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Novel Methods for Counteracting Dynamic Underbalance Perforating Scenarios

Presented by:
Shaun Geerts, Owen Oil Tools

AUTHORS: Shaun Geerts, Justin Coker, Jarrod Pearson - Owen Oil Tools

Perforating Challenges

Locked Into a Box

Customers desired completion design can limit perforating options:
- Reservoir properties
- Wellbore schematics
- Conveyance method
- Perforating orientation and shot densities

How do we overcome challenges when we seemingly have very little control over the variables.

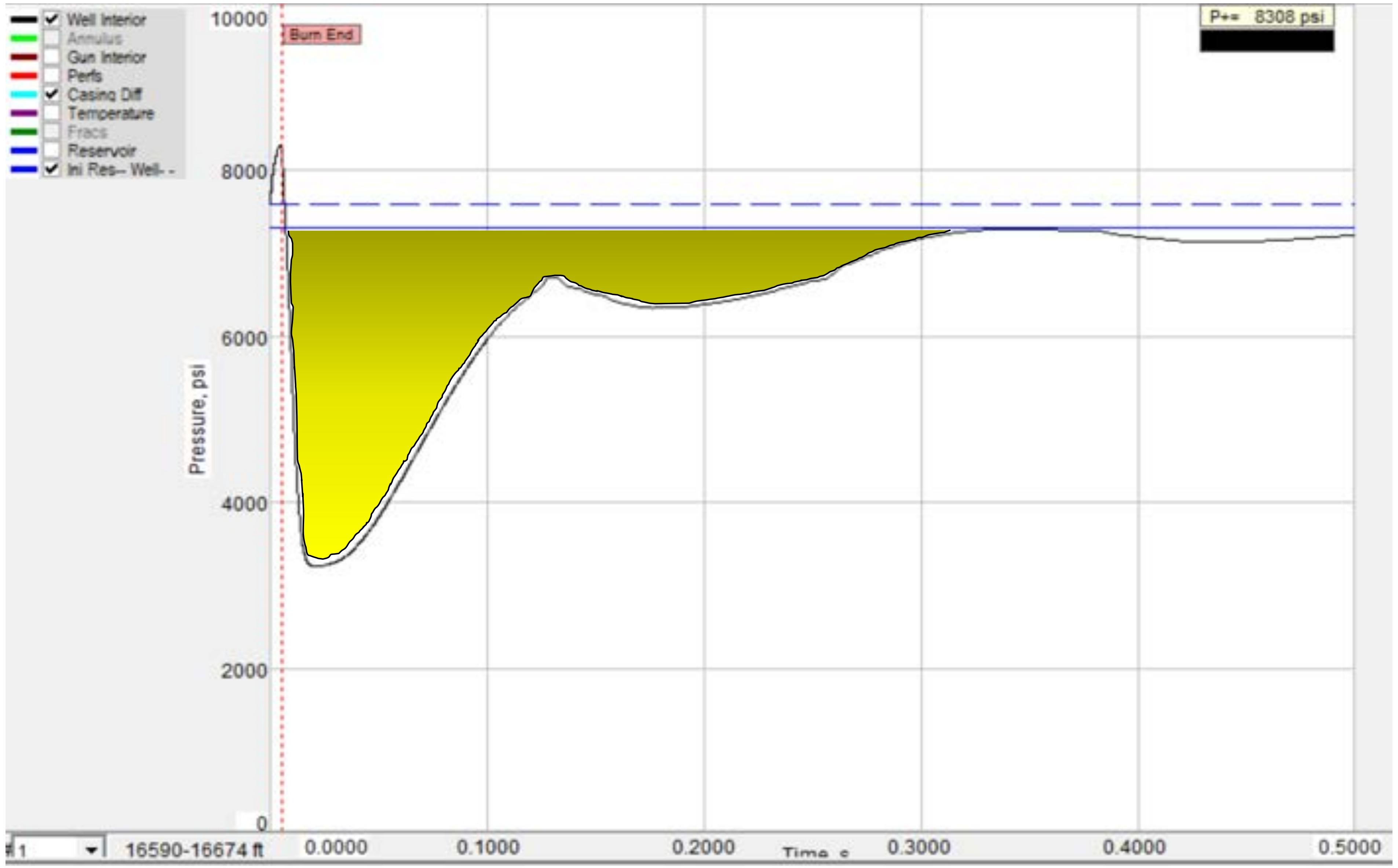
Dynamic Underbalance

Current Technologies

- Most perforating events create a dynamic underbalance (DUB) event naturally
- Main benefit to a DUB event is to achieve cleanup of the perforations

- Custom systems designed to increase the DUB effect
  - Reduced shot densities
  - Large blank spacers
  - Pressure activated ported subs
  - Propellants

- Solutions for mitigating DUB also exist
  - Overbalanced perforating
  - Gun designs to reduce available free volume

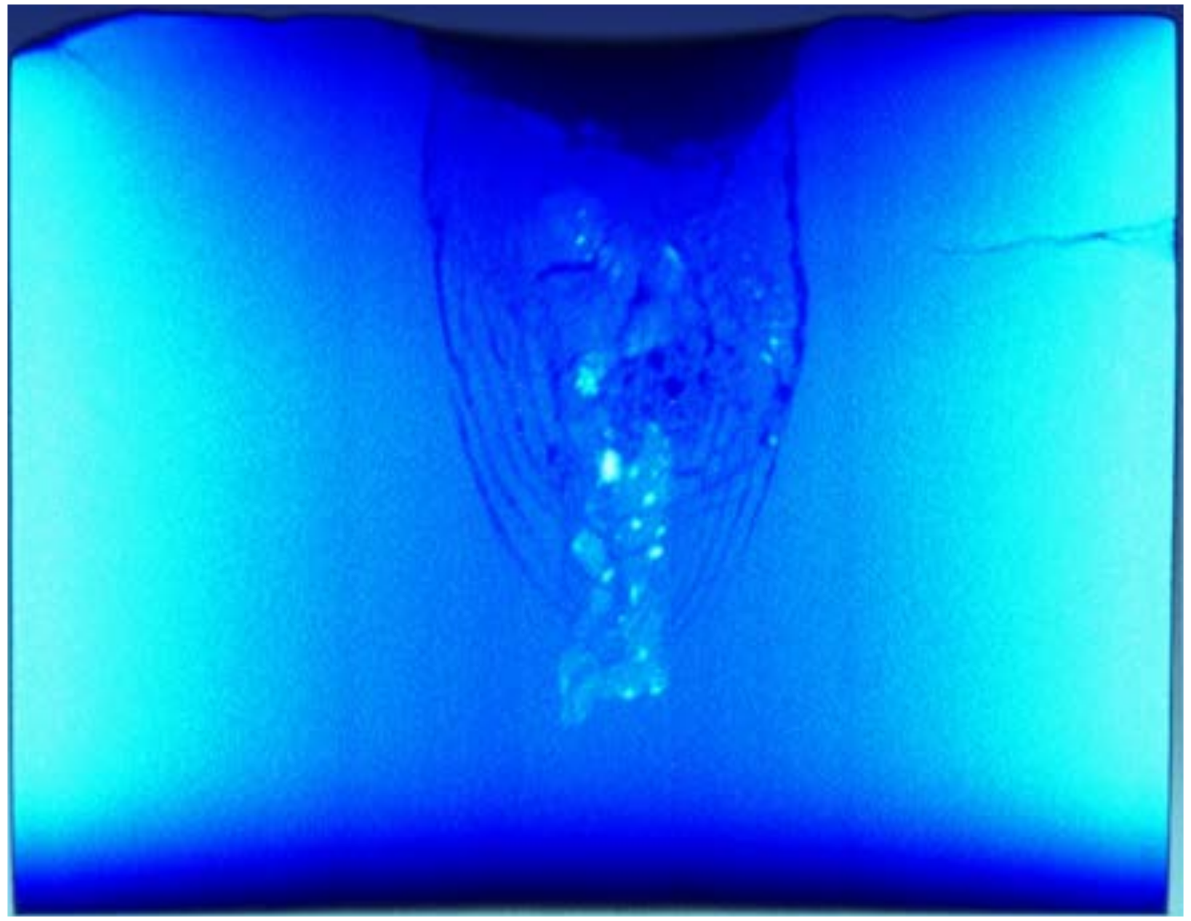


Dynamic Underbalance

Challenges

- While there are many benefits to DUB perforating, there are many instances where it creates more issues than it solves
  - Large diameter gun systems with low shot densities
  - TCP conveyance with long blank gun intervals introducing significant free volume
  - Weak or highly unconsolidated formations

- Negative consequences
  - High levels of initial sand production
    - Stuck tool strings
  - Collapsed perforation tunnels
  - Potential long term injection or production issues



Concept

Thinking Outside The Box

- Customers desired completion parameters can limit solutions

- Historically speaking, weak and unconsolidated rocks may not be good candidates for propellant enhanced perforating
  - Cause significant damage to reservoir
  - DUB event from propellant would be damaging and produce significant sand

- Could propellants be used to generate pressure while strategically aligning with the timing of the DUB event?

- Can we design a propellant system to overcome the potential negative consequences for the sole purpose of eliminating DUB?
  - Typical propellants are designed to create extreme overbalanced pressure situations
  - Designed to drive fracture extensions
  - Create perf breakdown, followed by a large DUB event to create good perforation cleanup

Computer Simulations

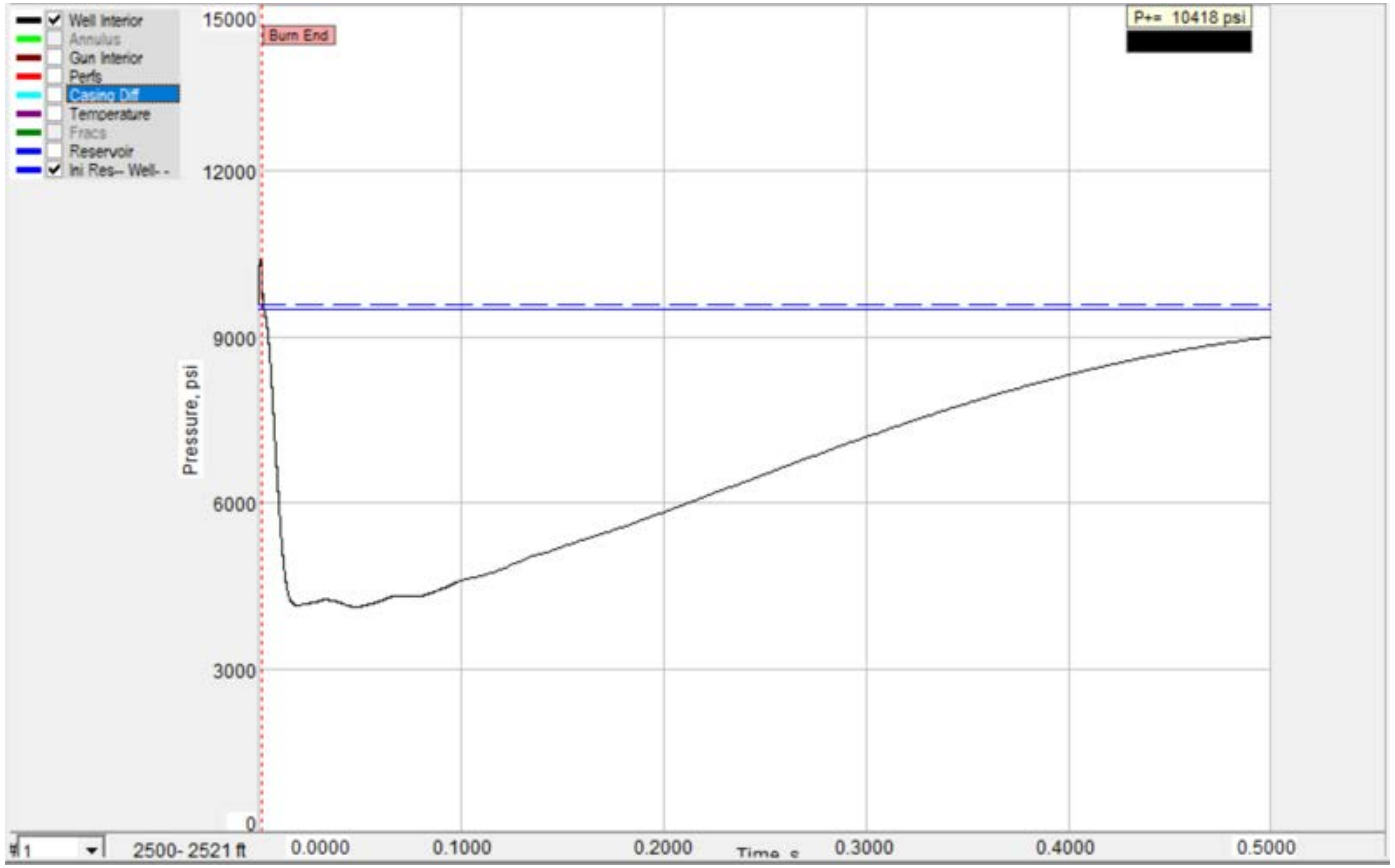
Model Parameters

- 7” perforating gun, 12spf 39 gram charge
- Single 21ft gun run
- PulsFrac software did not contain full propellant characterization parameters
    - Iterated and modified parameters through testing to validate against Section IV lab results
    - Evaluation was primarily focused on minimizing the DUB portion of the curve

Computer Simulations

Baseline

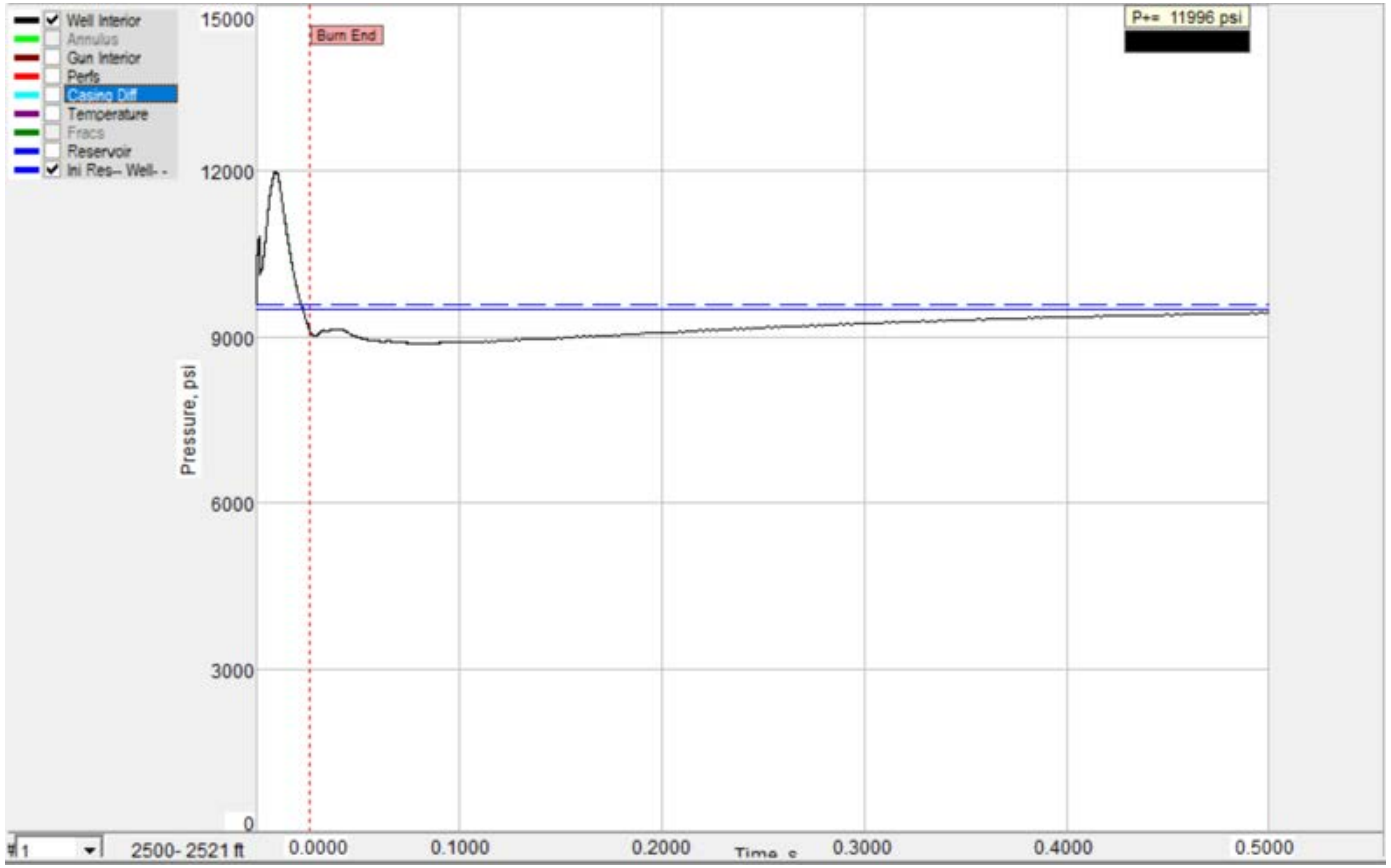
Initial Wellbore Pressure = 9,500 psi
Peak Pressure = 10,418 psi
Minimum Pressure = 4,120 psi
DUB = 5,380 psi



Computer Simulations

Propellant Model 1

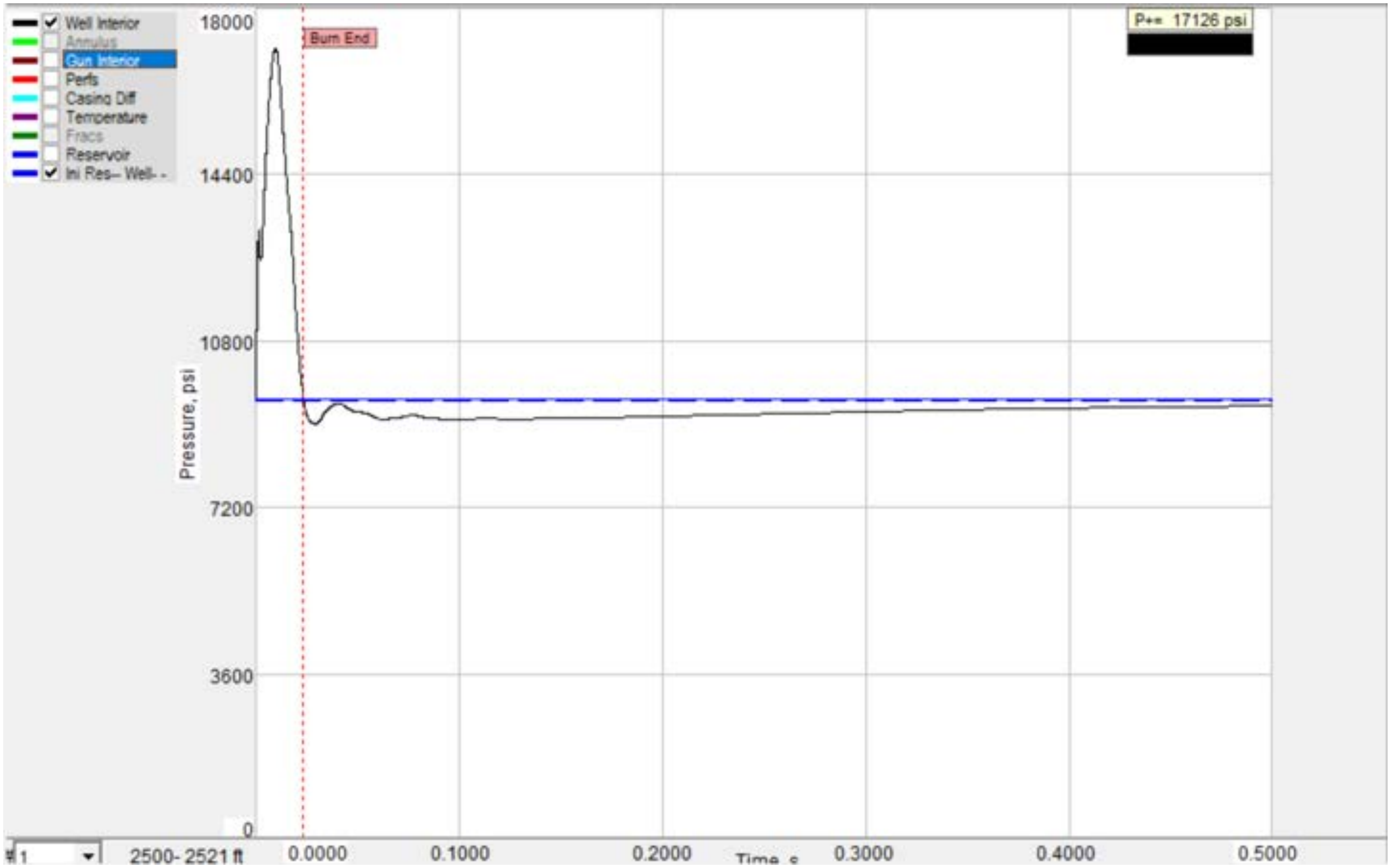
Initial Wellbore Pressure = 9,500 psi
Peak Pressure = 11,996
Minimum Pressure = 8,870 psi
DUB = 630 psi



Computer Simulations

Propellant Model 2

Initial Wellbore Pressure = 9,500 psi
Peak Pressure = 17,126 psi
Minimum Pressure = 9,011 psi
DUB = 489 psi



Lab Testing

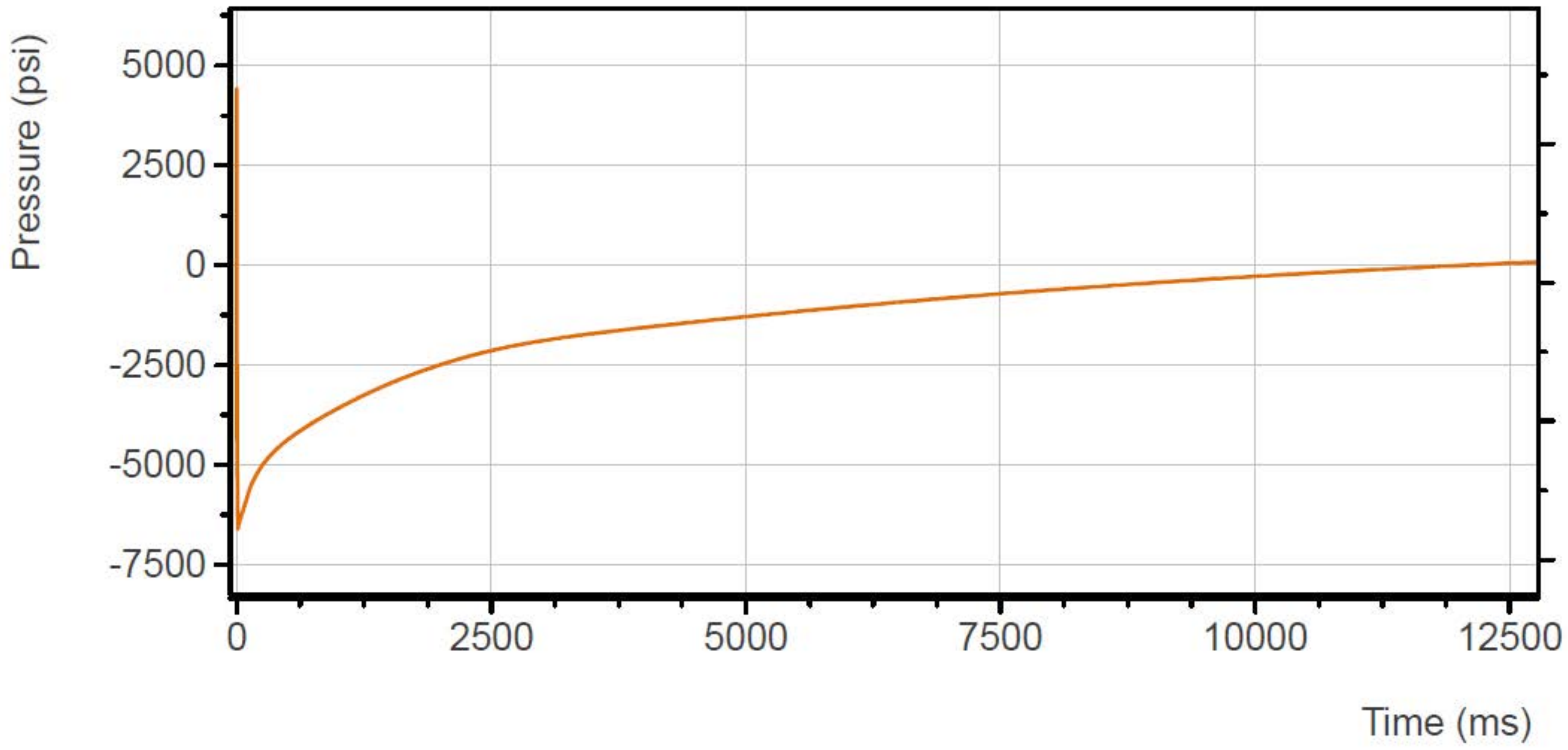
Section IV

- Design gun body hardware to accurately reflect system
- Primary focus was on the wellbore pressure dynamics
    - Conducted testing at a midrange well bore pressure
- Selected Castlegate sandstone for rock
    - Test conducted at a balanced condition to eliminate any underbalance or overbalance effects
    - Maintained 1500-2000psi net confining stress
        - Wanted to see if propellant damaged rock from pressure spikes
- No variable changes made between tests other than the propellant configurations

Lab Testing

Base Test

Peak Pressure – 13,867 psi
Minimum Pressure – 2915 psi
DUB ΔP – 6585 psi

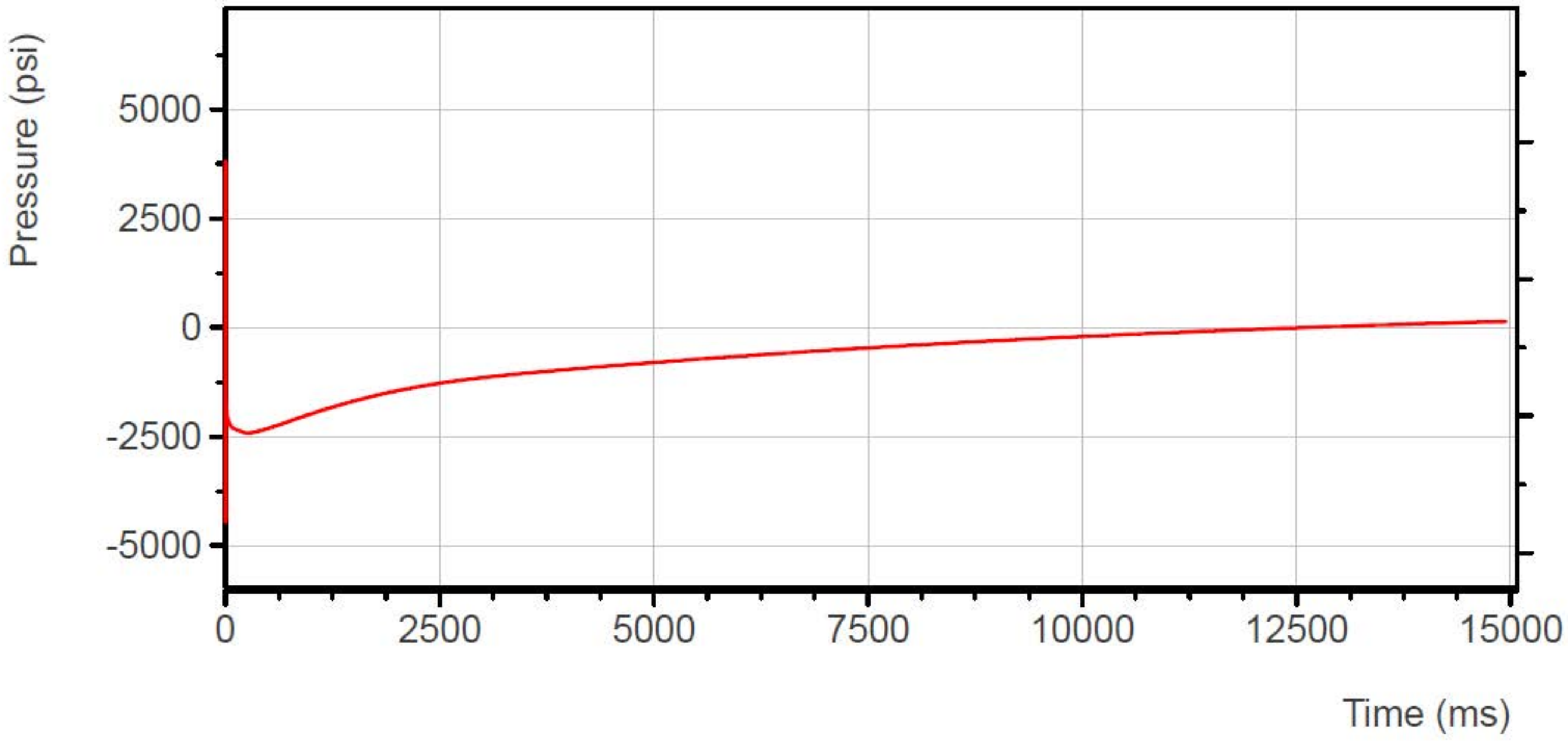


Lab Testing

Propellant Configuration 1

Peak Pressure – 13,223 psi
Minimum Pressure - 7093
DUB ΔP – 2407 psi

~73% reduction in DUB pressure drop from baseline charge only

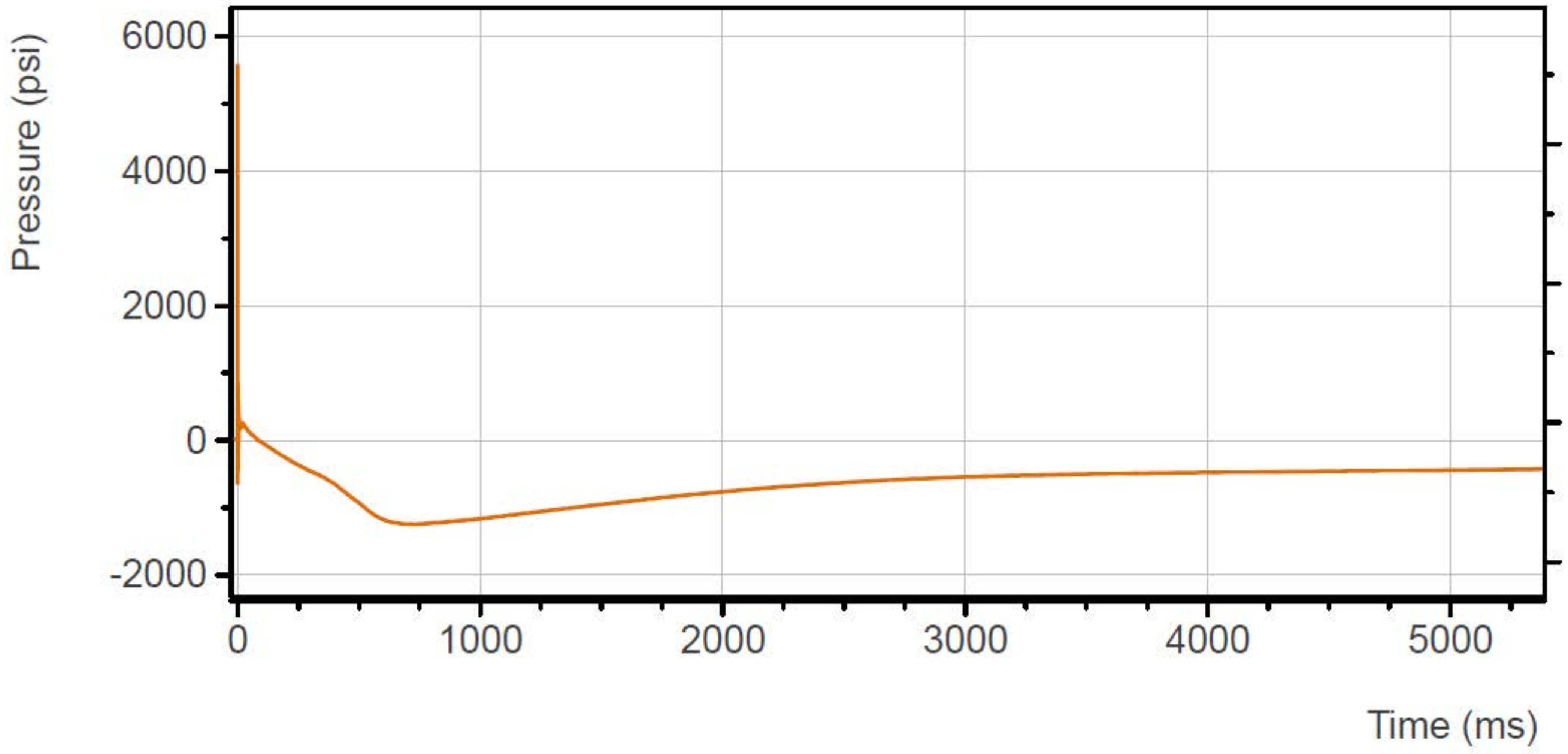


Lab Testing

Propellant Configuration 2

Peak Pressure – 15,003 psi
Minimum Pressure – 8262 psi
DUB ΔP – 1238 psi

~81% reduction in DUB pressure drop from baseline charge only



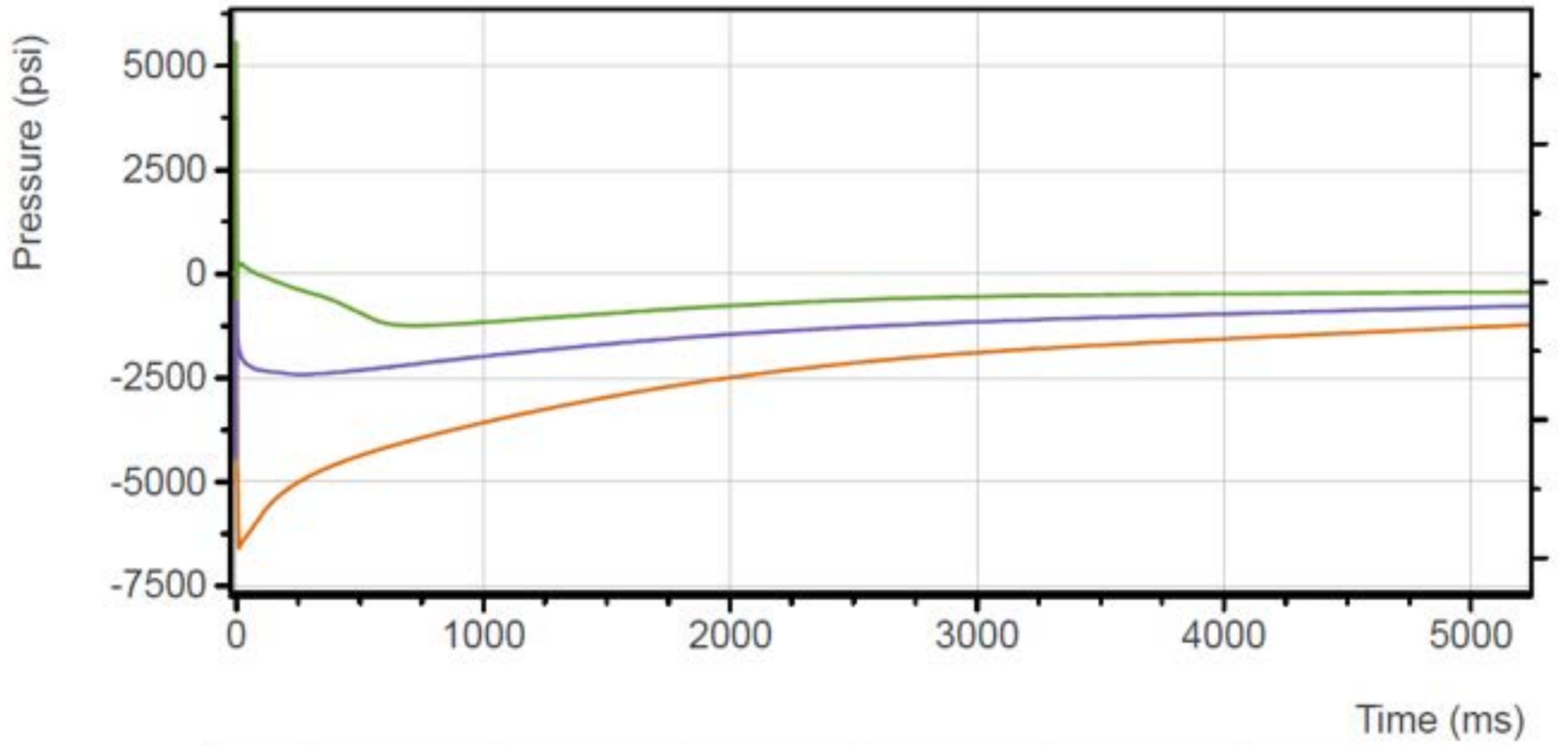
Summary

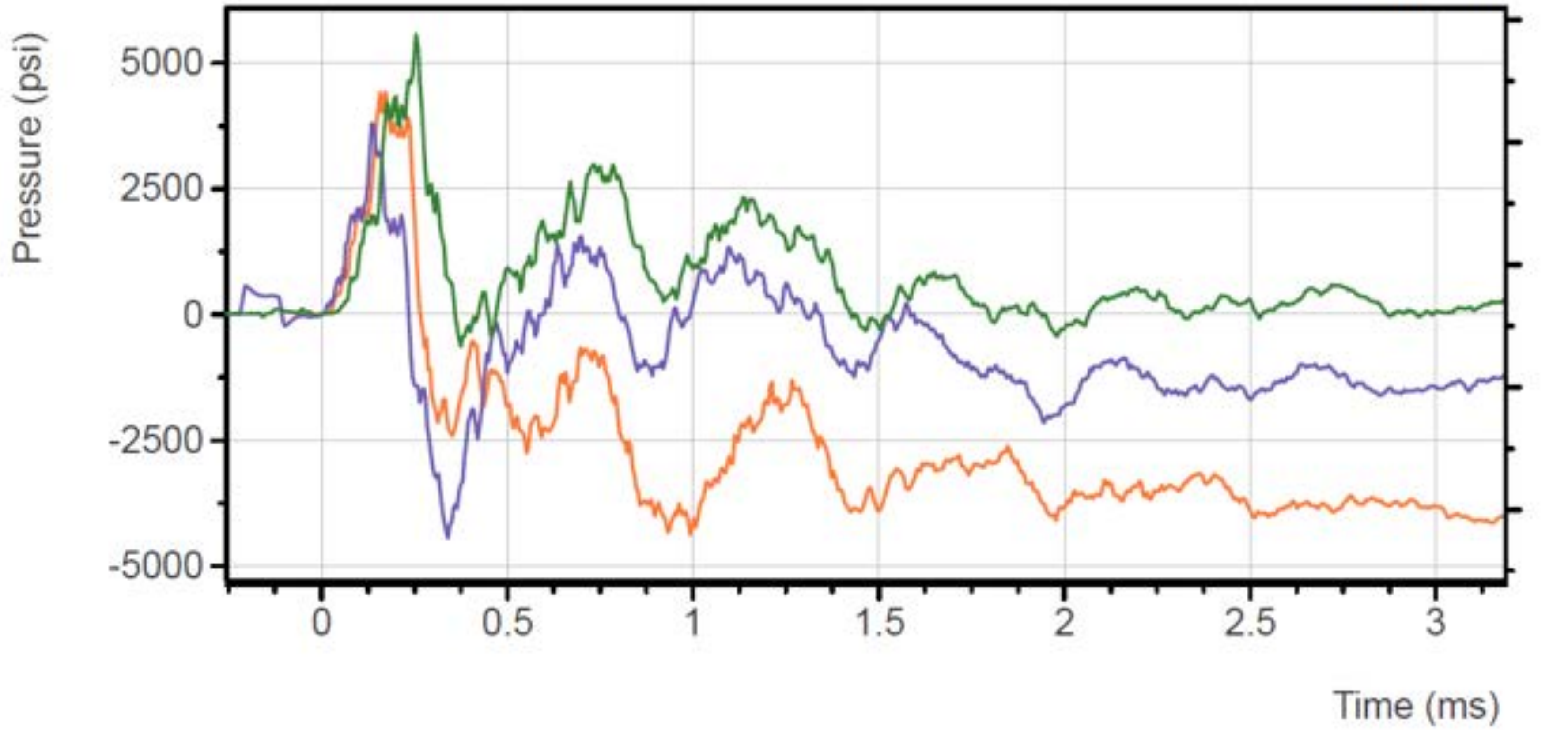
Computer simulations

- Showed large changes in peak pressures
- Diminishing return on reduction in DUB as propellant was altered

Lab testing

- Showed less than a 13% variation in peak pressures regardless of propellant design
- Demonstrated a more consistent decline in DUB based on amount of propellant





Scenario	Simulation DUB	Lab Testing DUB	% Difference
Baseline	5380 psi	6585 psi	20%
Propellant Configuration 1	630 psi	2407 psi	17%
Propellant Configuration 2	489 psi	1238 psi	13%

Conclusions

- Propellants can be used for applications where high overbalanced pressure conditions are not desired
- High peak pressures to fracture rocks can be mitigated completely
- Lab testing showed no increased damage to rocks
  - CT scans showed no fractures or splits commonly associated with propellants
- Can “tune” the propellant in several ways to control burn rate and pressure delivery
  - Alter chemistry and formulation
  - Alter propellant weight
  - Alter propellant design/envelope

Future Work

- Continued propellant evaluation in other gun system configurations
  - Alter charges to see if performance alters DUB reduction
  - Change gun sizes to see if total free volume impacts results or if scalable solution exists

- Development of an accurate “DUB killer” model
  - Standalone DUB calculation algorithms
  - Accurately build characterization and parameters to implement into PulsFrac if possible

- Full system testing for verification and certification

- Field trial applications

QUESTIONS?

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