Excerpts from Aug. 22, 2013 presentation

17th Annual Gulf of Mexico Deepwater Technical Symposium

# Evaluating In-situ Dynamic Behaviors of Perforating Guns and Wellbore Fluid in Tubing-conveyed Perforating Jobs


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HALLIBURTON



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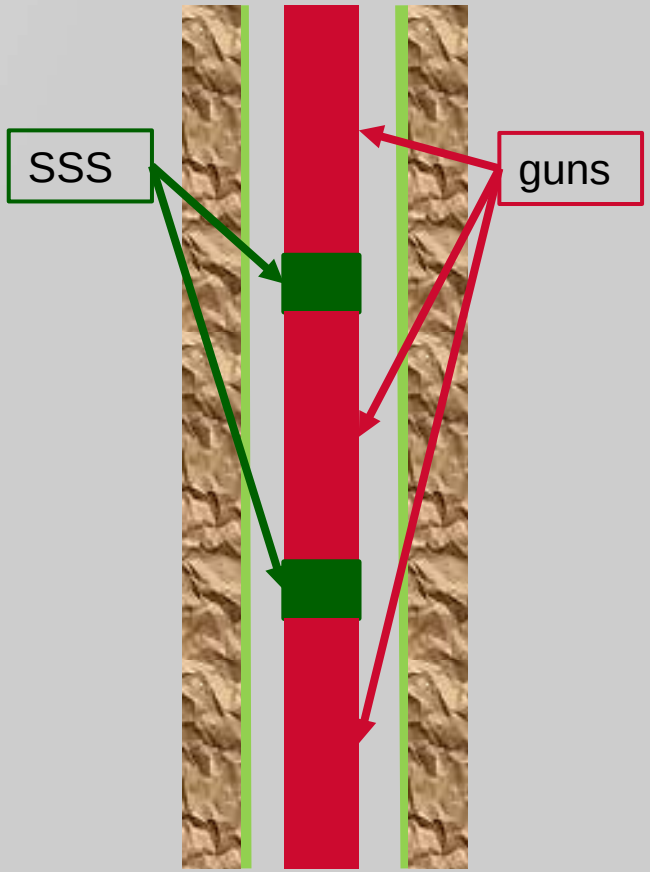
SPE International Delta Section

# Outline

- Intro to Shock Sensing Sub (SSS)
- Review of field testing
- Comparison of SS3D™ model to field test data
- Summary and findings

# Motivations

- Perforating, like many downhole operations, is largely a blind operation
- Operators have little indication of what goes on from surface
- Previous sensor tools offer limited data and poor proximity to action
- The Shock Sensing Sub (SSS) was developed to measure the structure and fluid response during perforating gun detonation between guns
- SS3D software is used to simulate the detonation event



# Features of the SSS

- Record multiple events (up to 10) in non-volatile memory
- 12 channels for 100 kHz high-speed recording of detonation event
- Sensors include
  - Mechanical loads in the string
  - Dynamic wellbore pressure
  - Acceleration of the tool string
- Also records pressure/temperature/load history for the entire job at a slower sample rate
- Handled like a loaded gun (det cord passes through)
- 4-5/8 and 6-1/2 in prototypes
- Owned and operated by Halliburton

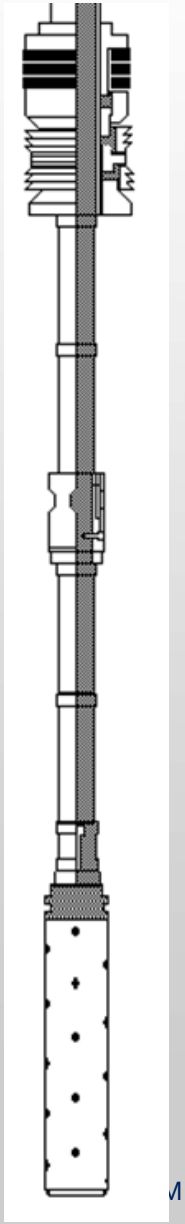
# On-board Sensors (Prototype)

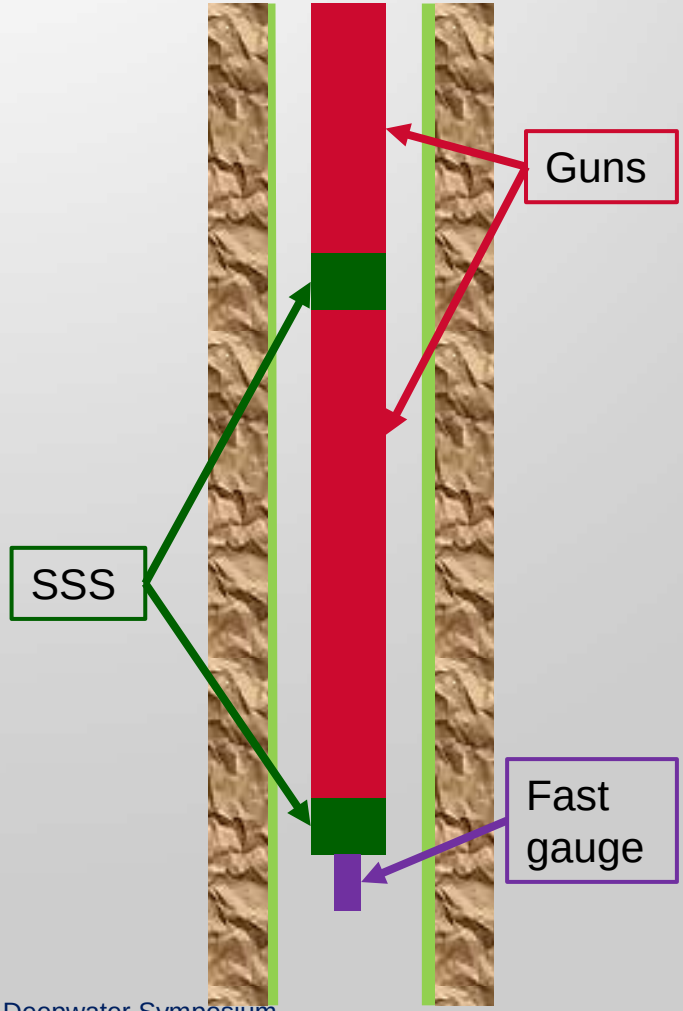
- Load measurement using strain gages to resolve:
  - Axial
  - Bending in 2 axes
  - Torsion
- Dynamic pressure (direct communication to annulus)
- Tri-axial acceleration
- Temperature
- One quality-control, placebo channel
- All sensors are configured to capture long-term history data and short-term event data

# SSS Field Test History

- Three jobs performed on US land
  - 1st job—SSS at the bottom of the string, 877 ft loaded
  - 2nd job—SSS is in the middle of the string, 1,100 ft loaded
  - 3rd job—one SSS at the bottom, one SSS in the middle. 500 ft loaded.
- One job in GOM
  - Water depth ~1500 ft, perf TVD ~15,000 ft

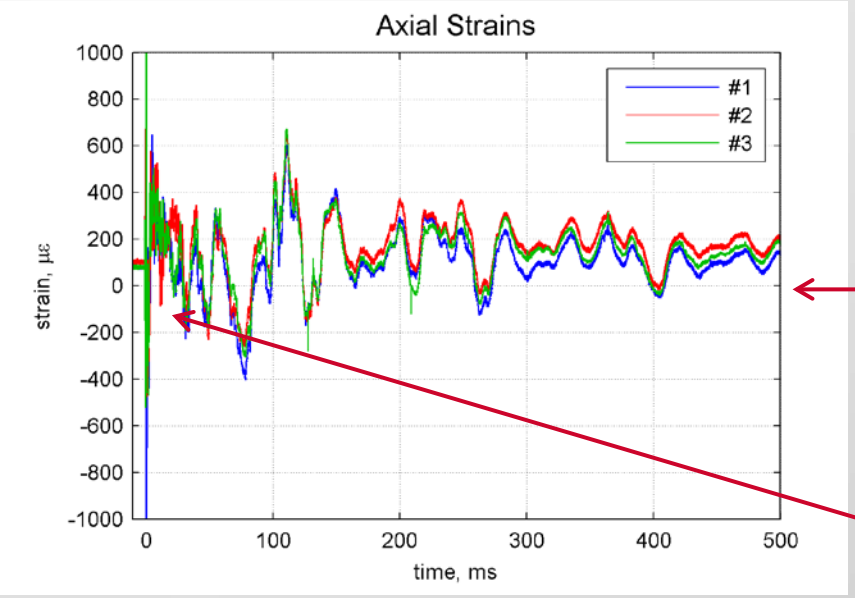
# 3rd US Field Trial Description






- 4 5/8-in. 5 SPF Millennium™ charge
- Existing perforations below
- Mechanical firing head
- Two SSS tools
  - One in blank interval
  - One below bottom gun
- Fast Gauge on bottom

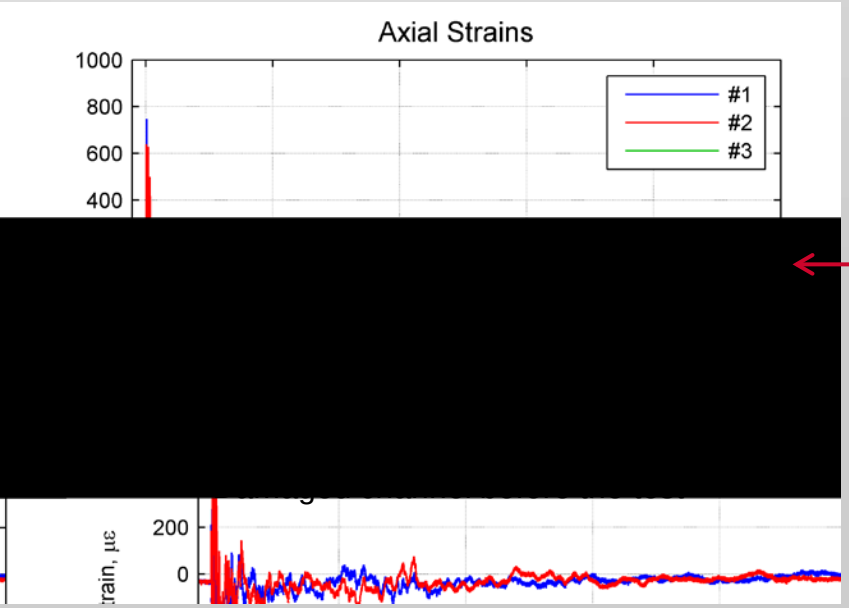
# Event Data – 3rd US Land Trial




**SSS in blank interval between guns**

SSS in middle of string observes axial strain (loads) due to detonation shock and resulting string dynamics

Initial high-frequency content from detonation shock




**SSS below bottom gun**

SSS at bottom is near free boundary and thus observes detonation shock but very little of string dynamics



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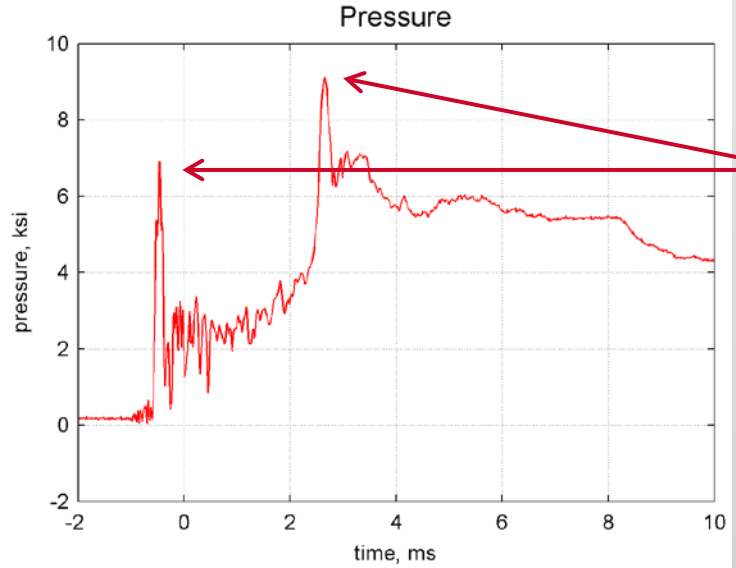
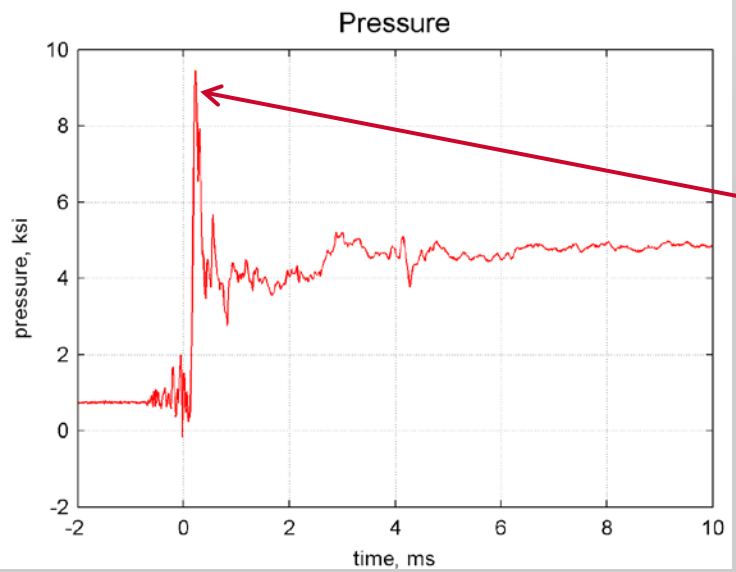
# Event Data – 3rd US Land Trial




**SSS in blank interval between guns**

Tool observes 2 peaks: shock from zone above and zone below




**SSS below bottom gun**

Single peak from loaded zone above



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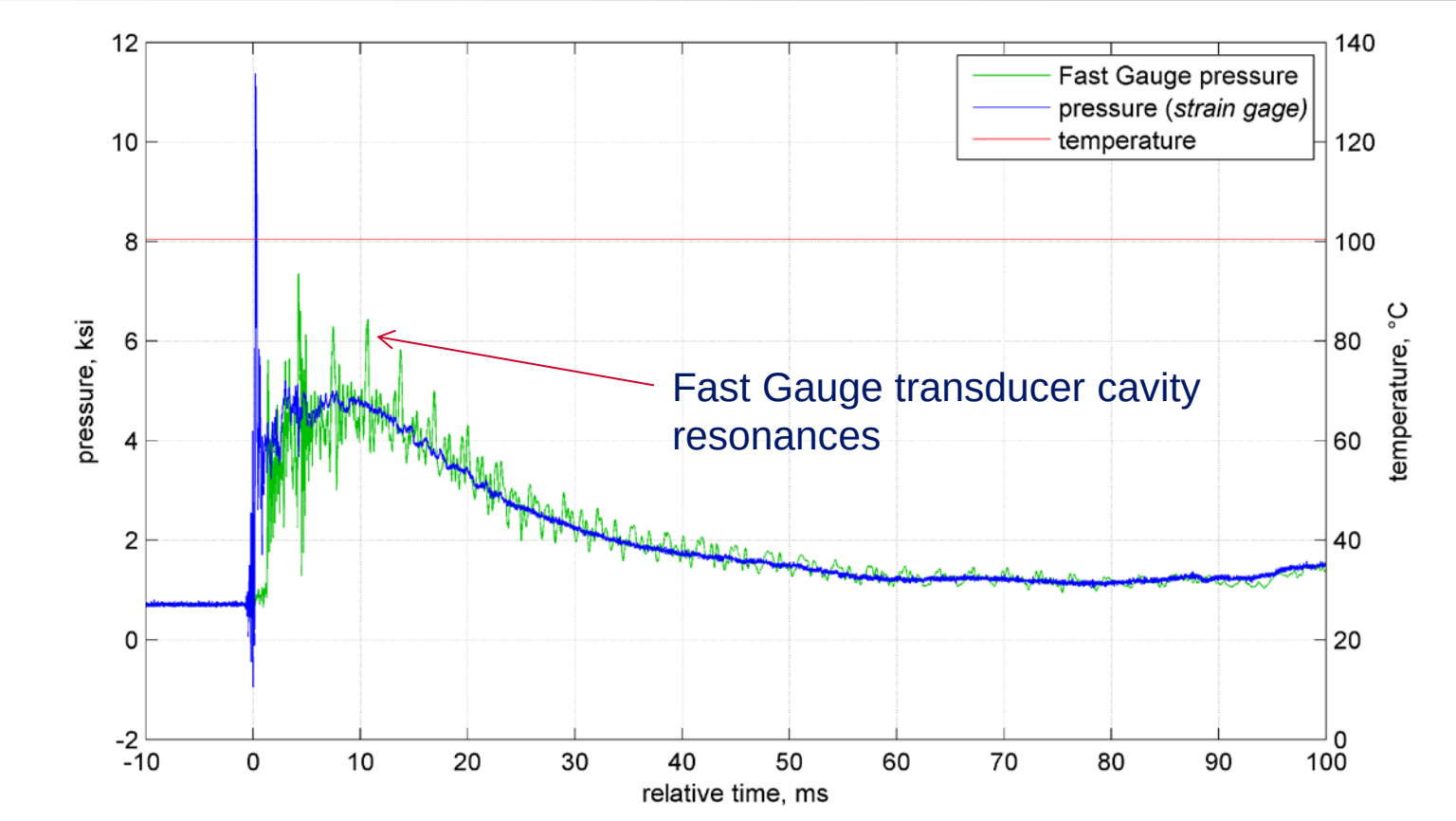
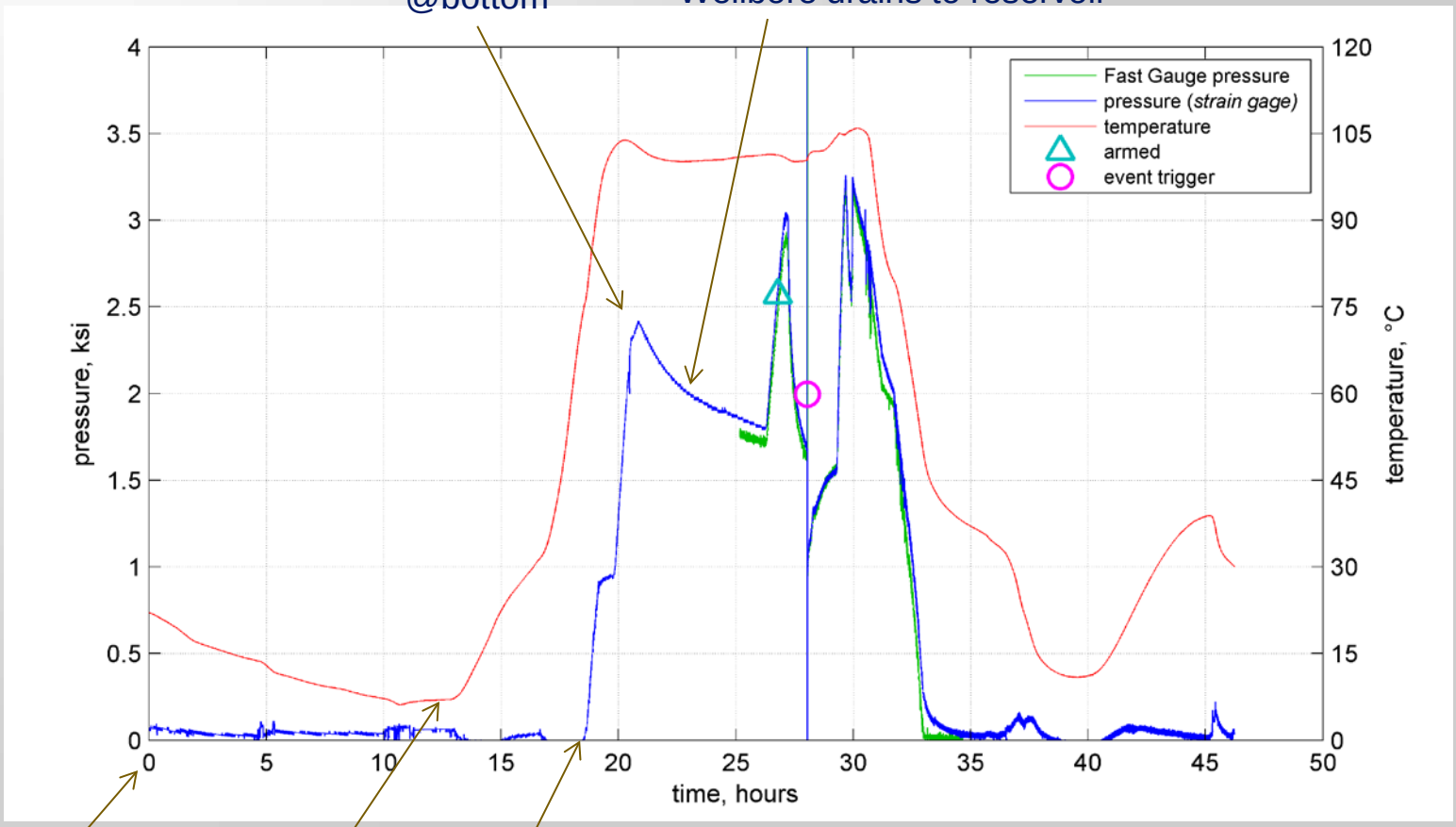
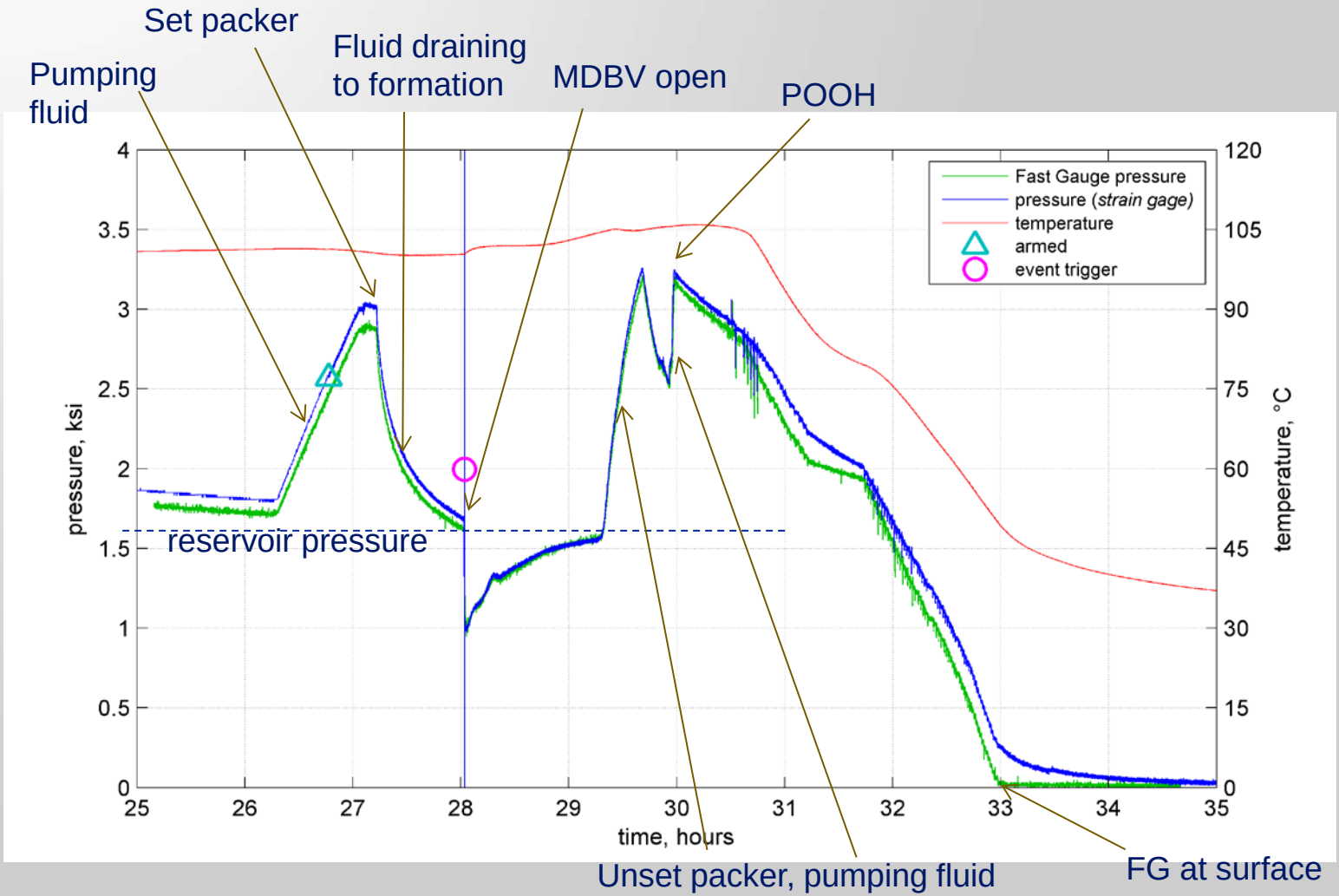
# Comparison with IES Fast Gauge – 3rd US Land Trial



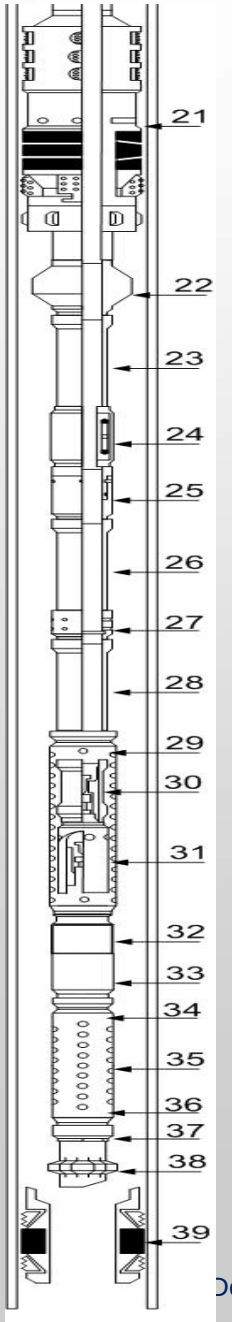
# Captured Job History – 3rd US Land Trial



# Job History Zoom-in – 3rd US Land Trial



# Deepwater Field Test Description




24. Fast Gauge

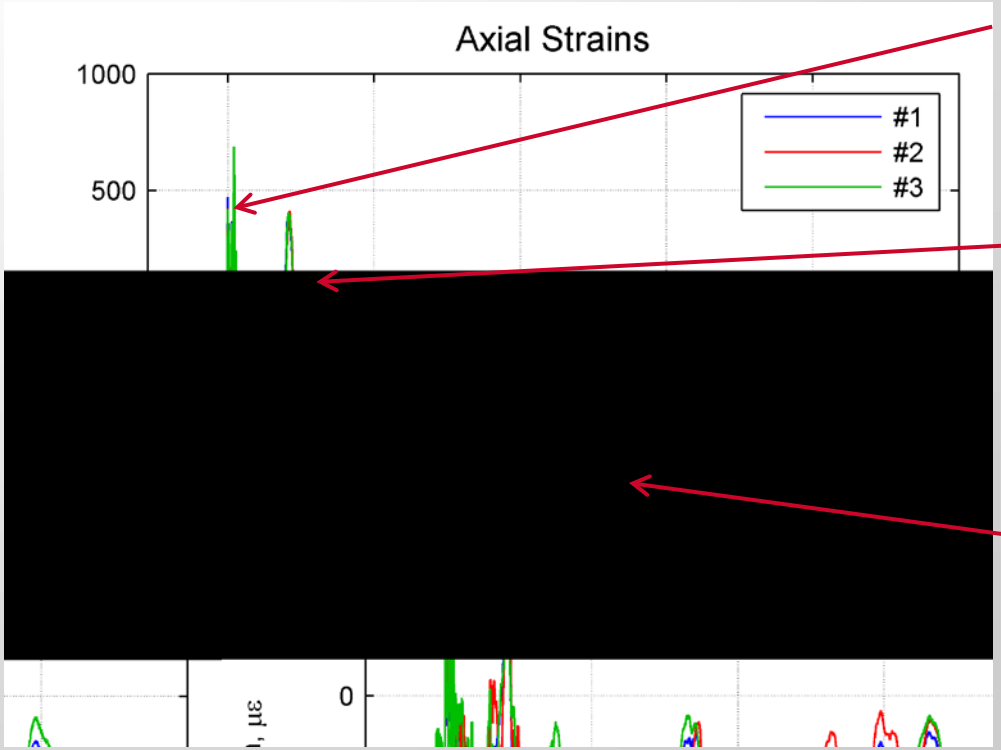
110 ft apart

33. SSS

34. Top shot

- Water depth ~1500 ft.
- TVD ~15,000 ft.
- 4-5/8 in. gun system
- Dual firing heads
- 12 SPF super hole, low debris charge
- Fast Gauge 110 ft above in tubing
- SSS located close to top shot
  - Provides more realistic dynamic underbalance (DUB)

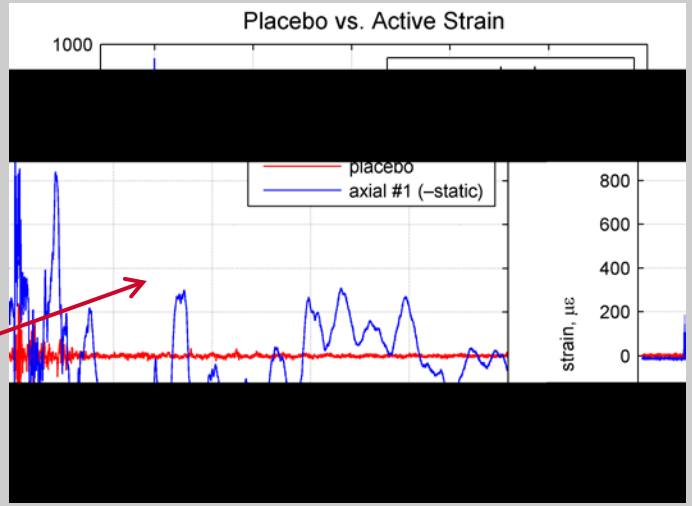
# Event Data – Deepwater Trial




Shock from nearest charges

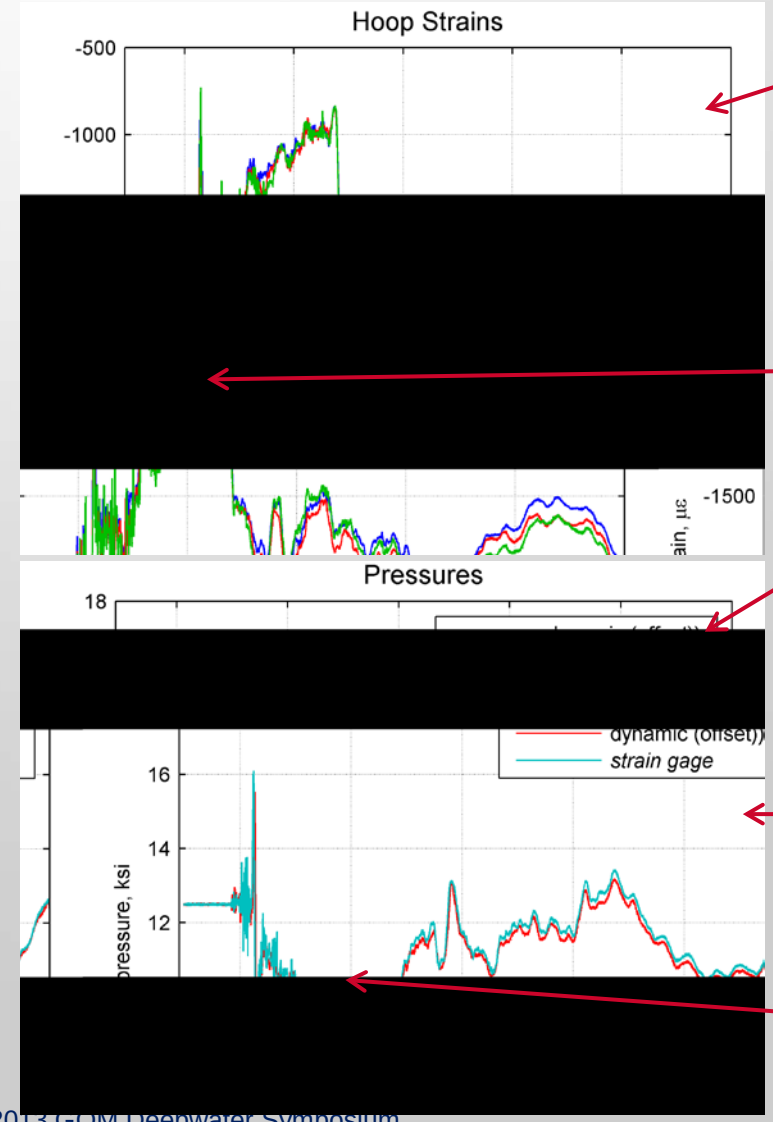
Initial response purely axial (3 channels in synch)

Axial strain differences indicate bending (35-60 ms)




Placebo response (red) quite small, indicating low noise

# Event Data – Deepwater Trial




Hoopwise strains largely reflect negative of pressure response

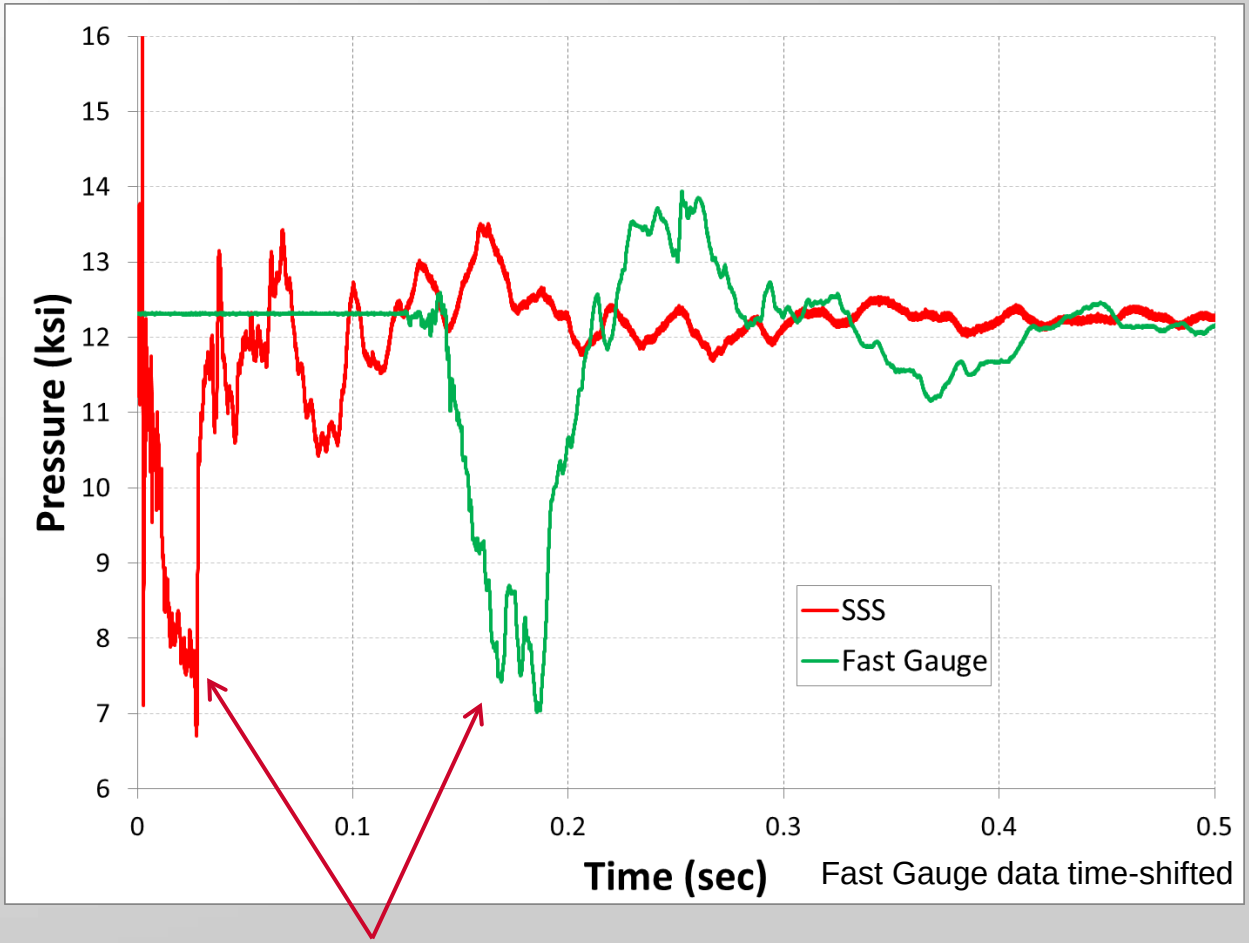
Strain gages are more sensitive to initial high-frequency mechanical shock than pressure transducer

Pressure calculated from strain gages (cyan) compared with direct dynamic pressure transducer measurements (red)

Correlation between pressure data collected from disparate sensors provides strong confidence in data quality and accuracy

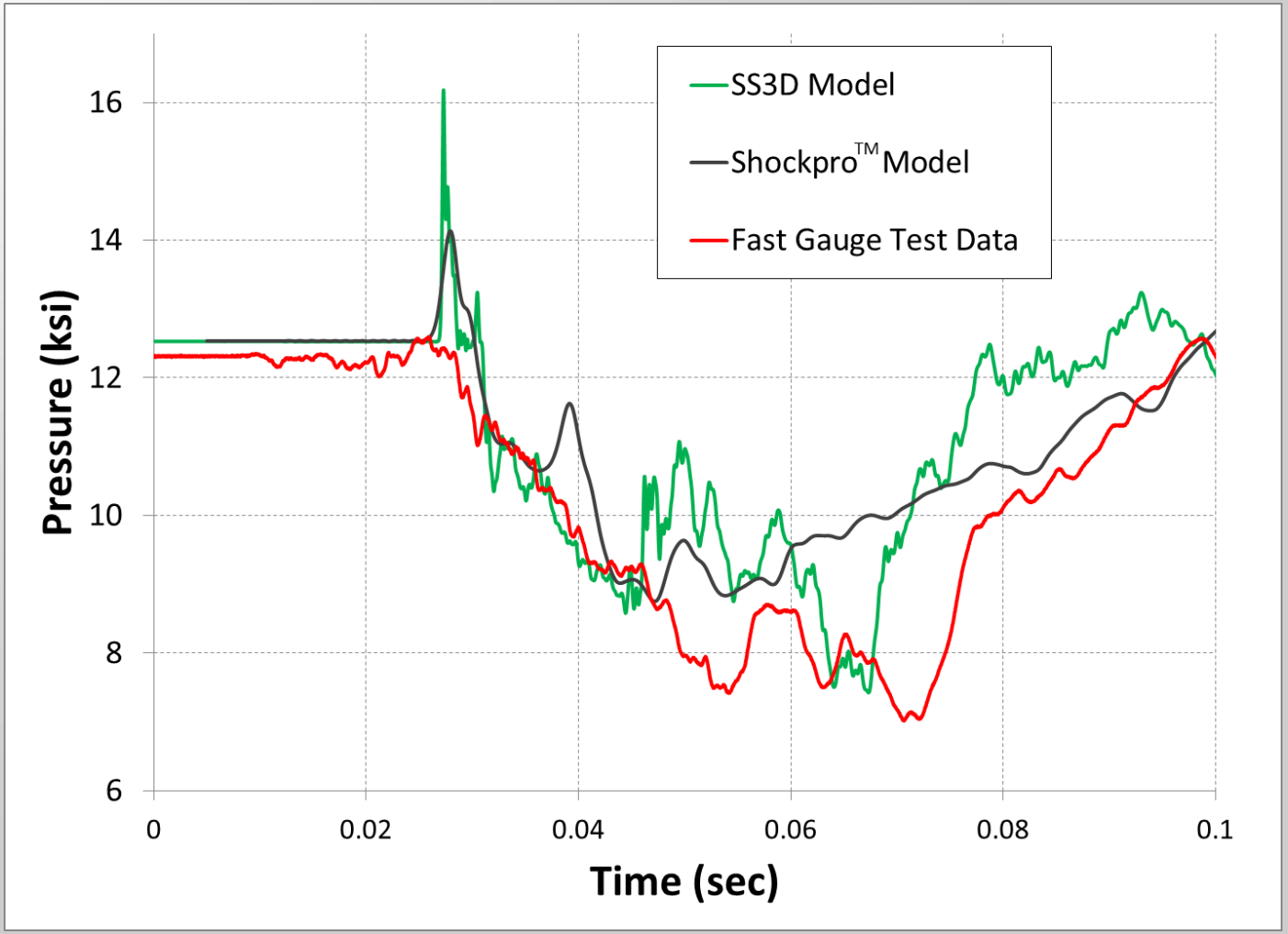
Dynamic underbalance adjacent to partially-loaded gun

# DUB Comparison at Two Locations – Deepwater Trial

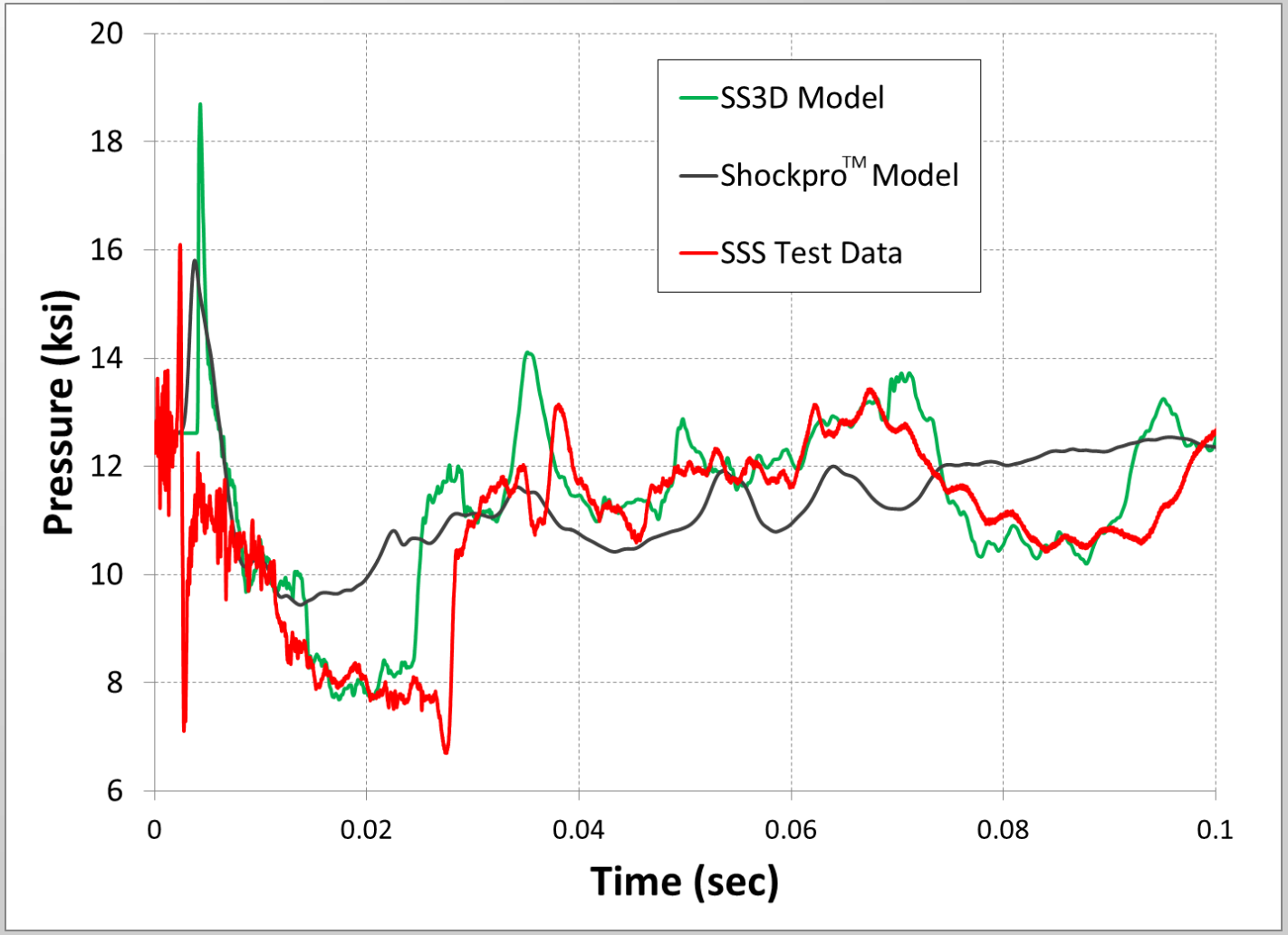



Longer duration of low pressure at Fast Gauge location

# Model/Data Comparison at Fast Gauge Location – Deepwater Trial



# Model/Data Comparison at SSS Location – Deepwater Trial



# Summary and Findings

- Shock Sensing Sub enables in-situ measurement of gun detonation event
  - Sensors integrated directly between guns
  - Load measurement within gun string
  - Direct dynamic pressure measured adjacent to perfs
- Multiple field trials successfully completed
  - Axial shock waves observed
  - Excellent dynamic underbalance observation
  - Simulation software demonstrated
- Halliburton is seeking additional field test opportunities for both 4-5/8 in and 6-1/2 in sizes