APPS 2018
ASIA PACIFIC PERFORATING SYMPOSIUM

Validation and Application of a Next-Generation Event Simulator for Perforated Completions.

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INTERNATIONAL PERFORATING FORUM

BAKER HUGHES
a GE company

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Presentation Overview

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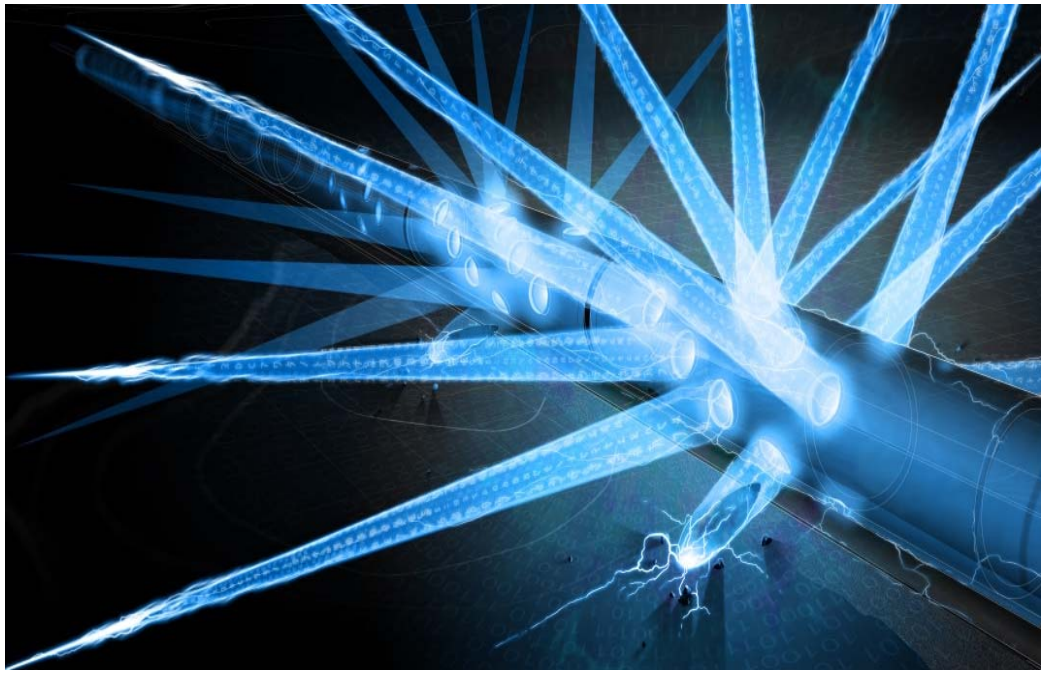
- Validation and Benchmarking
- Job Design and Execution: Examples
- Conclusions
- Digital Perforating Workflow



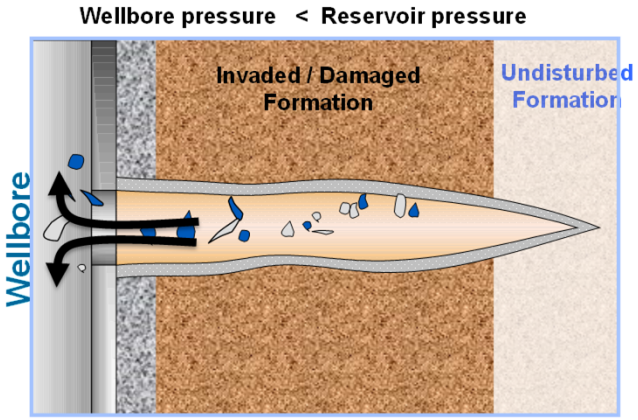
Introduction

- Cased hole well completions are widely used for onshore and offshore wells.
- Casing, cement and formation must be perforated to create the critical link between production tubing and hydrocarbon reserves.
- Modern perforating operations are typically carried out using explosive shaped charges that create high-velocity jets to generate perforation tunnels.
- Perforating job design considerations
    - Perforation tunnel clean-up (Productive perforations)
    - Risk mitigation for gunshock damage (Safe Operations)

Introduction

Perforating Job-Design: Tunnel Cleanup

- Hydrodynamic process that ensues for tens of seconds after the tunnels are generated.
- Customizing the post-detonation hydrodynamics to generate a transient pressure underbalance that flushes debris and crushed-rock damage layers



Perforating Job-Design: Gun Shock Damage

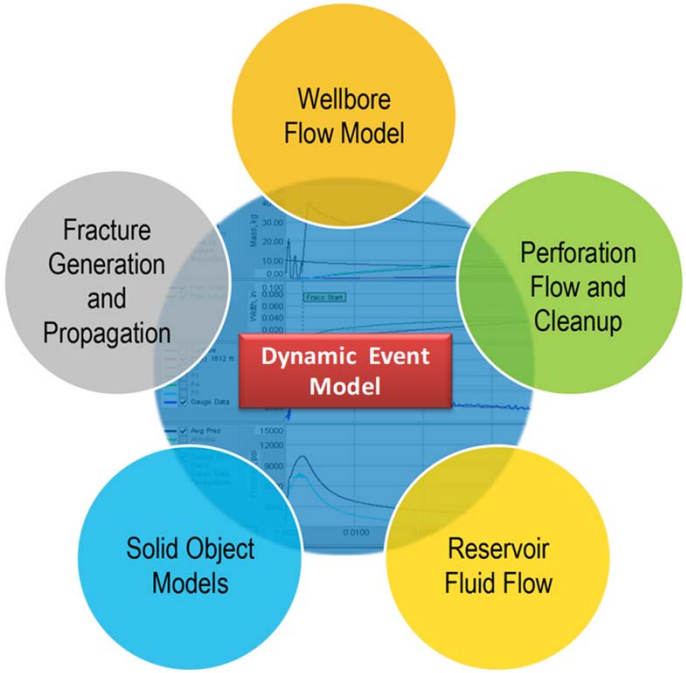
- Perforating events drive very large impulse forces on the downhole components, resulting in permanent damage to production tubing, isolation packers, and electronic monitoring equipment, as well as HSE risk.
- Mitigating the risk of gunshock damage is critical to ensuring a successful and safe perforating operation.

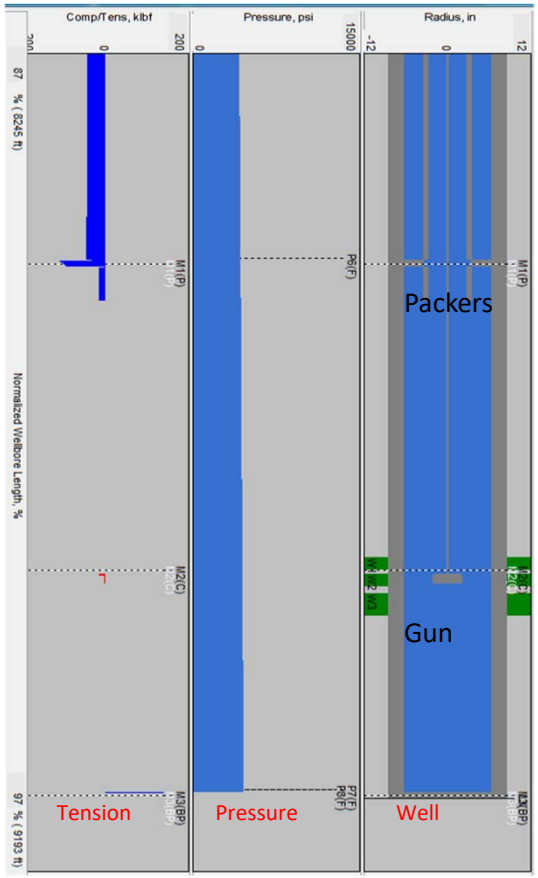
"A physics-based, robust dynamic modeling software is critical to dynamic flow modeling and risk mitigation for Optimized Perforation Design"

Introduction: Legacy Modeling Platform

- Scientific platform capable of simulating short-time (0.5-tens of seconds) dynamic events, widely used over the last 20+ years.

- Applications include:
  - Dynamics of perforating events
  - Propellants
  - Underbalance mechanisms
  - Tunnel Clean-up
  - Shock modeling
  - Risk Mitigation





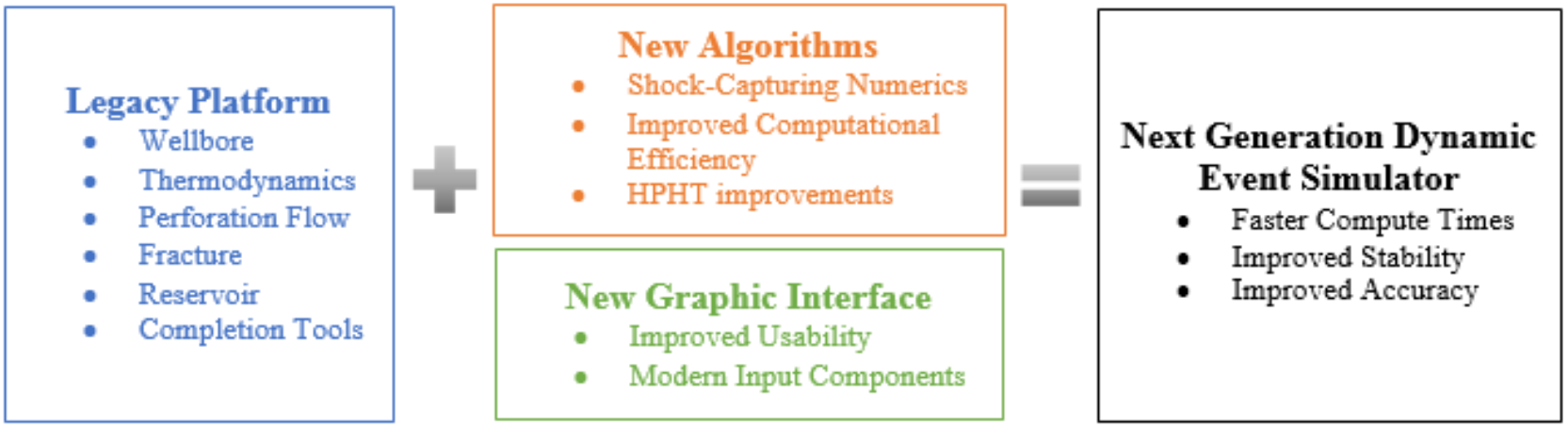
Next-Gen Dynamic Event Software

Integration of new physics and numerical algorithms

- New wellbore flow model developed and implemented
- Shock-capturing Riemann-based hydrodynamic solvers incorporated
- Improved fluid thermodynamic closure

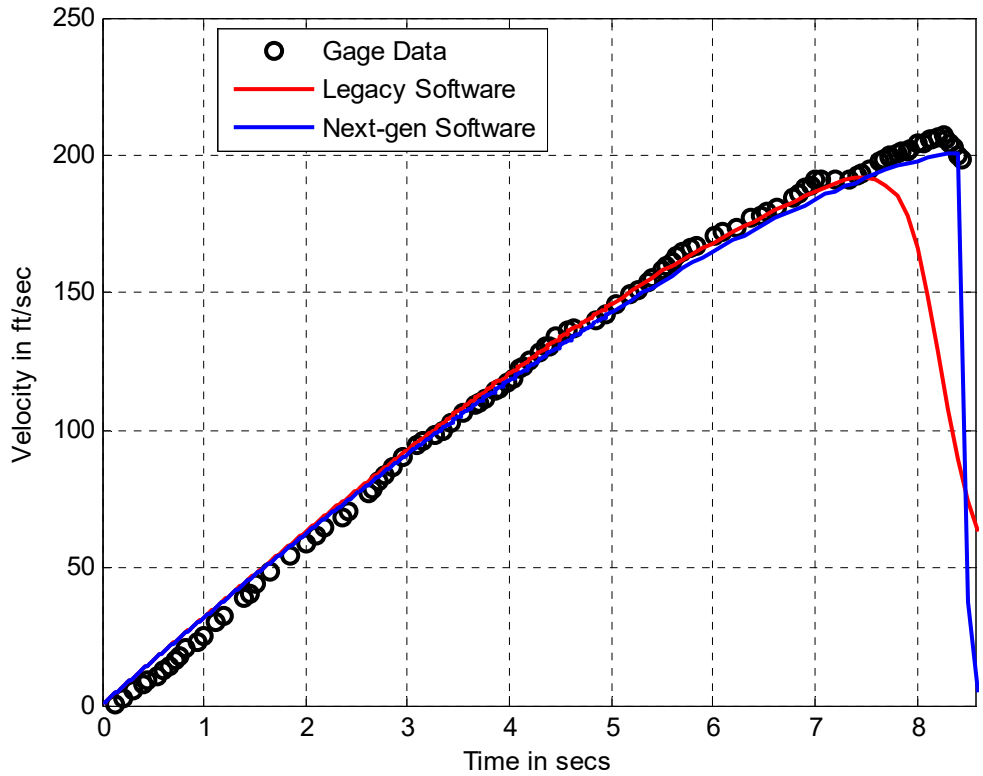
A new graphical user interface with a modern look and feel

- Updated input forms and software controls
- Simplified user input
- Automated report generation



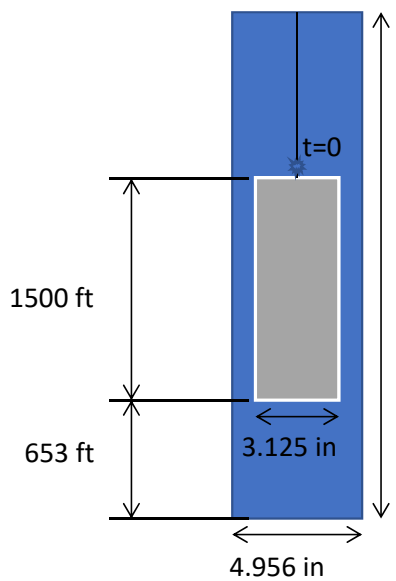
Benchmarking and Validation: Classical Drop Bar

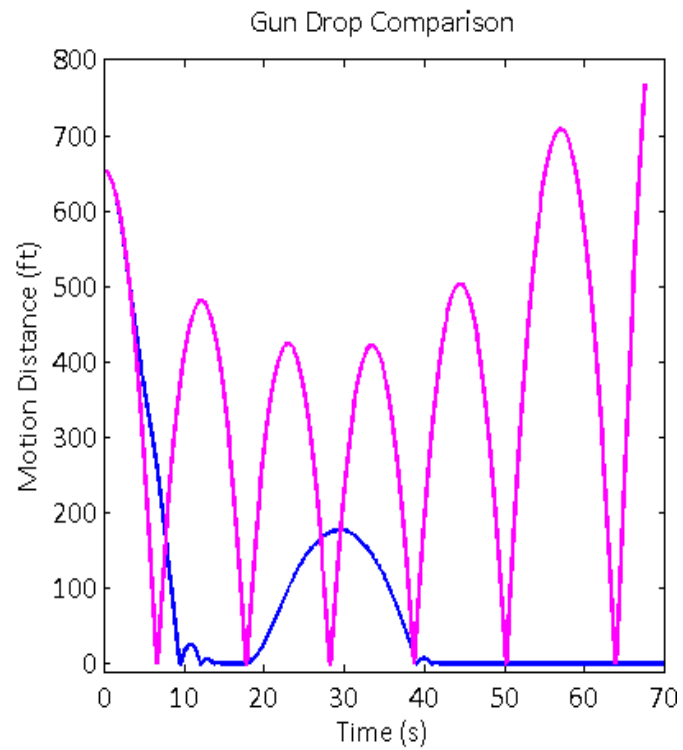
- Metal bar with transient gauges is dropped into a 1,500-ft vertical wellbore. The wellbore is filled with water between 1,000 to 1,500ft.
- Legacy software does not preserve the physical wave speeds and therefore transmits information at non-physical (i.e., numerically induced) speeds.
- Accurate prediction of impact time by next-gen software



Benchmarking and Validation: Transient Gun Drop

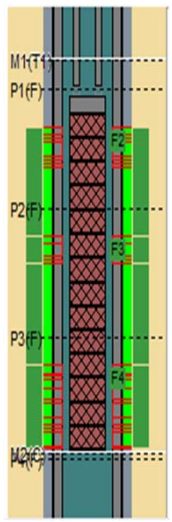
- Operator interested in a scenario where a perforating gun is dropped after detonation (at t = 0) to the bottom of the wellbore full of fluid, impacting a sub-surface valve.
- Dynamics of this example are dominated by fluid interactions with the solid structure of the gun.
- The next-generation simulator predicts a landing approximately 10 seconds after detonation, followed by few minor impact bounces.
- The legacy software experiences a numerical instability that drives a spurious oscillation of the gun bounce that grows indefinitely.

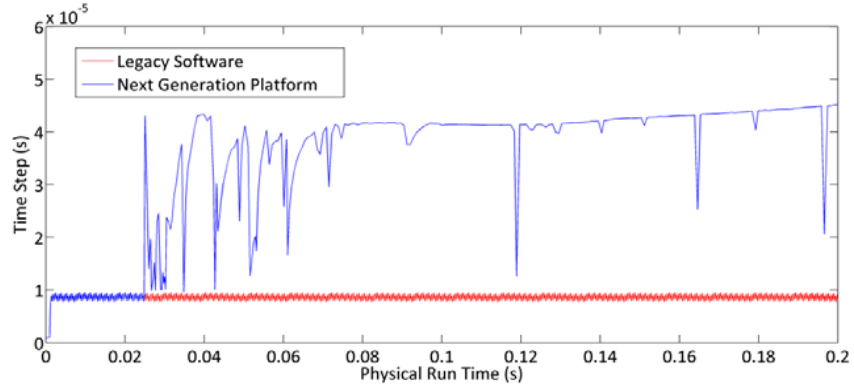


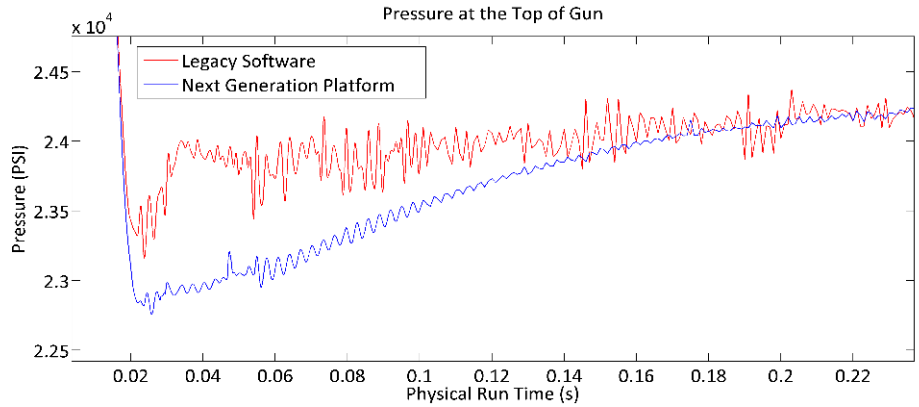


Benchmarking and Validation: Deepwater, HPHT

- Deepwater, HPHT well with a formation pressure as high as 28,000 psi. Tight rock formation, TCP conveyed.
- Computational efficiency: Next-Gen simulator uses a larger time step, more efficient computational time.
- Instantaneous, small-time scale dynamic behavior is mis-represented by the legacy software due to spurious non-physical oscillations.

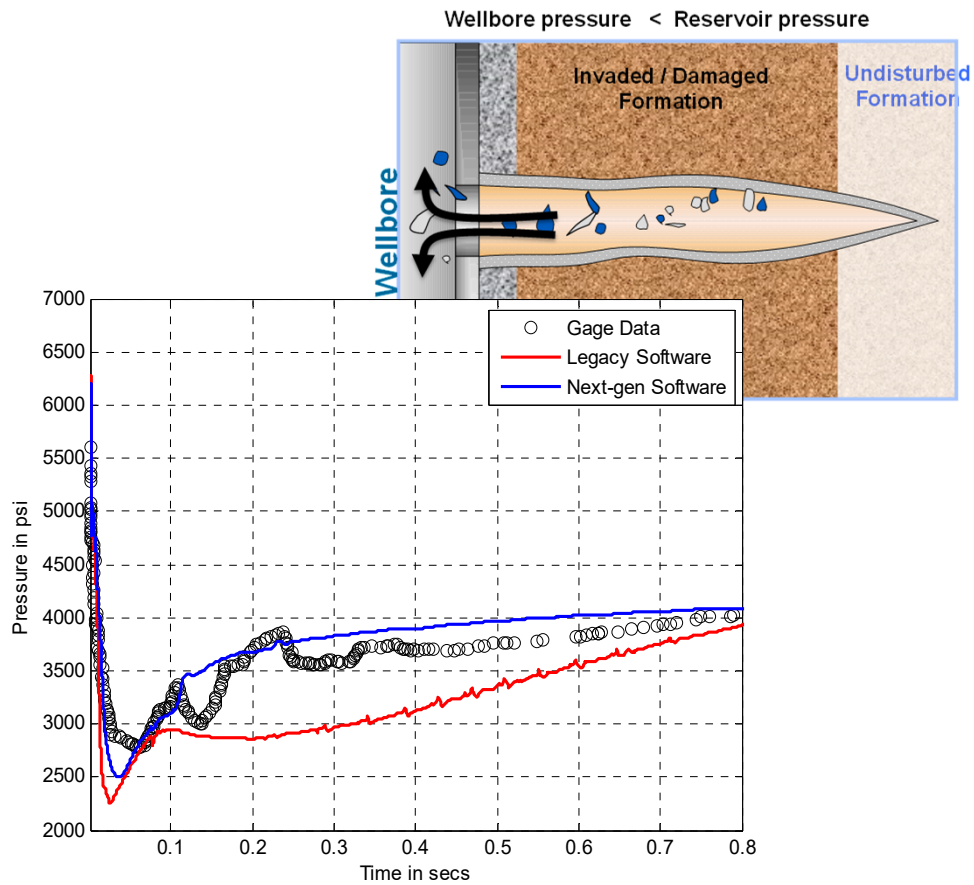






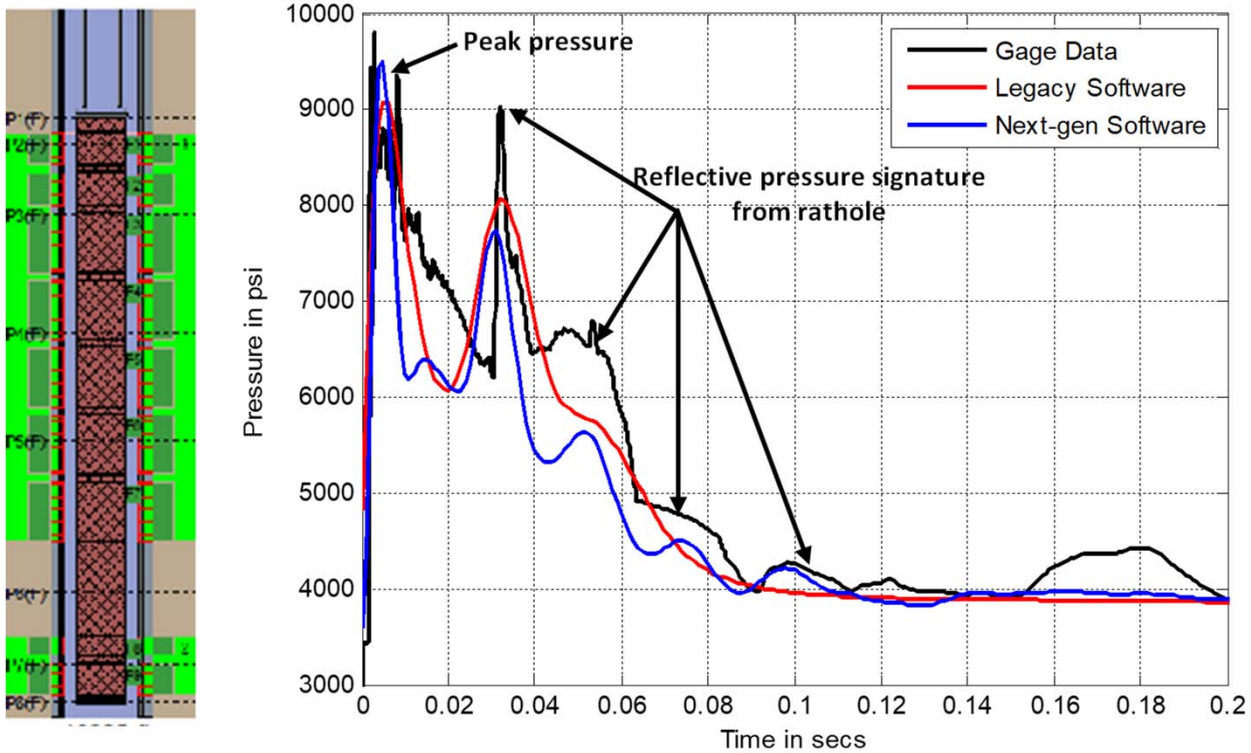
Benchmarking and Validation: Flow Optimization

- Middle East well completion, competent sandstone with a porosity of 20% and a permeability > 500mD.
- Deviated well with the perforating job run by wireline conveyance and additional blank chambers included in the bottom hole assembly to optimize cleanup.
- The underbalance magnitude from gauge data is ~2,700 psi compared to 2,500 psi (from next-gen software) and 2,200 psi (from legacy software).
- Subsequent recovery phase (critical to cleanup) indicates that the profile from the next-gen software is in excellent agreement with the gauge data.



Benchmarking and Validation: Gunshock

- Tubing-conveyed perforating job in a low-permeability carbonate formation.
- Better prediction of peak pressure (~9,500 psi) with next-gen software is observed in comparison to the legacy software.
- Reflective pressure signatures from the rathole are precisely captured with the next-generation software.



Job Design and Optimization: Example

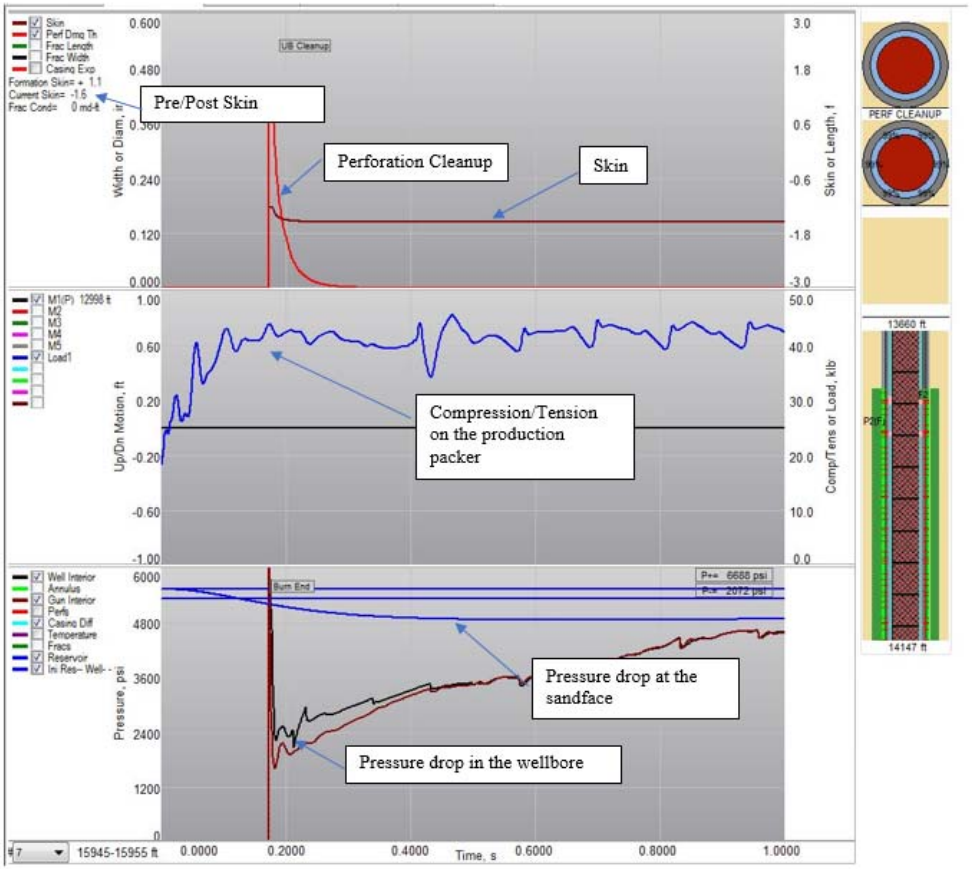
- North Sea Application
- Client's objective was to evaluate a matrix of gun systems and make a selection based on performance, clean-up, risk evaluation etc.
- Amount of underbalance, clean-up, skin reduction and any shock loading on completion equipment was investigated.

Cleanup	Zone 1 (6.6 mD)	Zone 2 (15 mD)	Zone 3 (26.6 mD)	Zone 4 (6.6 mD)	Zone 5 (.10 mD)	Zone 6 (20 mD)	Zone 7 (20 mD)
2⅞-in. 6spf 60° Phased	0%	15%	12%	1%	2%	9%	53%
4½-in. 5spf 60° Phased	0%	11%	12%	54%	57%	63%	99%

	Zone 1 (6.6 mD)	Zone 2 (15 mD)	Zone 3 (26.6 mD)	Zone 4 (6.6 mD)	Zone 5 (.10 mD)	Zone 6 (20 mD)	Zone 7 (20 mD)
2⅞-in. 6 spf 60° Phased DUB only	0%	15%	12%	1%	2%	9%	53%
2⅞-in. 6 spf 60° Phased 1,300 psi static UB	13%	25%	23%	5%	3%	21%	59%

Job Design and Optimization: Example

- Physical insight provided by the software on dynamic events
- Pre-job planning
- Post-job analysis



Conclusions

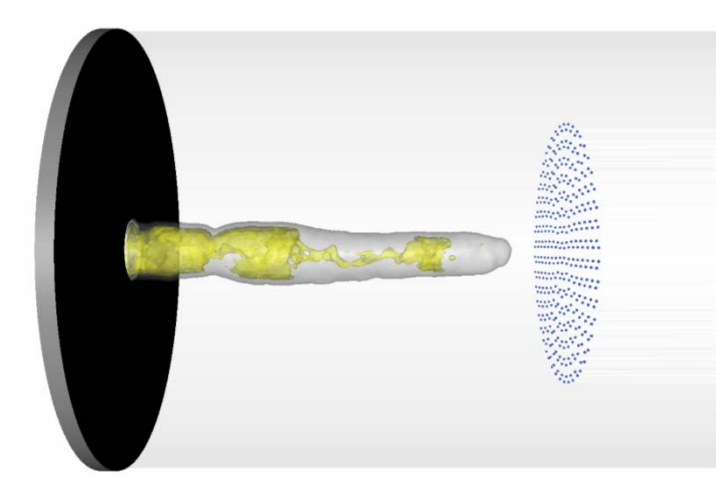
- Results clearly demonstrate that the next-generation dynamic event simulator represents a more accurate, numerically stable, and computationally efficient software platform than the legacy code.

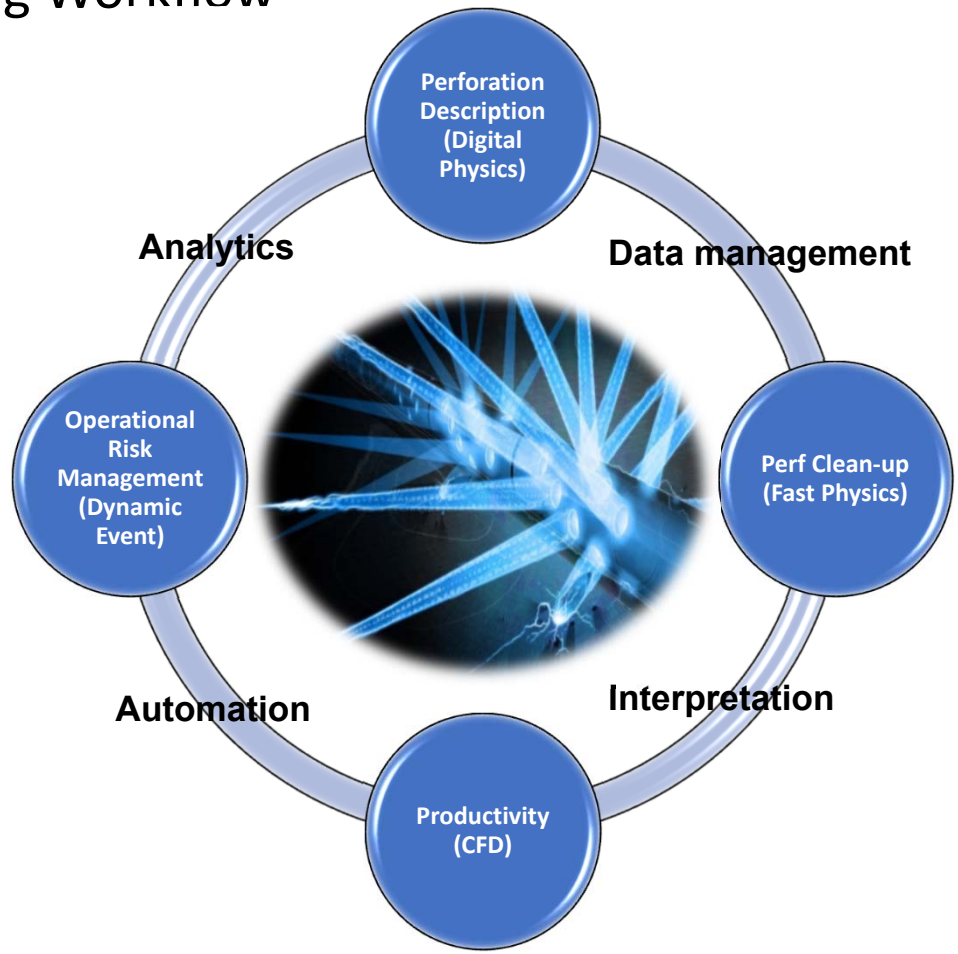
- The new advanced computational tool presented here is a critical component in the ongoing development of a digital perforating workflow, which is based on technology-centric solutions for optimizing perforated completions.

- These solutions are centered on the following aspects that are critical to achieving operational efficiencies and delivering expected productivity:
  - Thorough assessment of the formation and the wellbore architecture
  - Understand and mitigate the risk associated with highly energetic, perforating events
  - Efficient communication between wellbore and reservoir
  - Integrate with completion design strategies (including hydraulic fracturing and stimulation)
  - Fully automated, integrated and scalable job design workflows

Digital Perforating Workflow

- Comprehensive data analysis
- Physics-based models
- Analytics tools
- Data management
- Automation





Acknowledgements / Thank You / Questions

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QUESTIONS?
THANK YOU!

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