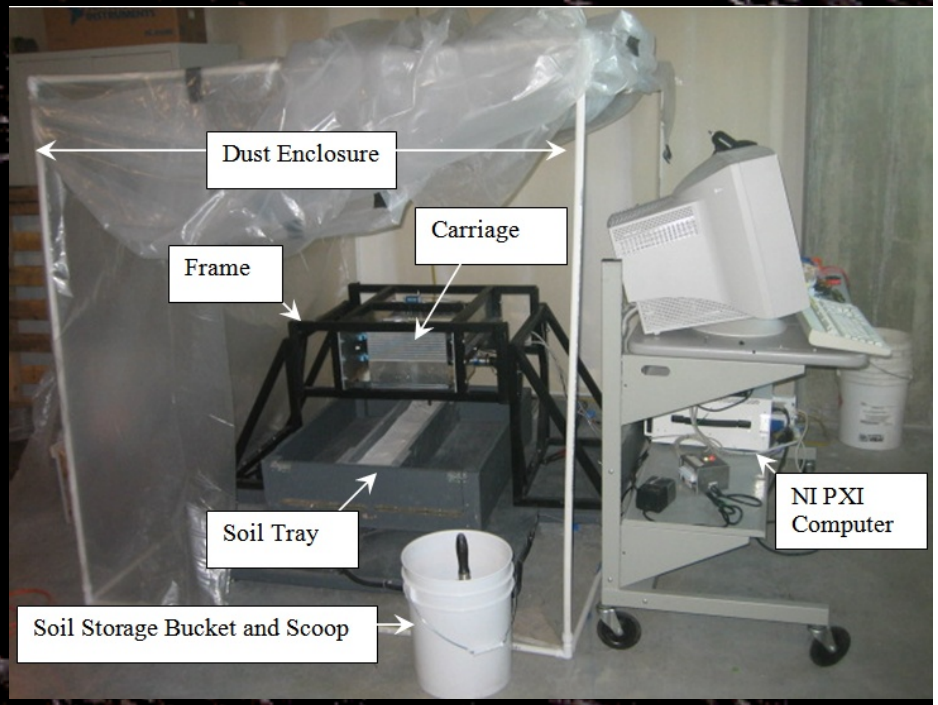
- Modify Lance blade
- Do some blade types have lower stresses/ reaction forces than others for the same excavation rate?
- Better force model to improve FEA
  - Other models only calculate total load
  - Accurate distributed load model will minimize overdesign

Excavation Force Modeling

- Extension of Mark Gefreh's measurements to blade tools and measuring force distribution

Original Measurement System

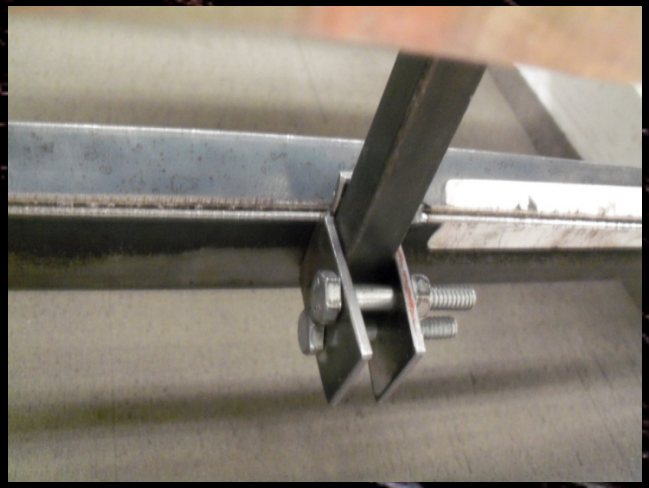
- Holds Model blade still while moving soil-box underneath
- Measures total load in vertical and horizontal directions
- Uses rods for excavation tool

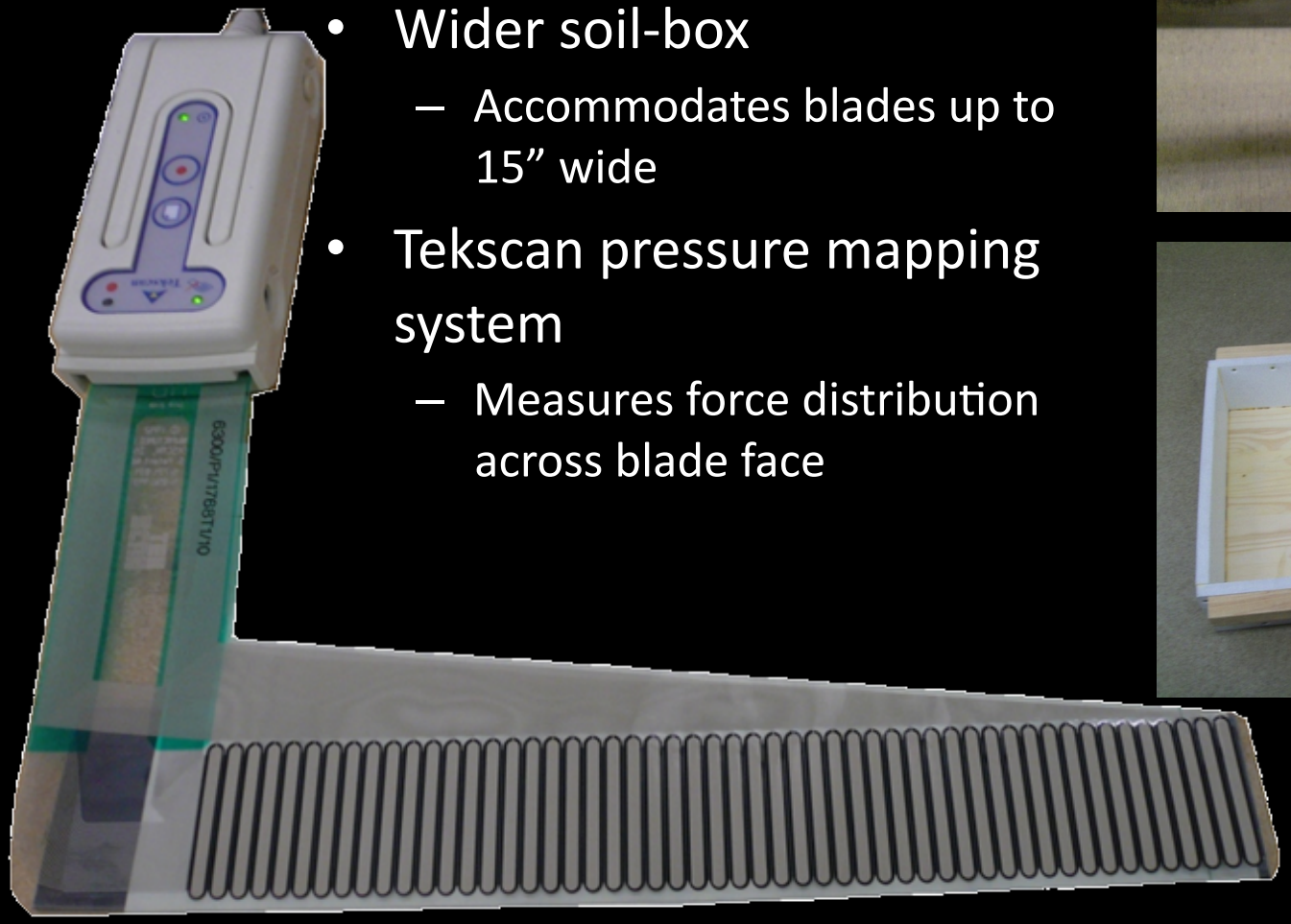


Gefreh, Mark, Comparison of Excavation Forces in JSC-1A Lunar Simulant to Theoretical Models, CSM Master's Thesis, 2008.

Measurement System Additions

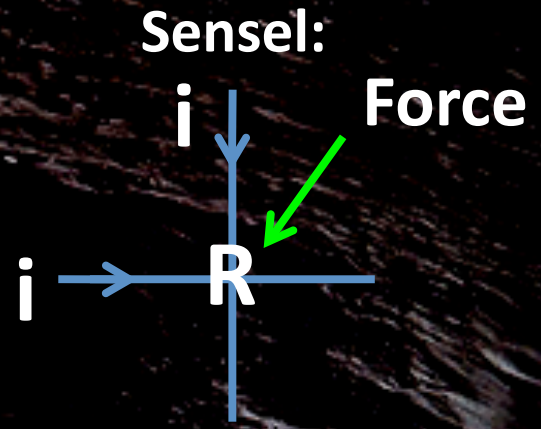
- Excavator blade mount
  - Mounts directly to square rod
- Wider soil-box
  - Accommodates blades up to 15” wide
- Tekscan pressure mapping system
  - Measures force distribution across blade face

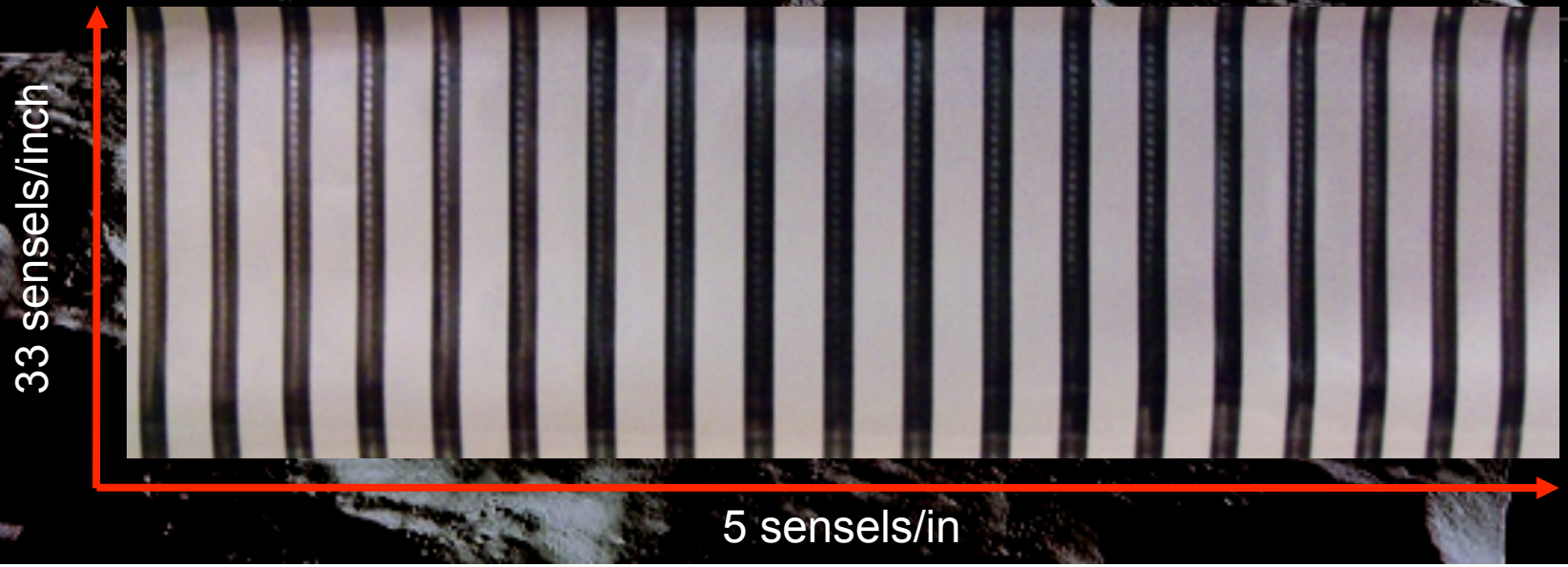




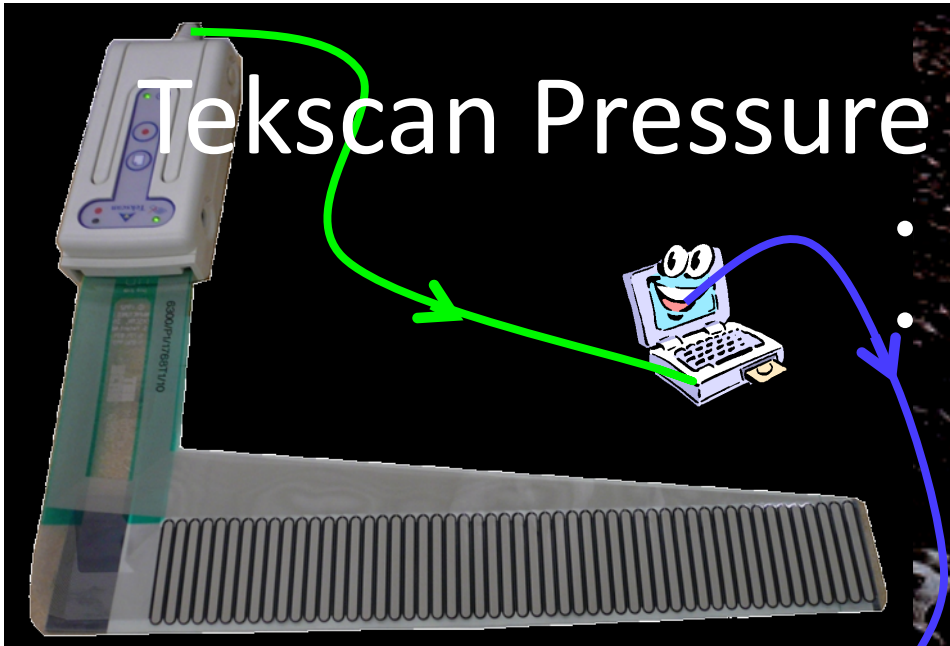
Tekscan Pressure Mapping System

- **Model 6300 thin-film resistive sensor**
  - **10.4” X 1.32” active measurement area**
  - **166.7 sensel/in^2 spatial resolution**
  - **2280 sensels**
  - **100 Hz max. sampling rate**
  - **10 psi pressure range.**

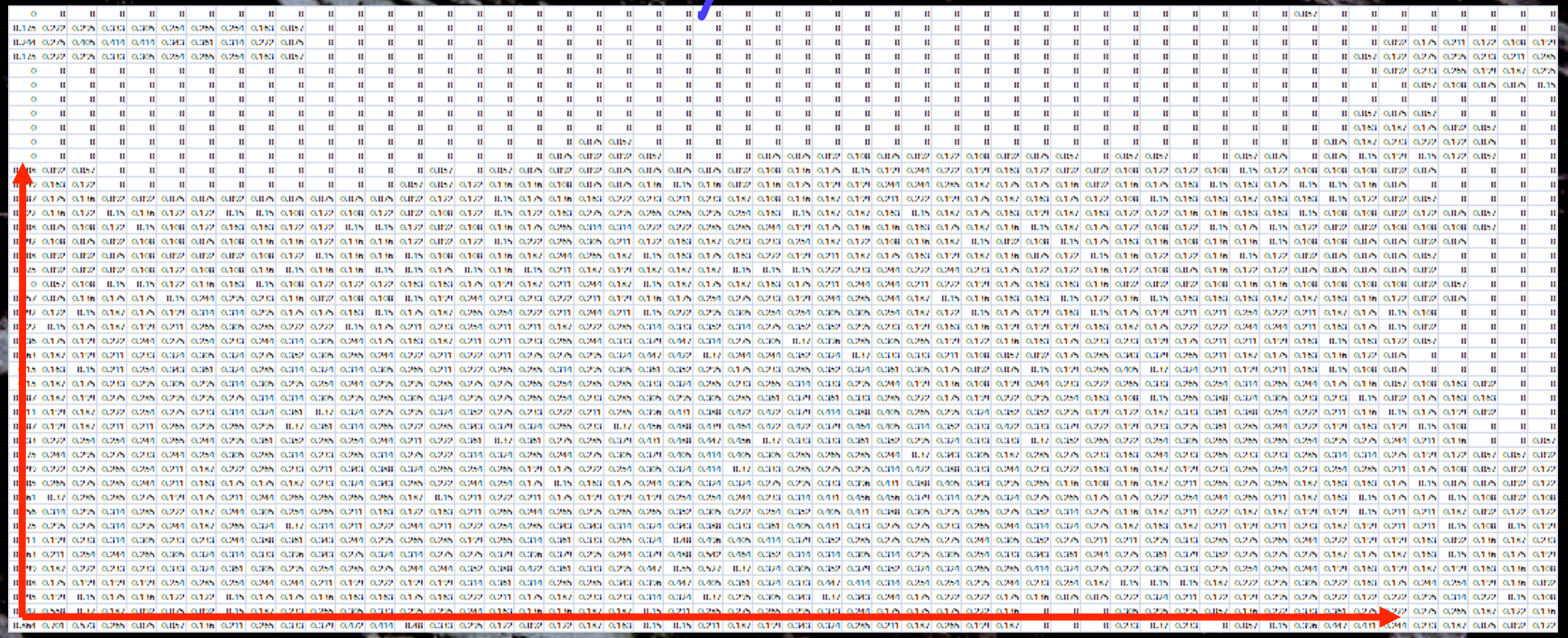




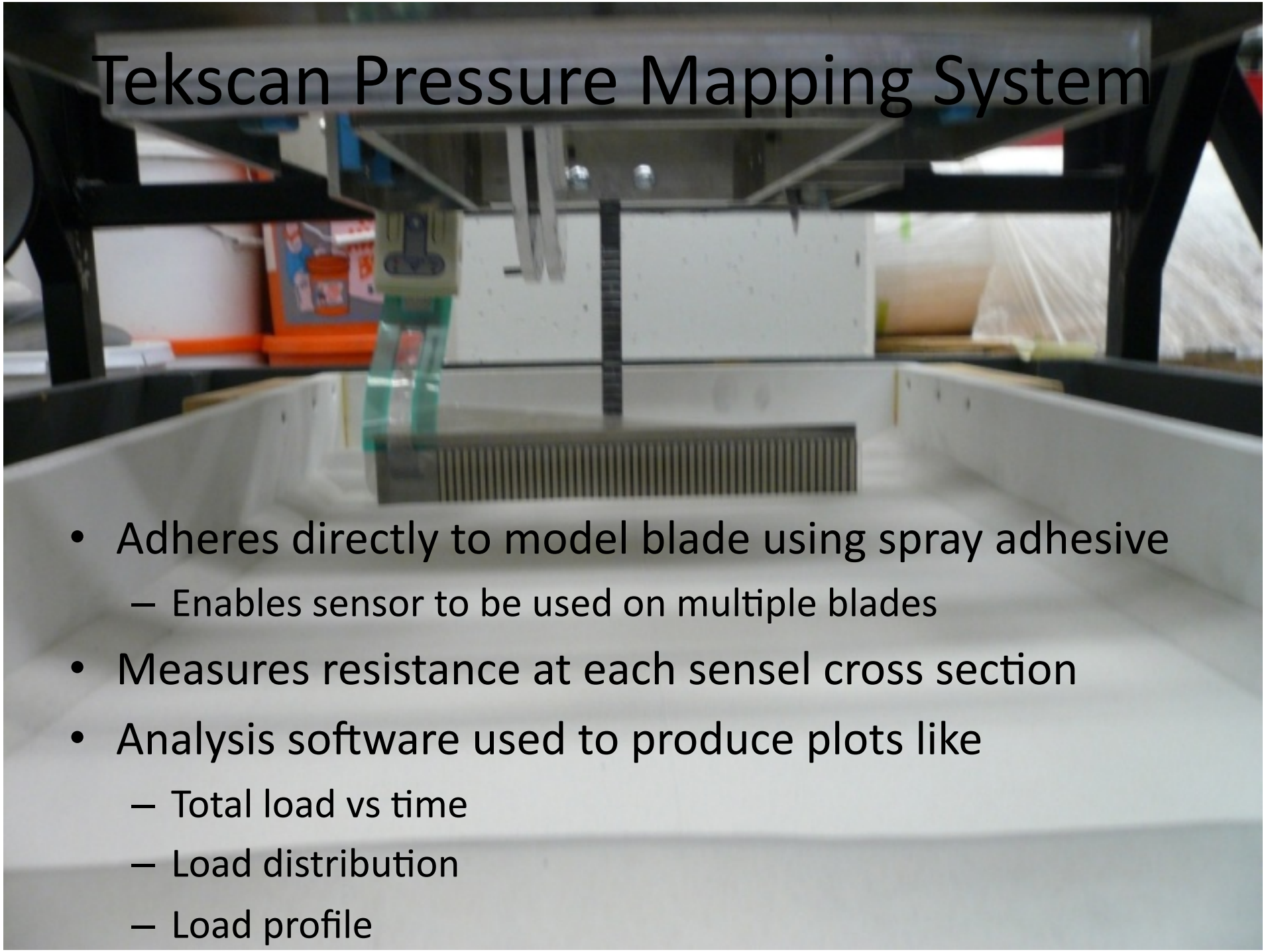
Tekscan Pressure Mapping System



- **Fully integrated USB interface**
- ***I-Scan 6.02* data acquisition and analysis software included**
  - **Separate from test-bed apparatus**
  - **Raw data is a resistance value at each sensel**

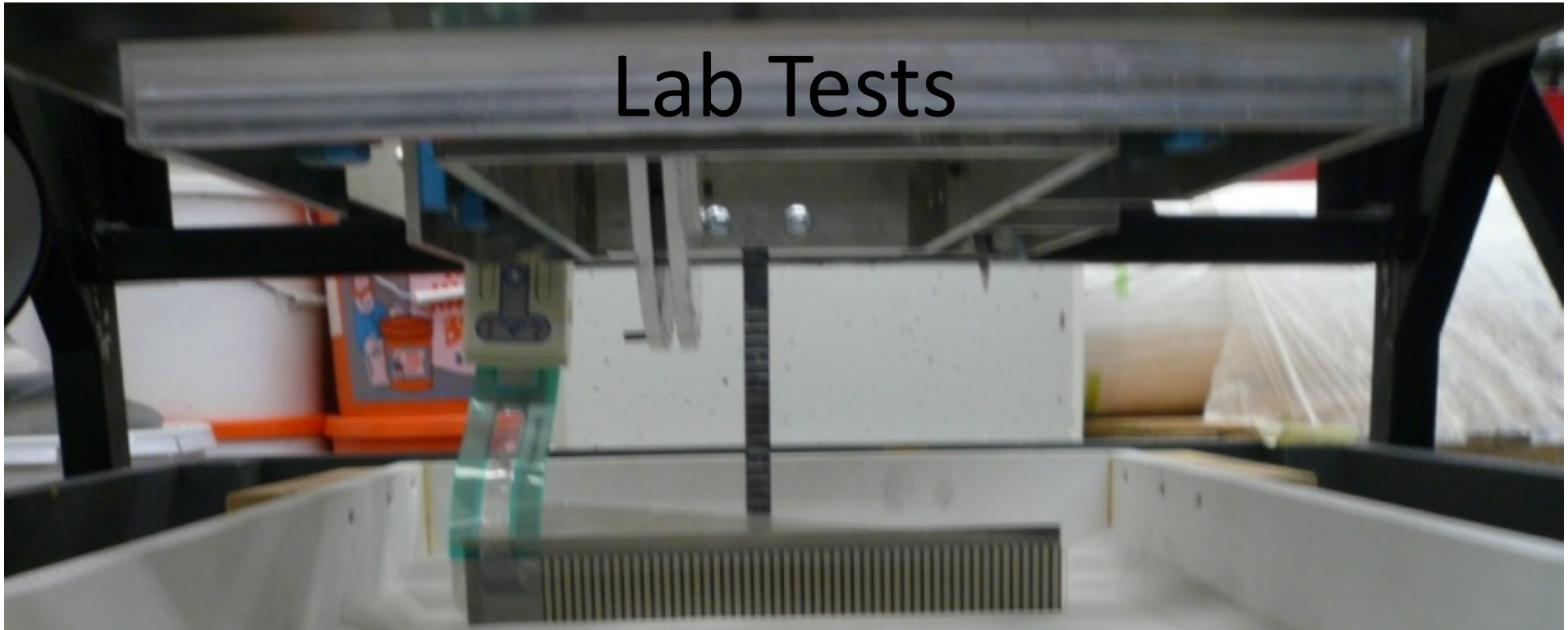


Tekscan Pressure Mapping System



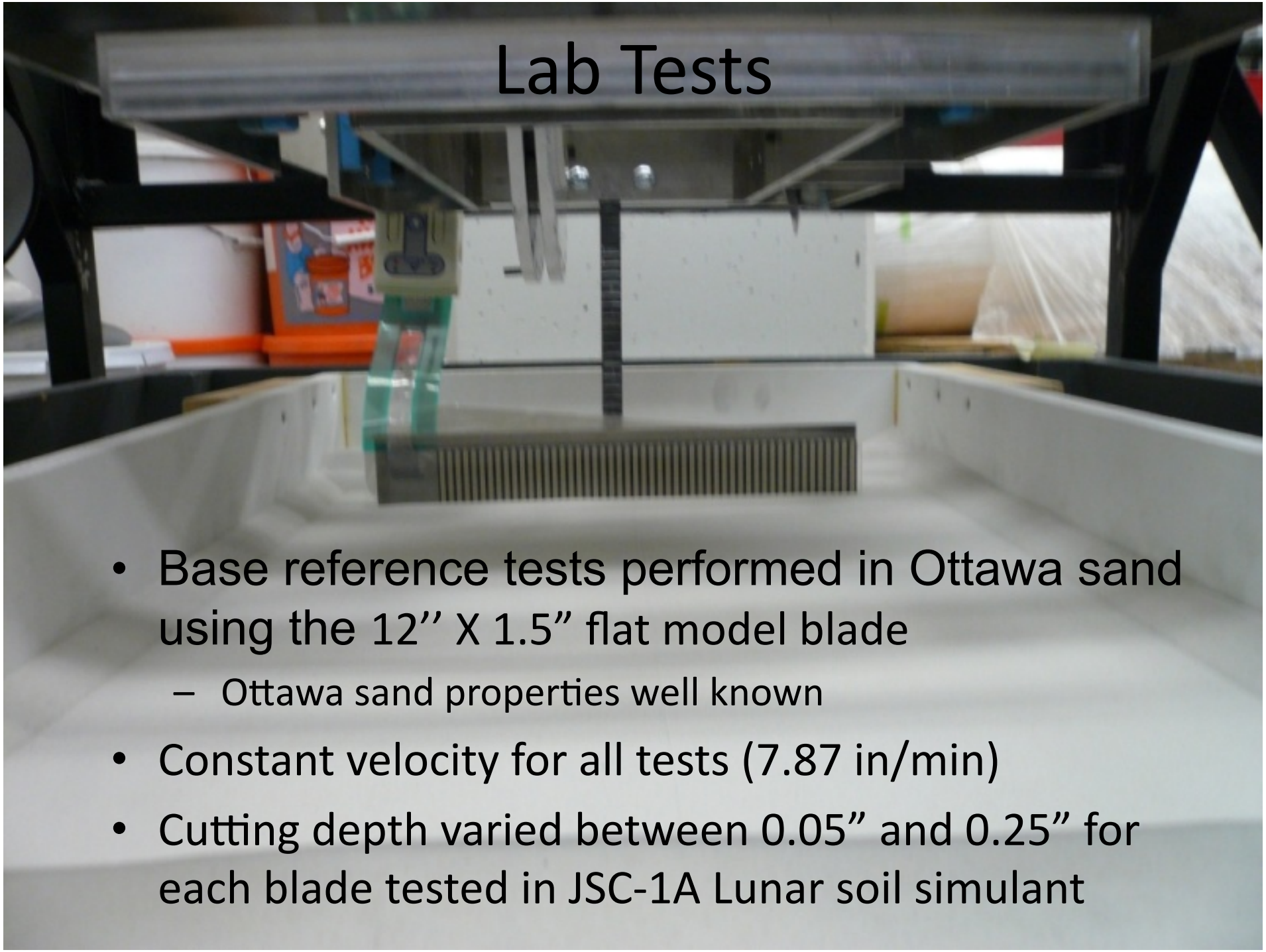
- Adheres directly to model blade using spray adhesive
  - Enables sensor to be used on multiple blades
- Measures resistance at each sensel cross section
- Analysis software used to produce plots like
  - Total load vs time
  - Load distribution
  - Load profile

Lab Tests



- Evaluate basic blade configurations
  - Blade width
  - Cutting depth
  - Rake angle
  - Operating angle
- Evaluate three blade shapes on basis of Force vs Excavation Rate
  - Flat, straight blade
  - Curved, straight blade
  - Flat, V-shaped blade

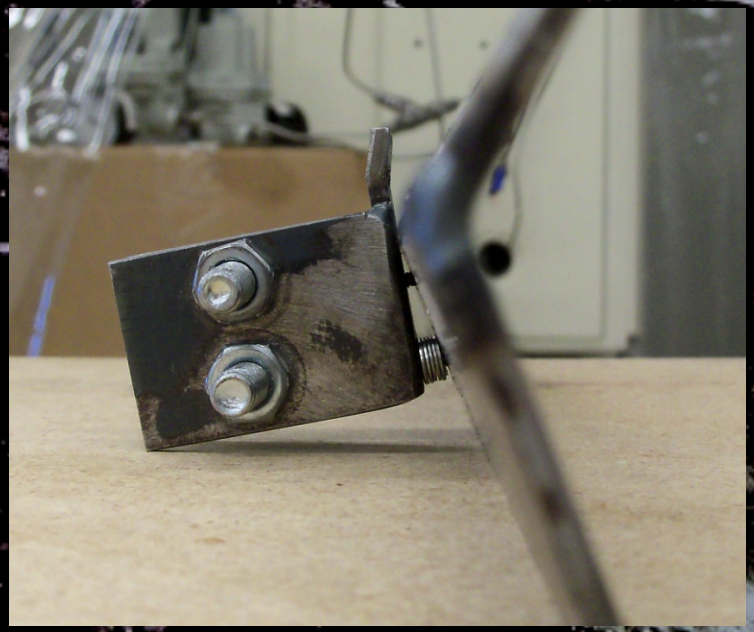
Lab Tests



- Base reference tests performed in Ottawa sand using the 12’’ X 1.5” flat model blade
  - Ottawa sand properties well known
- Constant velocity for all tests (7.87 in/min)
- Cutting depth varied between 0.05” and 0.25” for each blade tested in JSC-1A Lunar soil simulant

Curved vs Flat Blades

- Curved and flat blades tested
  - Same angle as Lance blade
  - characterize cutting angle
  - Evaluate blade shape
- Cutting angle varied between 90^o and 80^o for both blade shapes

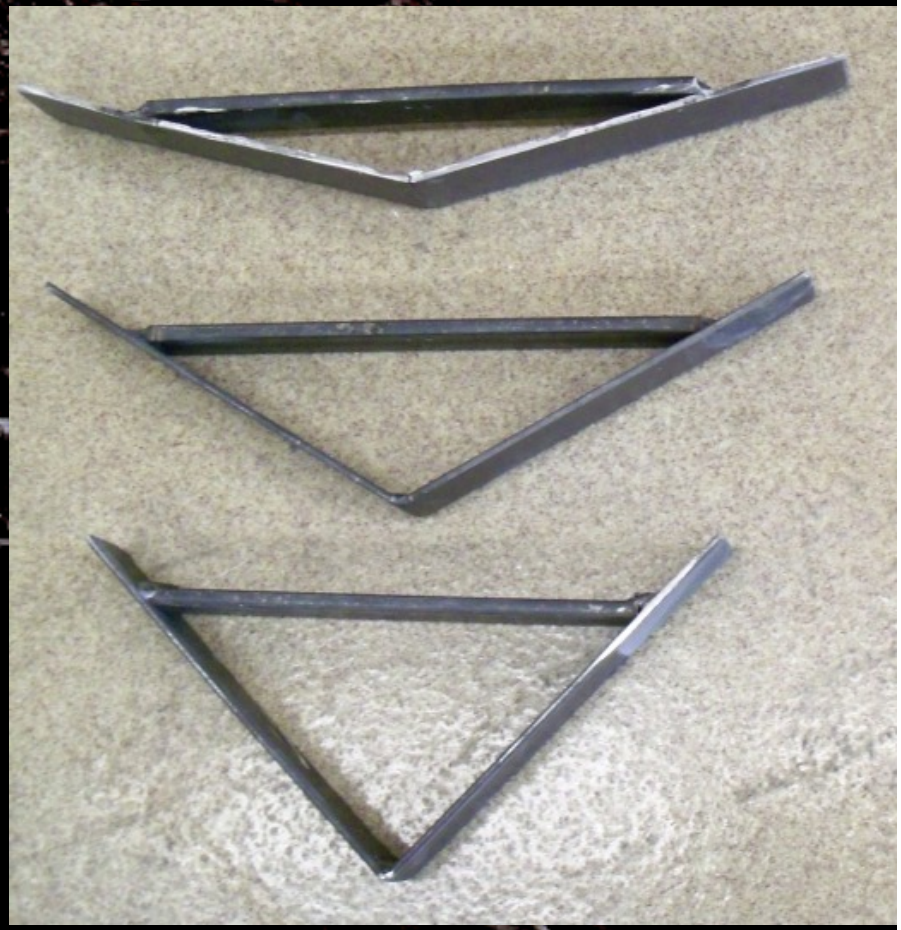


video

video

Straight vs V-shaped Blades

- Tested for benefits of using V-shaped blade
- Load vs excavation rate
- Tested 30^{o}, 60^{o}, and 90^{o} angles
- Also used to represent an angled straight blade

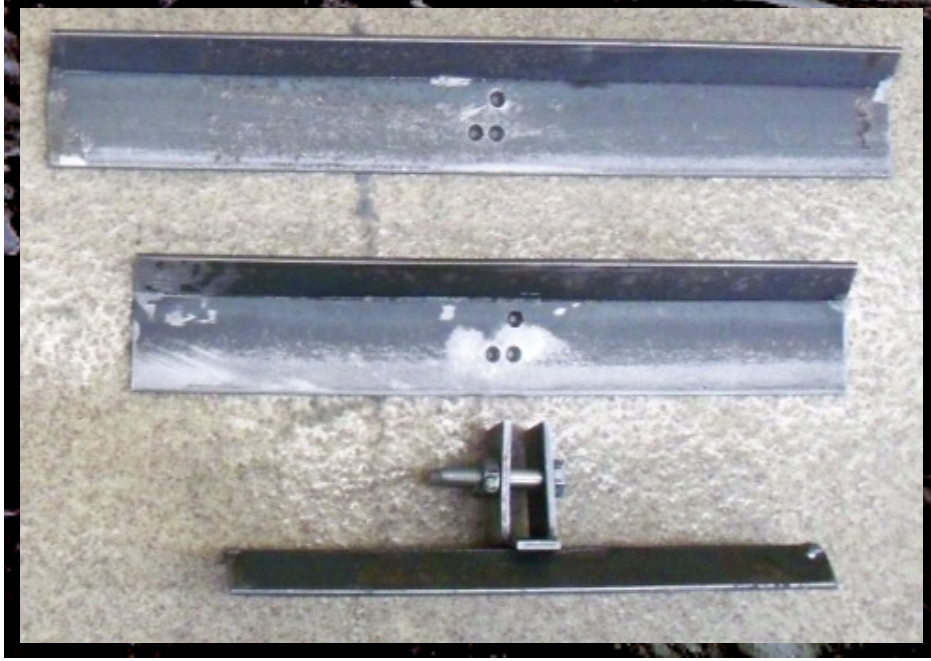


video

Varying Blade Widths

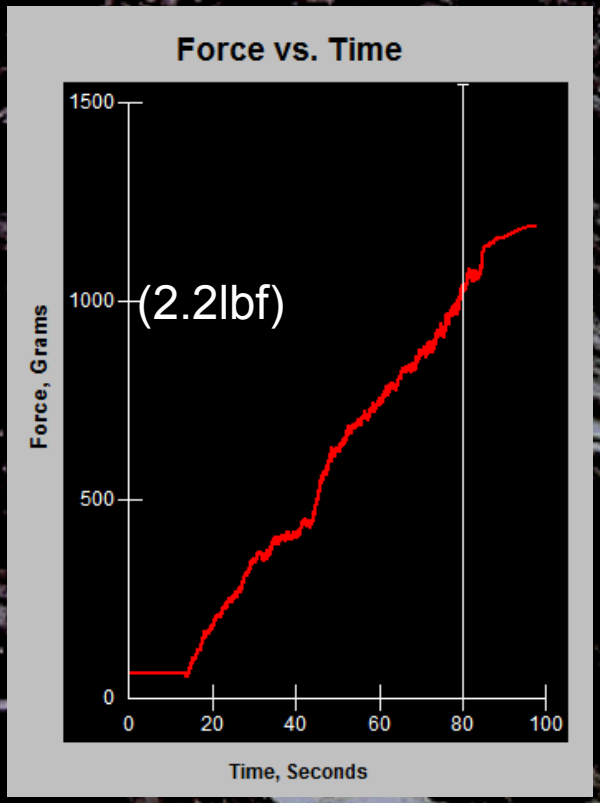
- Three widths tested using both flat and curved blades
  - 12”, 10”, and 8”
- Characterize total load and force distribution vs blade width

video

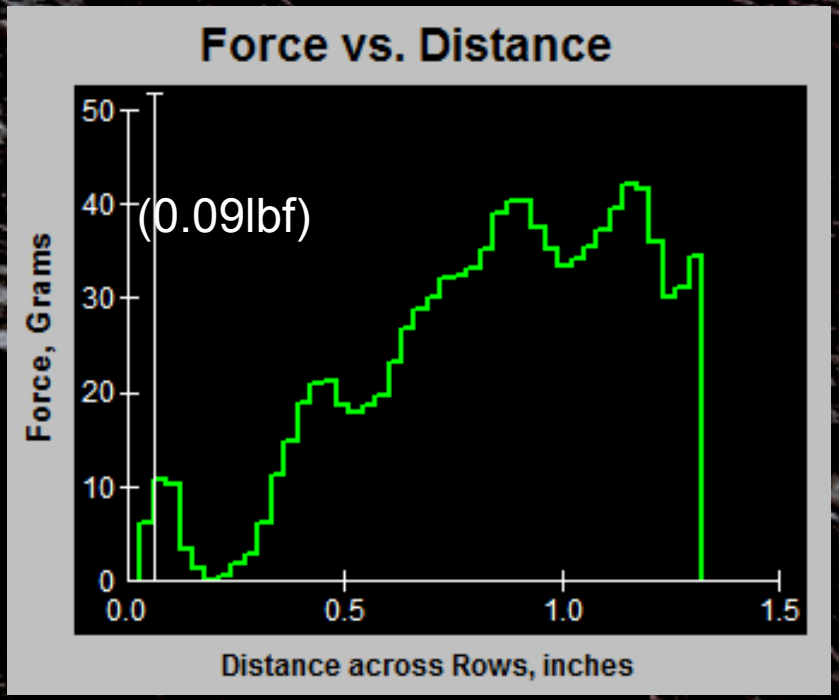


Initial Data Analysis Results

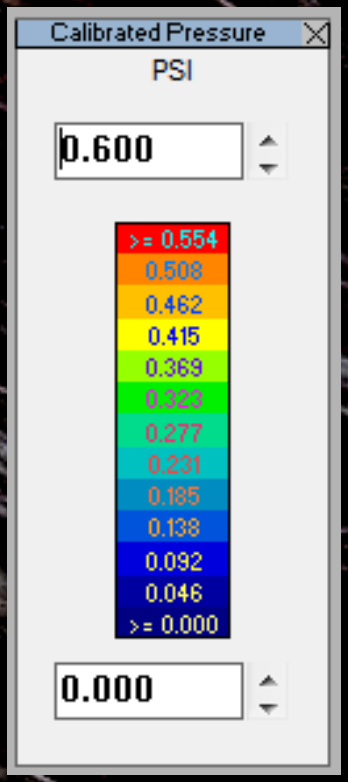
Tekscan sensor sensitive enough to capture distribution

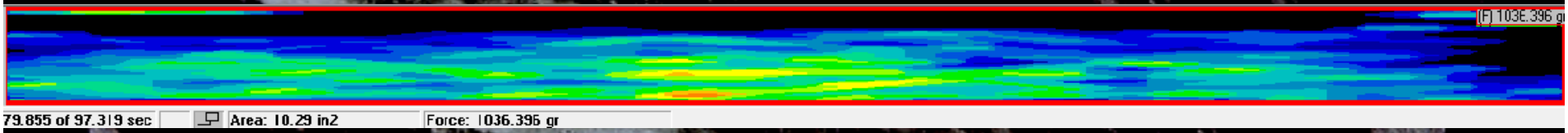


Total Load vs Time



Load Profile

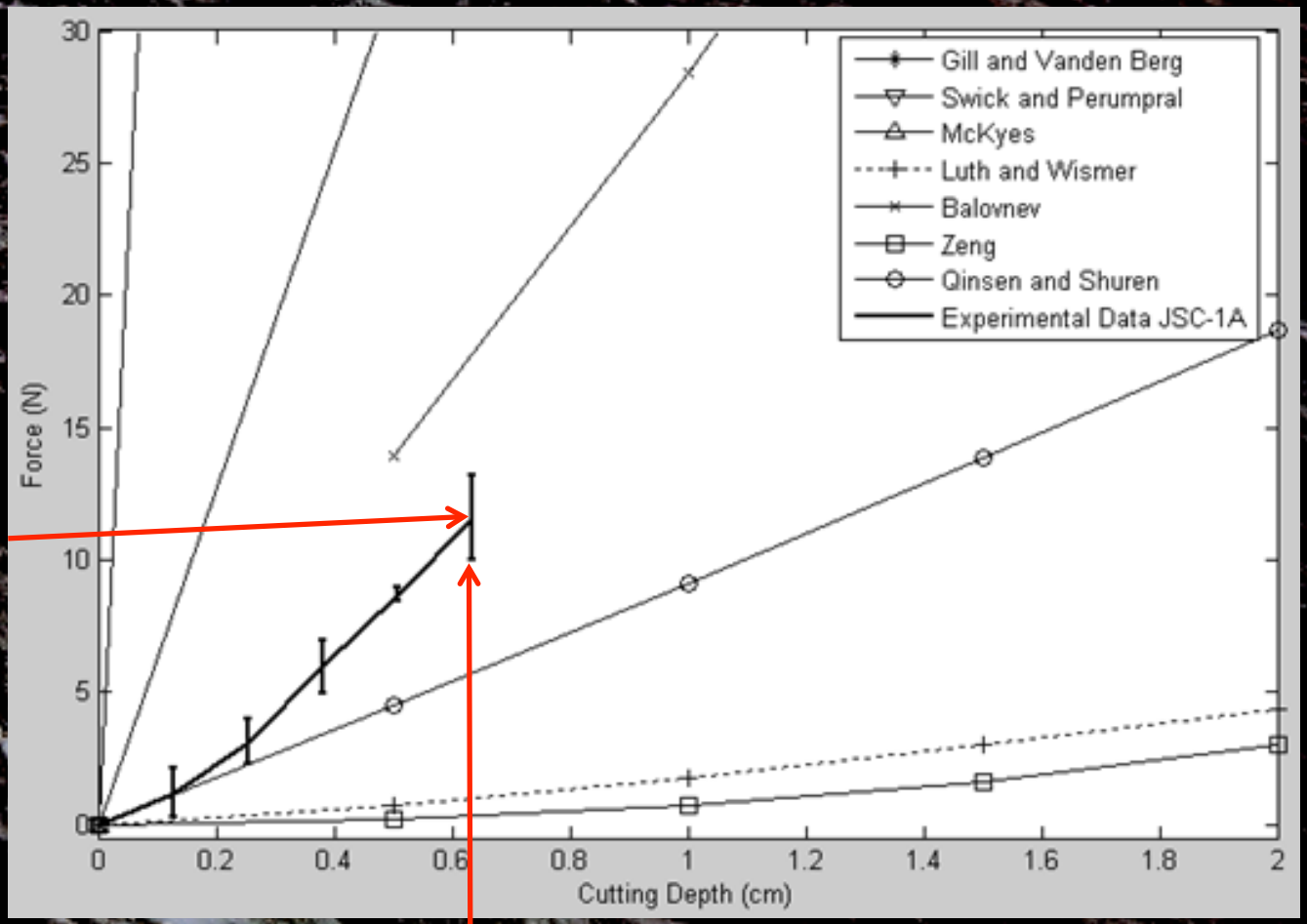




Pressure Distribution

Initial Data Analysis Results

Total loads within range of existing force models



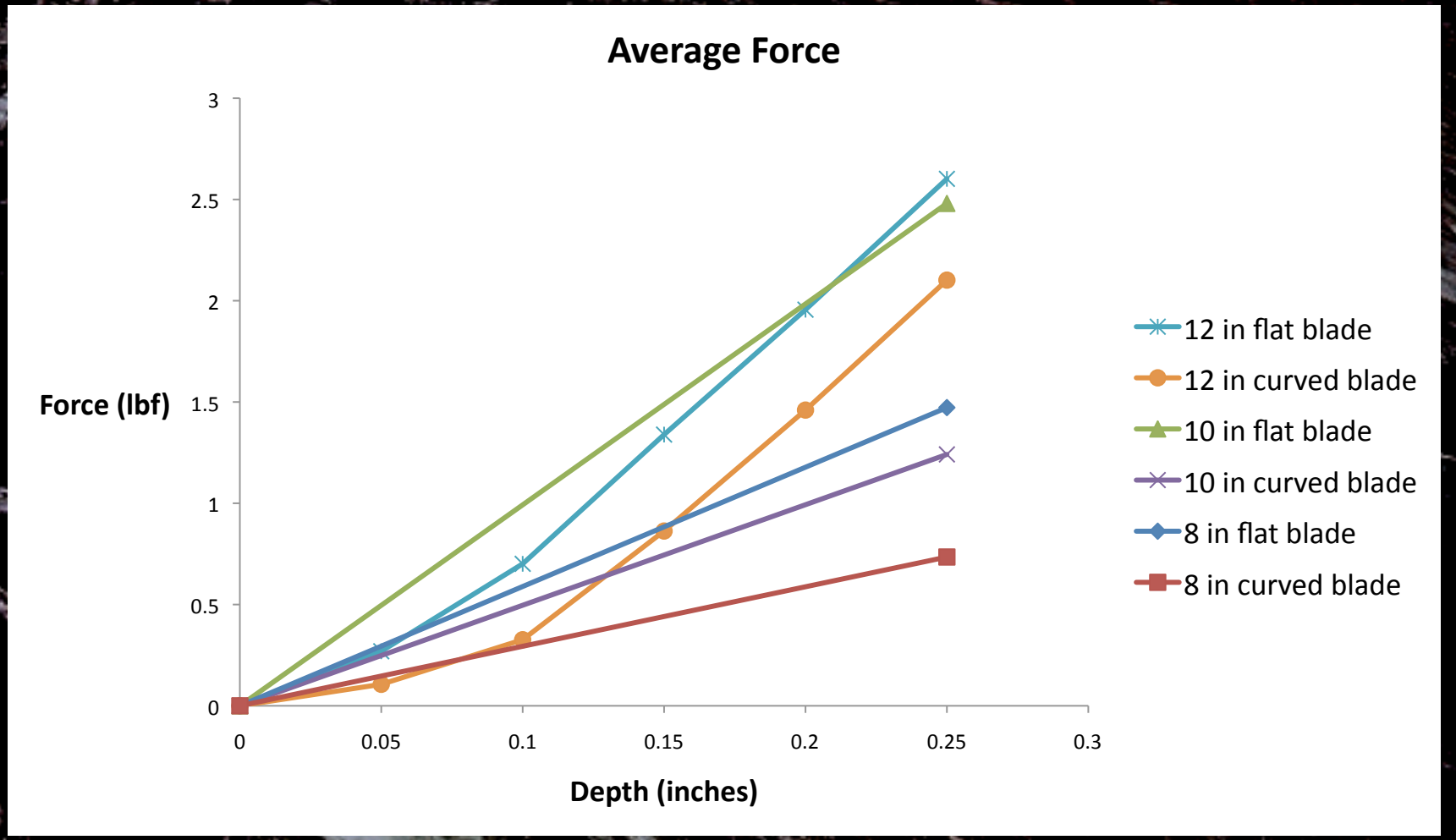
(2.6 lbf)

(0.25inches)

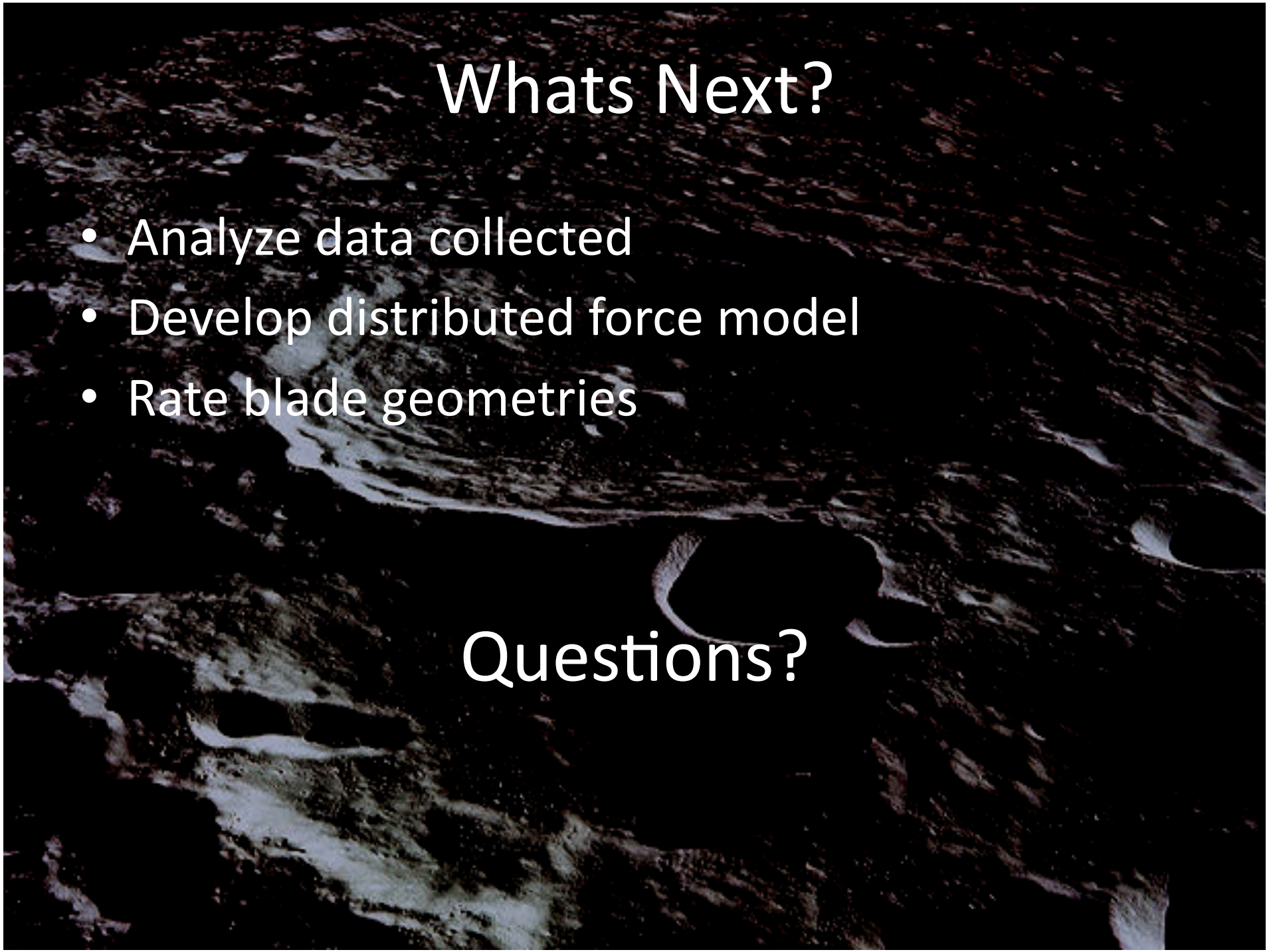
Total Load vs Cutting Depth for 12" Flat blade

Initial Data Analysis Results

Total load results follow a logical trend



Total load results for different blades and cutting depths



Whats Next?

- Analyze data collected
- Develop distributed force model
- Rate blade geometries

Questions?