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NORTH AMERICA PERFORATING SYMPOSIUM

GALVESTON, USA

High-Fidelity Finite Element Analysis of Deepwater Gun-Parting Failures

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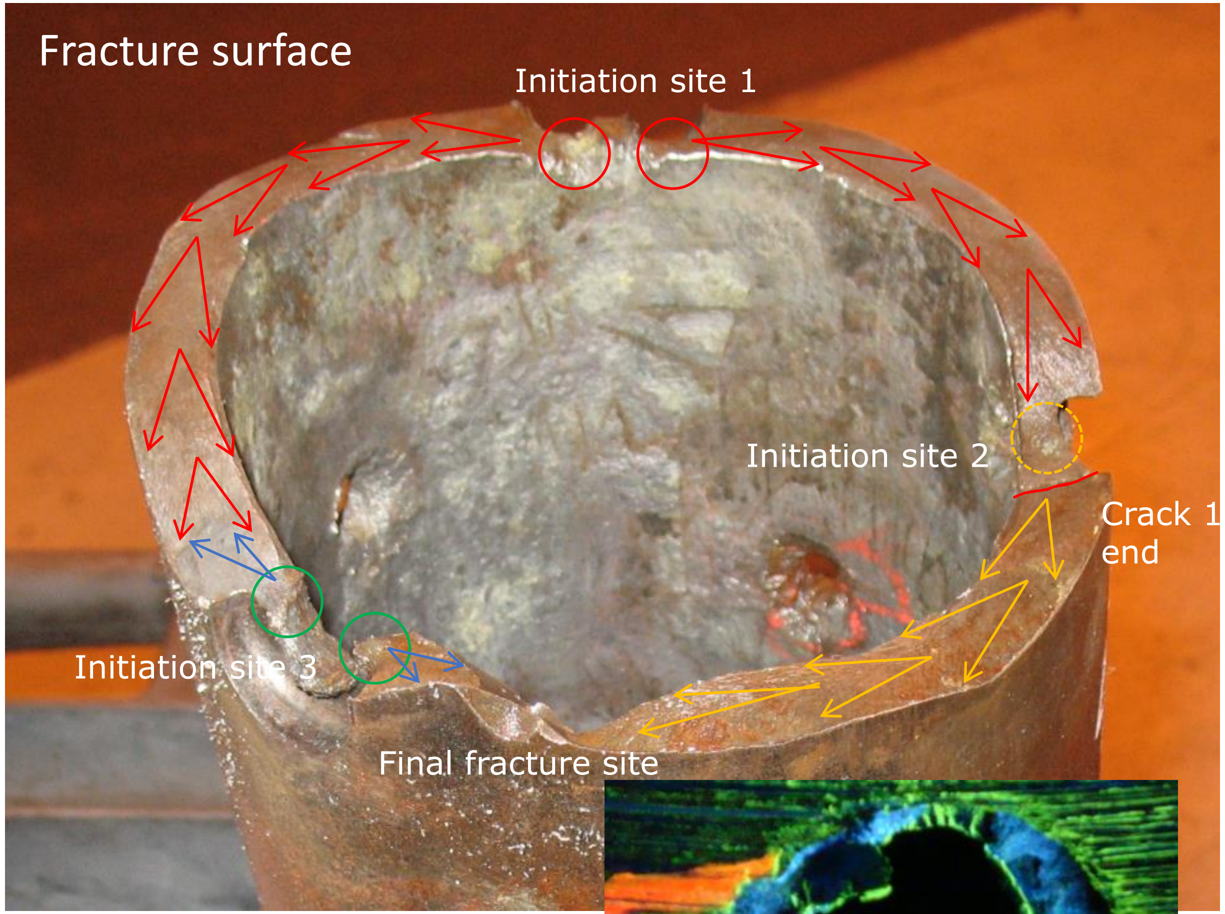
Dynamic Modeling and Failure Prediction

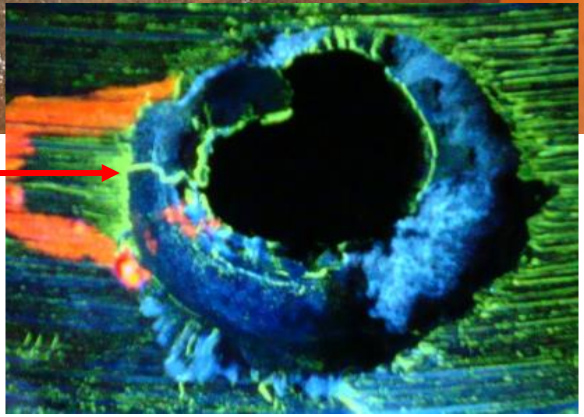
- 3-D finite element simulations are used to predicting the dynamic response of the gun string and wellbore fluids
- The models can identify a range of potential failure modes as well as perforating performance
- High fidelity models are used to understand the local stresses that result from detonation
- Global string models are used to predict the greater response of the tools in the string
- Controlled, instrumented experiments have been used to build up confidence in model physics, with growing complexity
- Field trials with integrated sensor subs provide calibration and validation data

Gun-Parting Failures

- The primary motivation for dynamic models has been a desire to mitigate the risk for gun string failures
  - Gun parting failure in particular
- While rare, these failures can be extremely costly have generally not been well-understood
- The clues provided from tools retrieved from the wellbore include ruptured steel surfaces and crack patterns
- Metallurgical examinations indicate rapid propagation of cracks, initiated at one or more exit holes

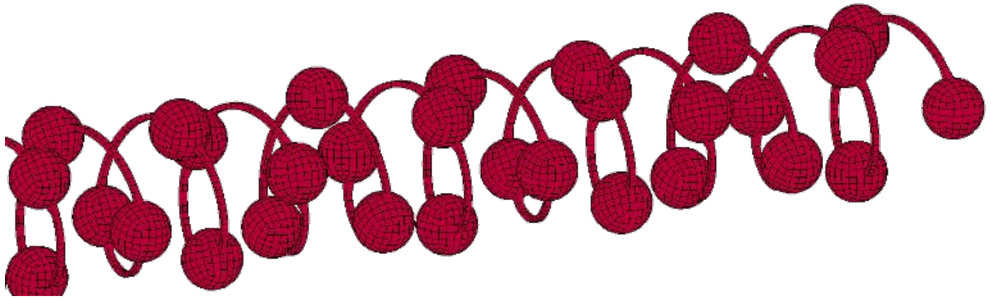


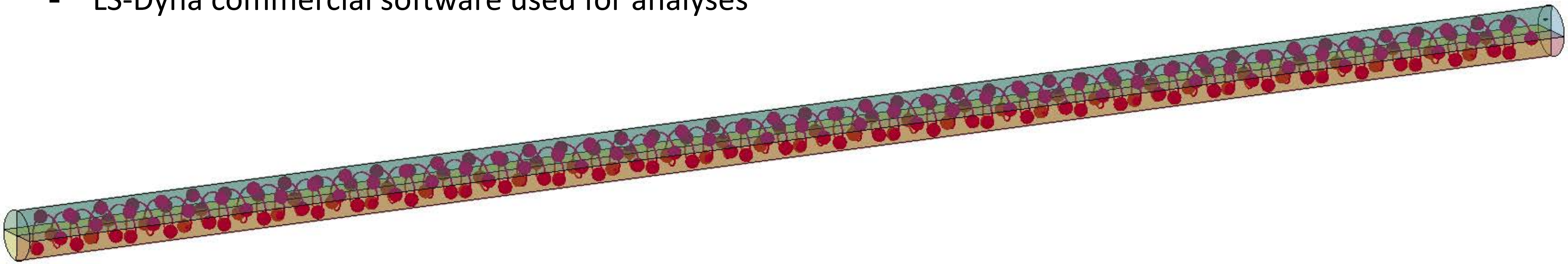
Example exit hole crack



High-Fidelity Single Gun Model Approach

- 3-D high-fidelity models of a single scalloped gun (6.5 in - 14SPF, 16 ft., 47g HMX charges)
- Spiraled det cord
- Spherical charge approximations – jet is not modeled
- Exit hole opening timed with det cord, opening fluid communication to annulus
- ~500,000 fluid elements
- Timescale of interest—peak stresses occur in the first few milliseconds after detonation
- LS-Dyna commercial software used for analyses





High-Fidelity Internal Gun Pressure Predictions

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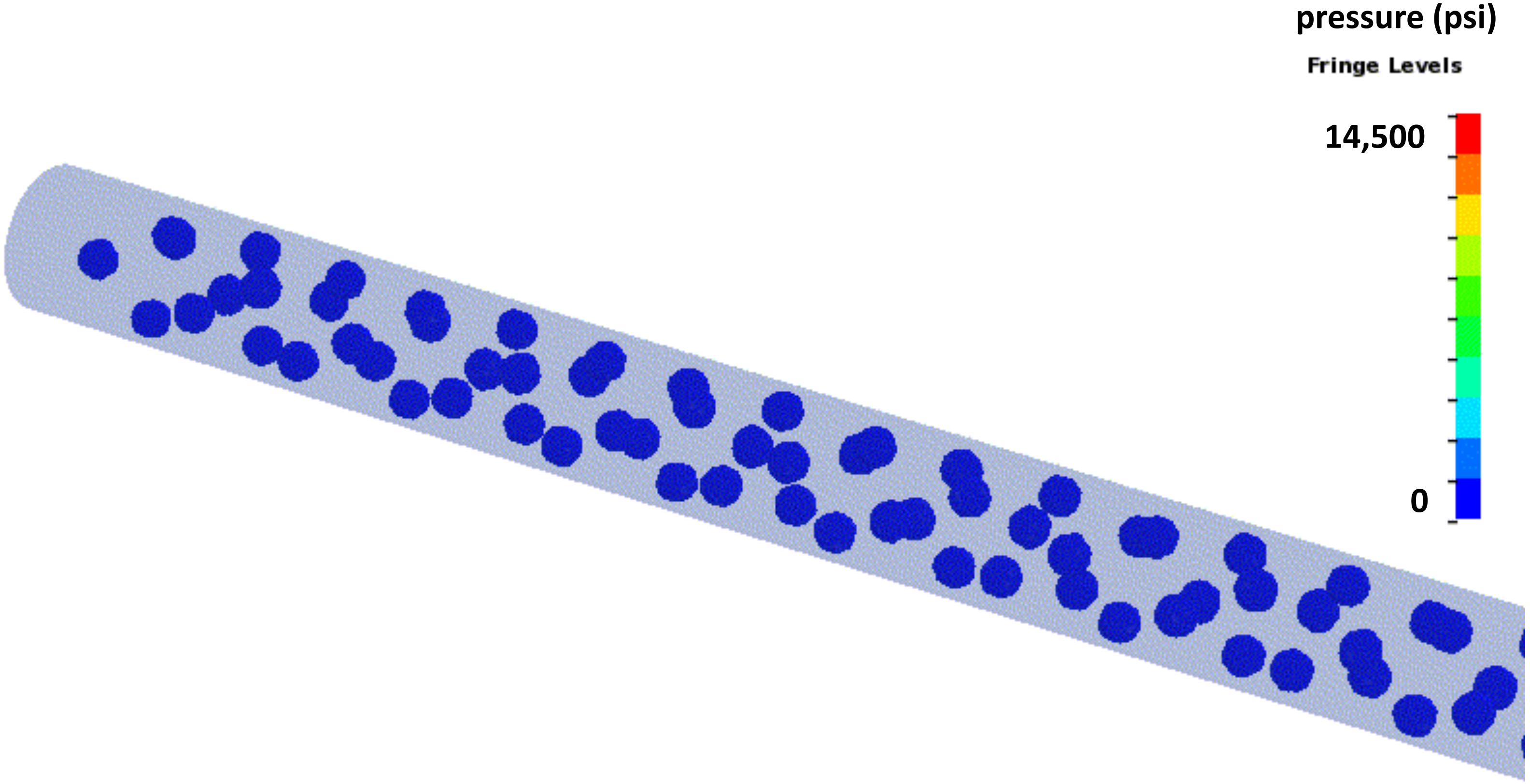
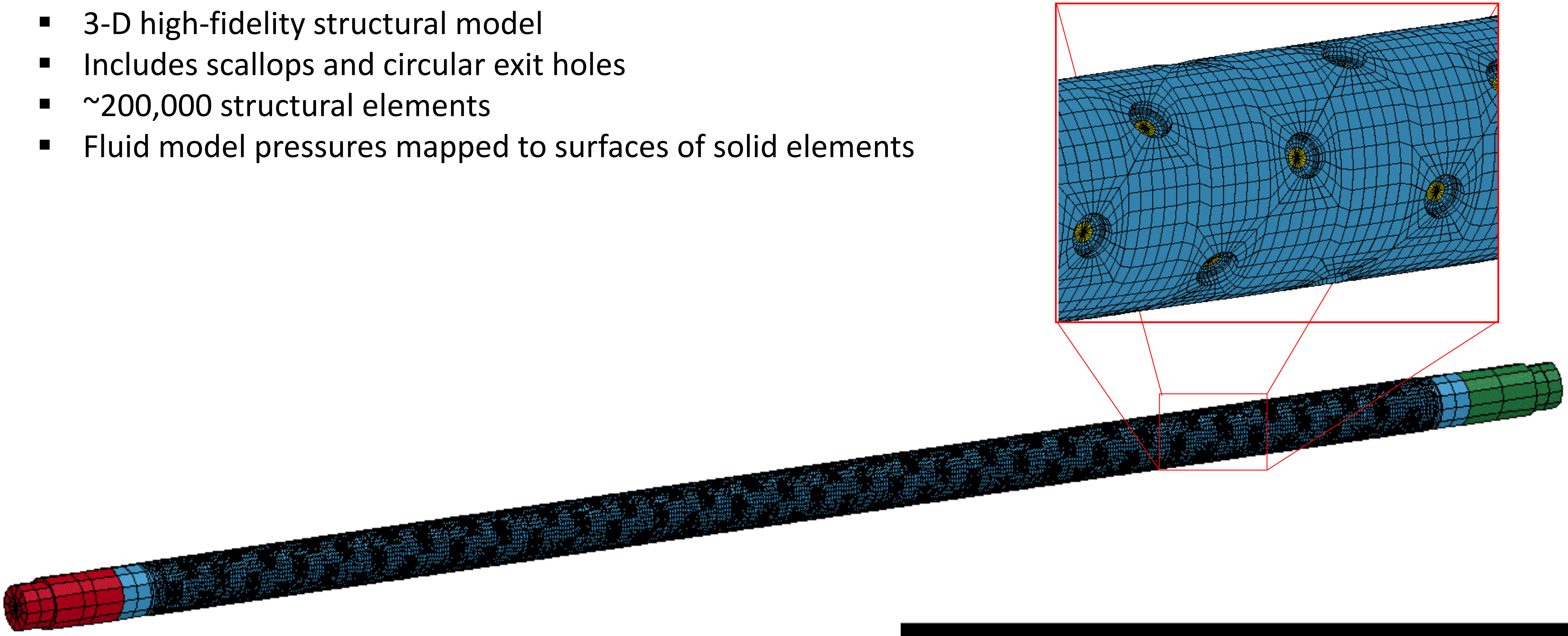
- Pressure predictions are shown below for the gun interior
- Pressures load the interior radial walls of the gun as well as the lateral surfaces of the end connectors



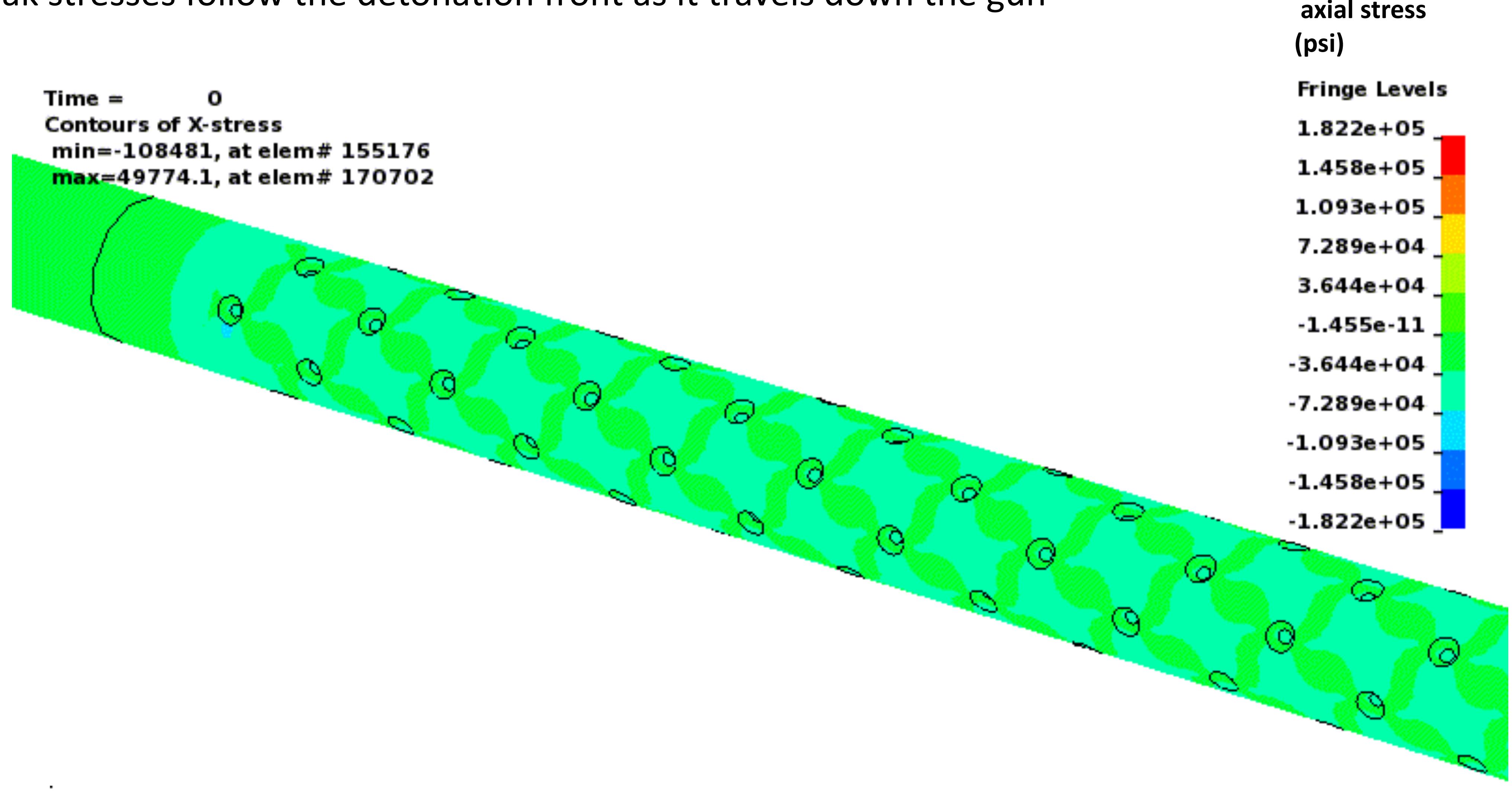
High-Fidelity Solid Model

- 3-D high-fidelity structural model
- Includes scallops and circular exit holes
- ~200,000 structural elements
- Fluid model pressures mapped to surfaces of solid elements



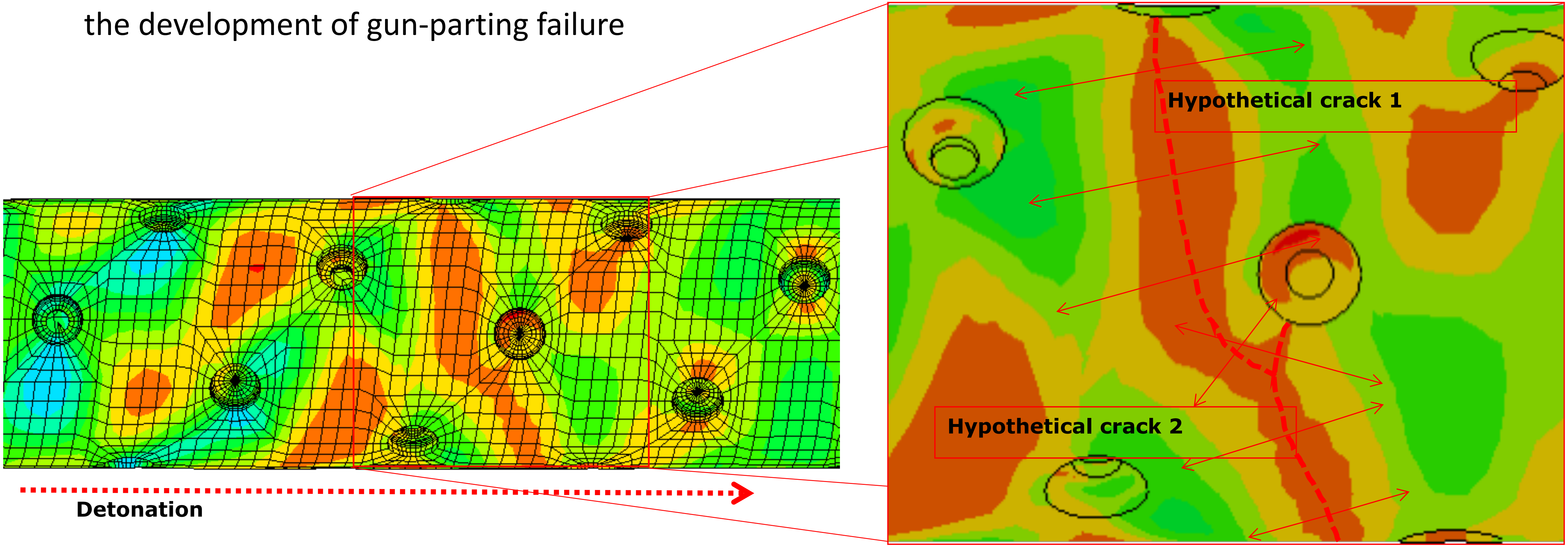
High Fidelity Gun Carrier Stress Predictions

- Axial stresses are shown in the animation below
- Peak stresses follow the detonation front as it travels down the gun



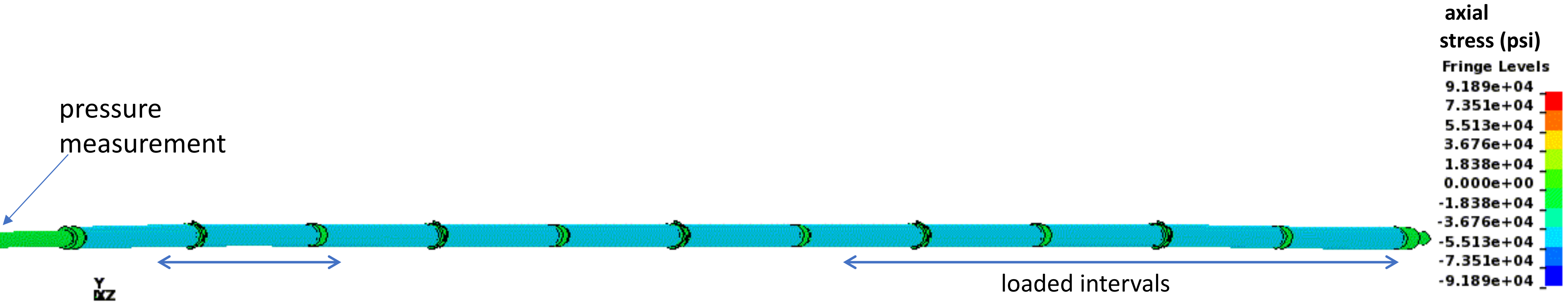
High Fidelity Gun Carrier Stress Predictions

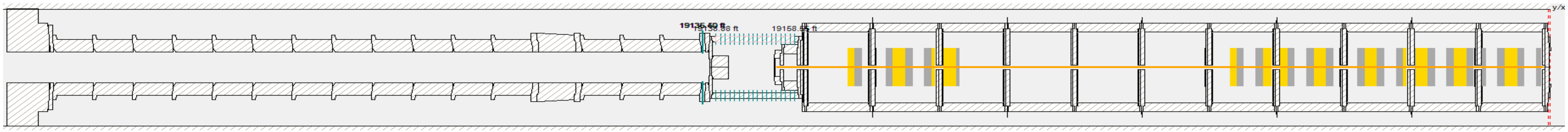
- Detail at right illustrates the peak tensile stresses that can cause cracks to grow
- Maximum stress bands indicate pathways for the development of gun-parting failure



Extending to Full String Models

- In order to be computationally efficient, simplifications are required for modeling a full downhole string
- The model has lower fidelity but is sufficient to capture the required details of the fluids and structures
- The string is initialized for hydrostatic pressure and gravity, and includes casing contact
- Guns are initially in compression due to hydrostatic pressure
- Loaded guns lengthen as the differential pressure reverses and equilibrates





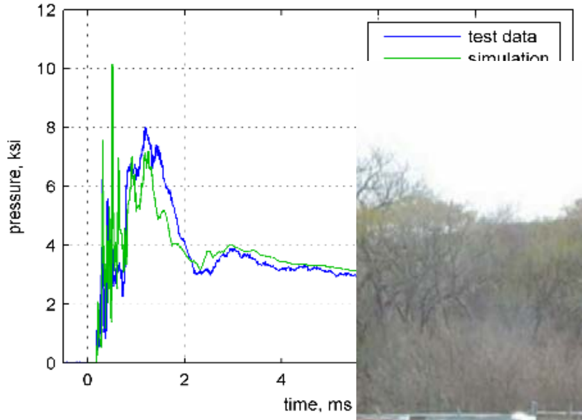
Failure Prediction and Risk Mitigation

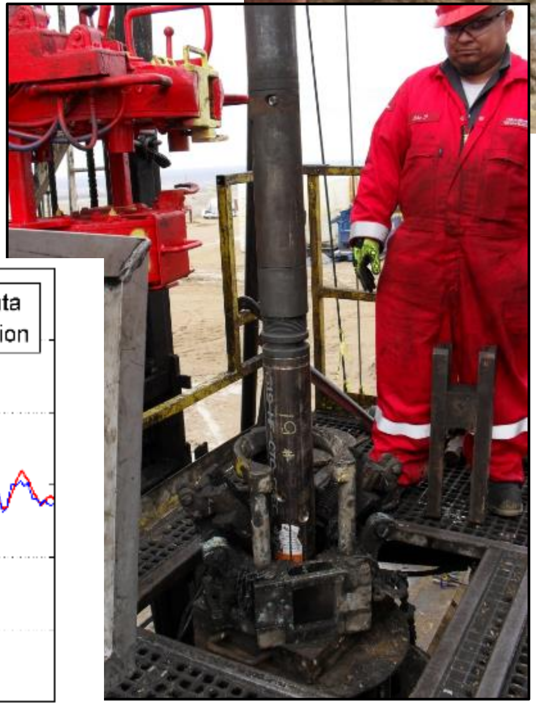
- Full 3-D dynamic models can predict many modes of failure, including:
  - Gun parting (tensile)
  - Spacer gun collapse
  - Partially-loaded gun burst
  - Tubing buckling and yielding
  - Packer damage and slippage
- Differential pressures across the gun/tubing wall indicates burst and collapse
- Axial stresses provide indication of tensile loading and risk for gun parting
- von Mises stresses and plastic strains provide indication of material rupture or collapse
- Animations provide a visualization of the failure processes – such as the gun burst example below

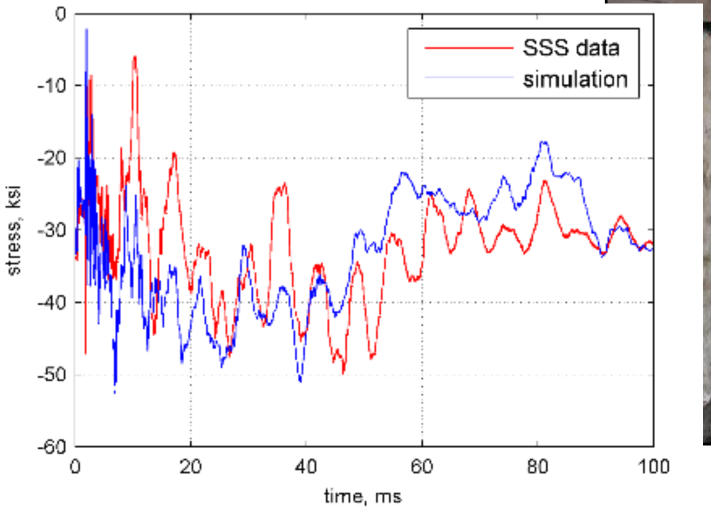
Hoop stress (psi)

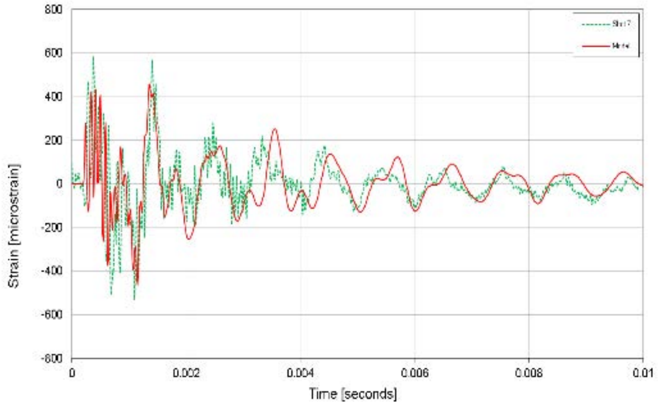
Model Calibration

- Confidence in models must be developed with calibration and validation
- Test complexity is built up from small-scale controlled experiments to field trials
- Proper instrumentation must be located in close proximity in order to observe pressures and loads, etc.
- This includes gun internal pressure measurements and dynamic pressure and loads measured within/between loaded intervals









Comparisons of Model and Data

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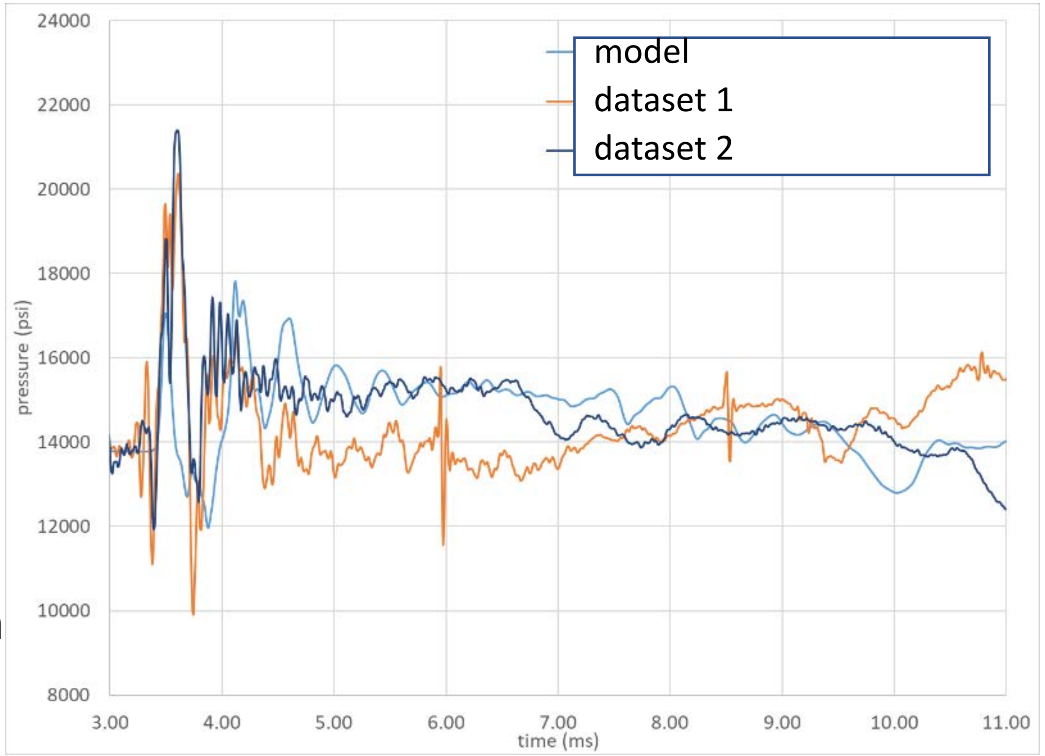
- The data at right compares data from 2 different measurements, each taken 2.5 ft above the top shot of a loaded interval of ultra low debris guns
  - Hydrostatic pressures were shifted to facilitate this comparison
  - Timescale was shifted to align the initial peak with model timing
- These datasets are compared against a full-string model (blue) over a short timescale
- Models capture the pressure response near the perforation very well with some variation evident between the two intervals—indicating possible differences in the perforation tunnel geometry or other local formation factors in the two locations



Summary and Conclusions

- 3-D high-fidelity models have been used to create a foundation for understanding the behavior of perforating guns
- The models have been extended to full-string simulations with some trade-offs in fidelity to gain efficiency
- Critical to calibrate and validate with good data
- Local effects are consistent— and provide a means of evaluating and comparing gun systems
- Predictive modeling provides value in that every job brings something new that can affect the dynamic response
- Continued software development and calibration is a necessity as model complexity builds and new gun systems are fielded

Acknowledgements

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