

# Demonstration of pressure wave motion in the well caused by a dynamic event

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When a downhole tool releases a large amount of energy in milliseconds, pressure waves are created that travel away from the tool in both directions. Good job design must minimize or control these waves while still injecting a maximal amount of energy into the formation. The tool energy should breakdown, cleanup, and stimulate and not be wasted in the hole. Unfortunately, it is impossible to completely eliminate these waves when the tool resides in wellbore fluids, as it must. When the waves are created, most often they are harmless, but if too large, they do have the potential to strongly move the wireline (if used), and adversely affect packers, bridge plugs and other hardware. These waves eventually travel to the surface, but are usually not a problem there. However, for the more shallow wells, potential impact upon surface equipment must be considered. In this article, a case study is provided in which three recorders were placed in a hole surrounding a StimGun™ assembly. The study shows matching calculations and finally, with the help of the PulsFrac™ simulation, shows the progress of the waves up and down in the hole, including reflections. With knowledge gained in this way, and similar computer runs made for planned jobs, the potentially adverse effects of pressure waves can be understood and controlled.

## Test results

The wellbore configuration for the test is shown in Figure 1. The source device is a tubing-conveyed StimGun™ assembly containing 10 ft (3.1 m) of propellant sleeve on a 14 ft by 4.5 in. (4.3 m by 114.3 mm), 12 spf (39 spm), 30° phased perforating gun. The formation is low-consolidation sand. Three downhole recorders are in place. One is below the tool and near to it. One is slightly above the tool, and one is well above the tool and near to the packer holding the tubing in place. Calculations have been made to match all of the data obtained.

The sequence of events starts with the source ignition followed by upward and downward propagating

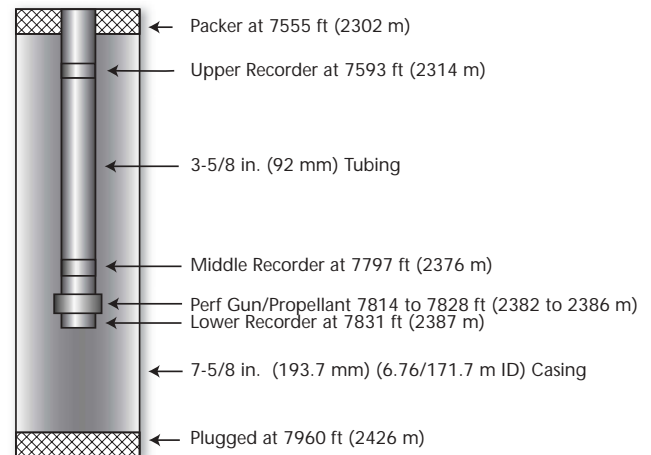
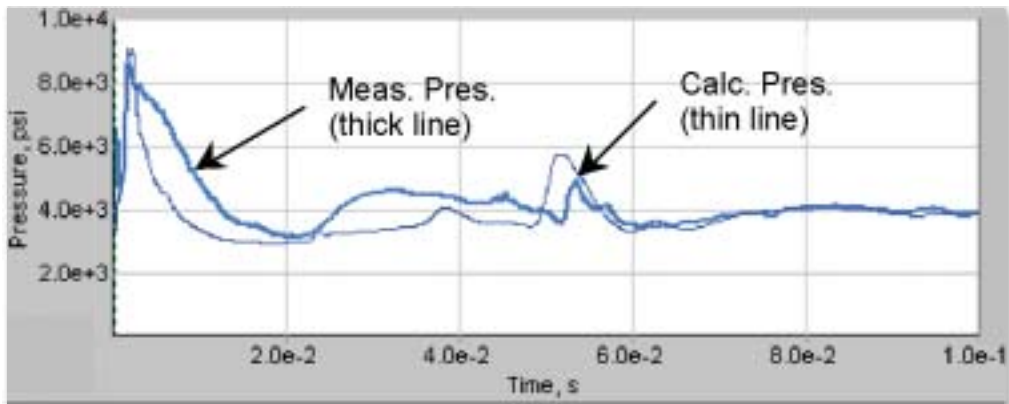
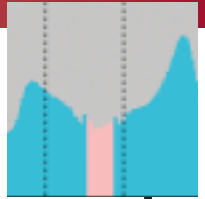


Figure 1 – Simplified schematic diagram of wellbore configuration for dynamic reflection example.

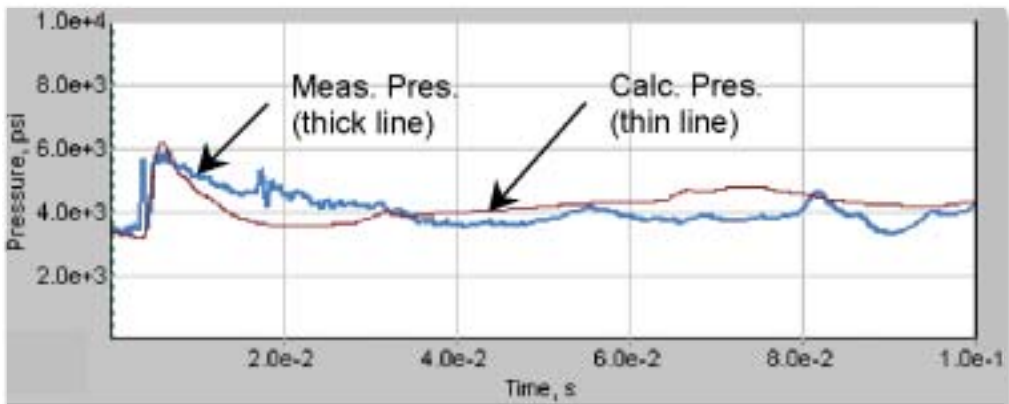
waves. The upward propagating wave reflects off the packer and then returns downward. The full complexity of equipment in the hole is not modeled, so some details of the pressure behavior are not captured. However, all of the main features are easily identified and calculated.

Figure 2 shows measured and calculated pressures for the lower gauge (below the source) to a time of 100 ms. Measured peak pressure is about 9000 psi (62 MPa), and is matched by calculation. All perfs break down (not shown). Calculated fracture length (also not shown) in this soft sand varies from a maximum of 5.2 ft (1.6 m) in the stress-preferred direction to 0.75 ft (0.23 m) in the other. The steep drop to below hydrostatic (3500 psi/24 MPa) after ignition and the bottomhole reflection at 50 to 60 ms are both seen and calculated. The peak magnitude of the bottomhole reflection is somewhat high. This is commonly observed and can frequently be accounted for by debris or fluid density or compressibility changes near the bottom of the hole.

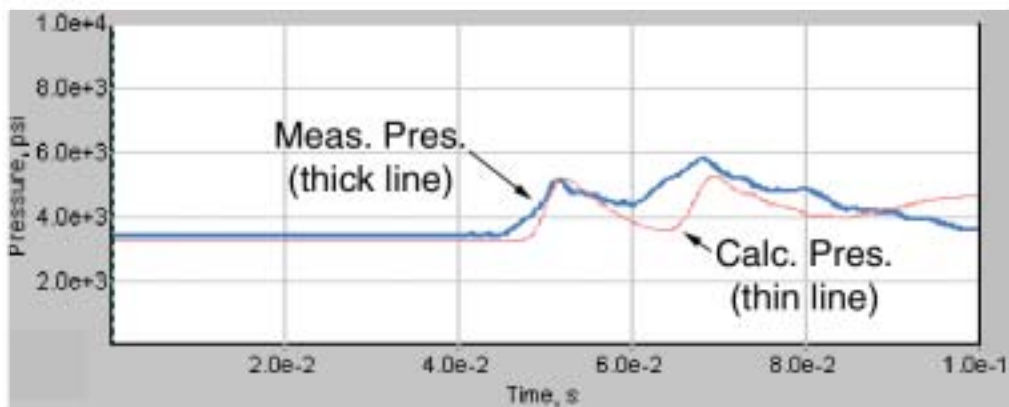
Figure 3 shows measured and calculated pressures for the middle gauge (above the source). The peaks match. The signal at about 80 ms is the bottomhole reflection after it has passed through the gasified,



**Figure 2** – Measured and calculated pressures for the lower gauge in the dynamic reflection example.



**Figure 3** – Measured and calculated pressures for the middle gauge in the dynamic reflection example.



**Figure 4** – Measured and calculated pressures for the upper gauge in the dynamic reflection example.

highly dispersive, and attenuating tool zone. The calculation somewhat overemphasizes these effects, smoothing the signal a bit too much.

Figure 4 shows measured and calculated pressures for the top gauge (near the packer). The double peak from the incoming and outgoing wave (with respect to the packer) is modeled. The reflected peak is slightly too small due to small differences in dispersion through the reflection zone.

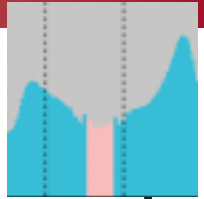
### Wave motion

The pressure wave motion triggered by this event is shown in the six sequential computational frames of Figure 5. These frames are seen as snapshots taken from a “movie” showing the pressure profile in the well from 3 ms until 69 ms. Each frame shows pressure vs. depth in the region between the packer at the top and the plug at the bottom. The well must be seen turned on its side.

Frame (a) shows the pressure immediately after the tool ignites. Pressure is approaching its peak and waves have begun to move upward and downward. Frame (b) shows motion at 15 ms. The downward wave is slightly stronger than the upward due to the asymmetric top-to-bottom burn of the tool. Frame (c) shows the peak of the bottomhole reflection. Pressure is nearly doubled, as expected in this type of reflection. Frame (d) shows the reflected wave from the bottom moving upward, while the original upward wave has not yet reached the packer. Frame (e) shows the top wave striking the packer while the bottom wave has been absorbed by the gasified region at the gun. Finally, frame (f) shows the reflection from the packer beginning to move downward. With this type of calculation, it is possible to reposition equipment in the hole and resize tools to consider the effect of pressure reflection effects. For example, a clean reflection will momentarily double the pressure

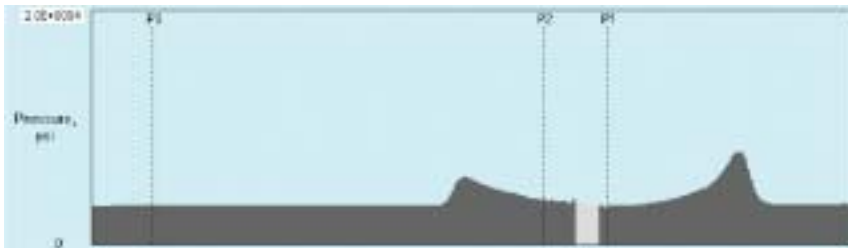
at a boundary such as the upper packer or the lower plug. In frame (c), the pressure has momentarily grown to about 11,000 psi (76 MPa) at the plug. Although doubling may exceed static packer or plug specs, if the pulse is short in duration (in the case shown less than 10 ms) no physical damage may occur. Unfortunately, packers and other downhole equipment are not commonly tested and rated for dynamic (impulse) loading.

All of the important wave features are shown in this event. If this was a job design calculation, and the modeled pressures at critical points, such as the packer, were too high, tool dimensions or other equipment could be modified to maintain pressure at an acceptable level while still successfully performing the job. This example demonstrates the potential importance of pressure waves and how measurements and calculations can be used to design and control even the most complex events.



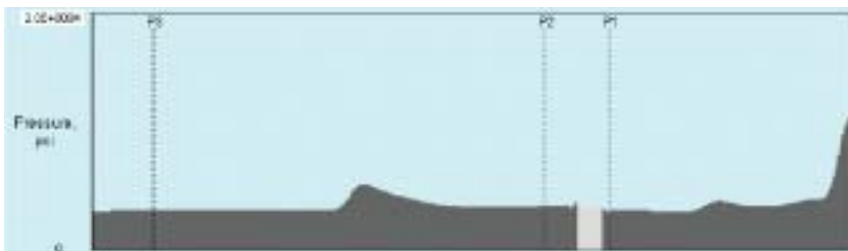
(a) 3 ms

(a) shows the wave structure forming at the end of the perforation gun burn and the early part of the propellant burn.



(b) 15 ms

(b) shows the waves moving upward and downward (left and right, respectively).



(c) 27 ms

(c) captures the moment when the downward incident wave strikes the bottom plug.



(d) 44 ms

(d) shows the reflected wave from the bottom nearing the tool zone, while the incident wave is approaching the upper packer.



(e) 61 ms

(e) shows the reflections at the upper packer and the gasified tool zone's absorption of the lower wave.



(f) 69 ms

(f) shows the reflected wave from the packer at the upper recorder.

Figure 5 – Calculated pressure wave structure for dynamic reflection example.