Thousands of perforating jobs are conducted successfully worldwide each month. However, for a small number of jobs, typically high-pressure deepwater wells, gun shock is a real and significant risk. The Cascade and Chinook projects presented the two largest deepwater high-pressure perforation jobs to date in the Gulf of Mexico (Fig. 1). These Lower Tertiary well completions have gross perforation intervals greater than 800 ft and downhole pressures higher than 19,000 psi. Perforating all intervals with long gun strings and then frac packing multiple zones in a single trip saves substantial rig time compared with performing conventional stacked frac-packed completions requiring multiple trips per perforated zone.

**Introduction**

Perforating several intervals in one run was required to complement a single-trip multizone frac-pack system in which all downhole packers, screens, and service tools are run at once and all zones are stimulated in a single trip. Planning, mobilizing, executing, and reviewing multizone perforating jobs at wellbore pressures higher than 19,000 psi and in water depths greater than 8,000 ft presents many challenges. Operational risks inherent to perforating multiple zones in a high-pressure deepwater environment were minimized by using a simple and reliable approach built on previous experience from high-pressure deepwater perforation jobs. Cost reduction is the main driver because of the very high daily cost of deepwater operations. With a one-way-trip time of 18–24 hours, eliminating just one trip in the well would save up to USD 2 million. Perforating three or four zones at once multiplies the savings.

**Planning**

Planning for these jobs began with evaluating the casing design configuration to ensure that the perforating bottomhole assembly (BHA) could be run in and retrieved from the well with no damage and that the casing could withstand the pressure requirements of the perforating operations.

The next step in planning was the design of the perforating tool and gun string to perforate several intervals in one run with minimal damage to the tubulars and perforating equipment. For Cascade and Chinook, peak gun-shock loads were evaluated with software that predicts the pressure waves in the completion fluid and the associated structural loads on all well components. Close attention was paid to the material of the guns and centralizers, the fishability of the guns in the event of sanding, the survivability of the perforating packer and associated well-control tools run in conjunction with the guns to control fluid losses, and other factors. The connections were upgraded, to the extent possible, to provide a more robust thread form. Detailed fishing plans for the BHA and other contingencies were made. Methods for releasing stuck guns were reviewed and tested. Experience garnered from other high-pressure (>17,000 psi) deepwater wells was used as the basis for the preliminary design and model.

The perforating tools used in these wells used a proven design and were able to handle the large perforating-gun-string detonation without damage to the integrity or functionality of the string before releasing the packer to pull out of...
the hole. The perforating string consisted of the following main components:

- A 25,000-psi dual valve was used to control fluid losses with low-pressure annular pulse commands.
- A pump-through safety valve served as a secondary means of downhole shut-in for a well-control contingency.
- A hydraulic jar was included to aid in freeing the BHA if it were to become stuck.
- A 3½-in. internal-flush (IF) cut joint was placed above the packer as a secondary release mechanism.
- A long-stroke retrievable packer was used to isolate the annulus from the formation and to serve as an anchor point for the gun string. As the anchor point of the perforating BHA, the packer takes the brunt of the mechanical and pressure-wave force generated by the detonation of the perforating guns.
- 3½-in. IF centralizer was included to keep the packer centralized in the casing through the tieback gap, minimizing the chance to catch a shoulder on the seal assembly muleshoe.
- 3½-in. IF drillpipe was used below the packer to space the packer out above the gun string and increase the distance from the packer to the perforating guns. A larger volume below the perforating packer provides more volume in which the pressure wave can diminish before affecting the packer.
- A 3½-in. IF long-slot debris-circulating sub served to fill the tubing while running in the well and to protect the firing head from debris.
- Two shock absorbers were used to reduce the shock transferred to the tubing and packer.
- A 25,000-psi tubing-conveyed perforating firing head is activated by low-pressure command pulses down the drillpipe.

### Operational Details

Two separate rigs with different crews were able to make up the 1,399-ft Cascade and 1,415-ft Chinook perforating BHAs in less than 6 hours, from picking up the first gun to making up the last tool. Making the tool string into pre-torqued assemblies saved time on the critical path at the rotary.

A fit-for-purpose set of becket and balls was built to fit the rig elevators. The becket and balls were set up to handle every lift in the perforating BHA, with a single change of elevators between the guns and the 3½-in. IF spacer tubing and the remainder of the BHA.

Using a pneumatic torque wrench to install and remove the safety clamps on the BHA components was another time saver. Manually, it takes an average of 1.5 minutes to install and 45 seconds to remove one clamp per connection; with a pneumatic wrench that can install the clamp and remove it in 10 seconds, we saved considerable time on 40–50 connections in the BHA. With 100 connections per run and just under 2 minutes per connection, a saving of 3 hours of rig time was seen. Saving 45 minutes in connections by building assemblies and minimizing handling-equipment changes and efficiently organizing the equipment baskets to eliminate double handling of the guns and tools contributed to significant time savings in both perforating jobs.

The assemblies were deployed and recovered on average 8 hours faster than planned. With an average cost of deepwater rigs in the neighborhood of USD 1 million per day, saving 8 hours per run in execution-efficiency steps saves USD 333,000 per well.

### Prediction and Verification of Perforating Gun-Shock Loads

For Cascade and Chinook, peak gun-shock loads were modeled and evaluated with software that predicts the pressure waves in the completion fluid after the guns detonate and the associated structural loads on all well components. All relevant aspects of the well-perforating event are modeled, including gun-carrier filling after firing, wellbore pressure waves and associated fluid movement, wellbore-fluid repressurization with reservoir flow and from tubing flow/debris subs, elastic deformation of tubing and guns, and plastic deformation of shock absorbers.

Chinook 4 is located in the Walker Ridge Block 469 and has a gross perforation interval of 25,170–26,000 ft, a maximum deviation of 20°, a temperature of 260°F, and a 14.7-lbm/gal Ca/Zn/Br completion brine. The perforating-gun string was composed of 13 gun spacers, 25 7-in. high-pressure high-shot-density (HSD) guns, and two 7-in. high-pressure HSD low perforating shock and debris (LPSD) guns; all guns were loaded with big hole charges at 18 shots/ft. The two LPSD guns had not been field tested and were run for testing at the bottom of the lowest interval. In high-pressure wells, LPSD guns produce much lower gun-shock loads than standard guns. Another advantage of LPSD guns is a dramatic reduction in the shaped-charge case debris normally produced by all HSD guns; this is because the cases remain practically intact inside the gun carriers. Therefore, when using LPSD guns, much less effort is required to clean up perforating debris before running completion strings.

Fast-gauge pressure data show that the predicted wellbore pressure transients are sufficiently accurate in both magnitude and time when the input reservoir data used are close to the actual field data.

### Conclusions

Perforating all intervals with long gun strings and then frac packing multiple zones in a single trip saved many days of rig time compared with performing conventional stacked frac-packed completions requiring multiple trips per perforated zone.

The software model used to predict gun-shock loads showed good correlation with actual measurements taken by the fast gauges deployed on the Chinook perforating run, thereby validating the model predictions.

The perforation runs on Cascade and Chinook were successful by all measures. The operations were performed with zero health/safety/environment incidents. Tools were deployed, functioned successfully, and were recovered in better-than-planned time. Planning, logistics, and procedures outlined in this paper led to a rig-time reduction of more than 67% for the execution of the largest deepwater high-pressure perforation jobs to date in the Gulf of Mexico. JPT