Survey Design Considerations for Full Azimuth Acquisition Using a Single Recording Vessel.

Authors, David Hill*, Gordon Brown, Rob Campbell, Ed Hager, WesternGeco

Abstract

Azimuth-rich towed-streamer acquisition is established as a successful method for exploration in the Gulf of Mexico. The azimuth-rich data acquired to date has delivered better illumination and imaging, a higher signal-to-noise ratio, and improved seismic resolution. However, the azimuth-rich towed-streamer acquisition configurations used in the Gulf of Mexico are all multi-vessel. Moldoveanu (2008) introduced a method of acquiring azimuth-rich data with a single vessel. This paper describes a survey design and field test for a single-vessel azimuth-rich technique, which has the same acquisition effort as a 3-survey narrow-azimuth survey.

Introduction

Azimuth-rich seismic acquisition is now a fundamental exploration tool in the Gulf of Mexico, (The Leading Edge 2007). The technique delivers higher fidelity seismic images than are achieved with the narrow-azimuth acquisition techniques that have been the norm for the last few decades. However, the azimuth-rich acquisition techniques utilised in the Gulf of Mexico rely on the availability of multiple source-vessels and multiple recording-vessels, a luxury not necessarily available in many parts of the world.

If the benefits of azimuth-rich seismic acquisition are to be utilised as an exploration or development tool in areas of the world where only a single seismic vessel is usually available, a technique for acquiring azimuth-rich seismic data from a single vessel is required. Moldoveanu (2008) introduced the concept of coil-shooting - a method of acquiring full-azimuth 3D seismic data where the sail line comprises a continuous set of curves, often continuous circles, rather than the conventional set of straight sail lines as had been used historically. There is no reason why this coil-shooting technique cannot be implemented using elliptical, hexagonal, octagonal, or other such sail lines, but for the purposes of this article, it will be assumed that the technique will use circular sail lines.

Coil survey design objectives

Figure 1, from Moldoveanu (2008), depicts the fold of coverage and four rose plots for a high-effort coil survey design. Shot-to-receiver offset is represented along the radii of the rose plot, with the near offsets in the centre and the far offset at the outer edge. Azimuth is represented clockwise around the circumference of the rose plot with zero degrees at the top. If we examine figures 1a and 1b, we can conclude that this particular coil survey design delivers:

a. Area "A": the central core area (orange) has a relatively uniform 1600-fold, 360 degrees of azimuthal coverage for all offsets, but the fold as a function of offset is variable
b. Area "B" (green) about 1100-fold and about 240 degrees of azimuthal coverage
c. Area "C" (pale blue) about 700-fold and about 180 degrees of azimuthal coverage
d. Area "D" (dark blue) about 300-fold and about 90

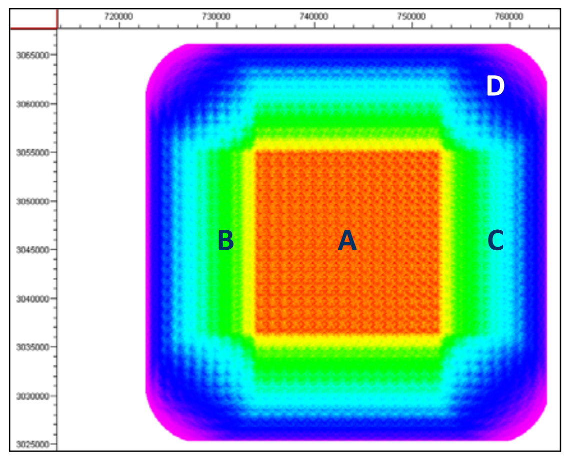

Figure **1a**: Fold and offset/azimuth distribution for a high effort coil survey.

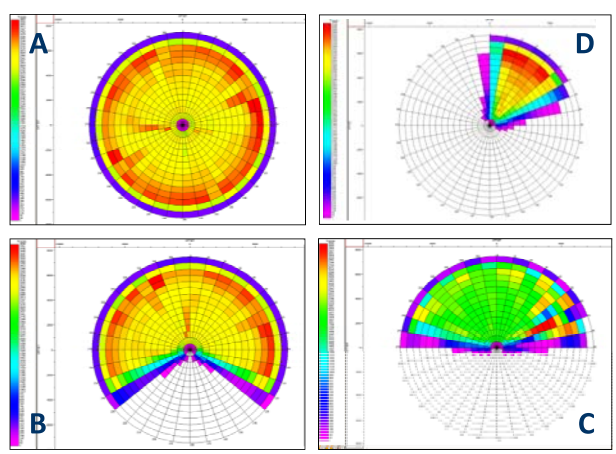

Figure **1b**: Rose diagrams illustrating the offset and azimuth distribution for the four areas a, b, c, & d in figure 1a

The boundaries between these four areas of azimuth/offset coverage for a survey of this type are a function of the circle radius. Figure 2a illustrates this; the circle (coil) radius is given by “r”. If the centres of the circles of the first and last columns, and first and last rows of circles, are centred along the outer coil centreline (the red solid line), then apart from the four corners of the survey:

a. The area bounded by the outer coil centreline (red line) has at least of 180 degrees of azimuth coverage.
b. The area bounded by “r/2” inside the outer coil centreline has at least 240 degrees
c. The area bounded by “r” inside the outer coil-centre line has 360 degrees
d. Some coverage exists all the way out to the survey outer boundary (purple line)

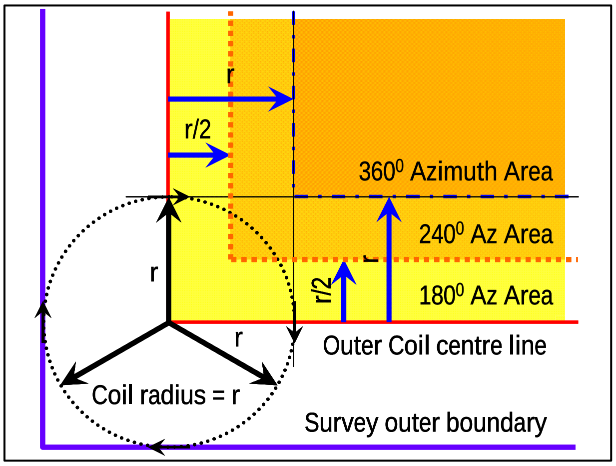

Figure **2a**: Coverage areas for a coil survey.

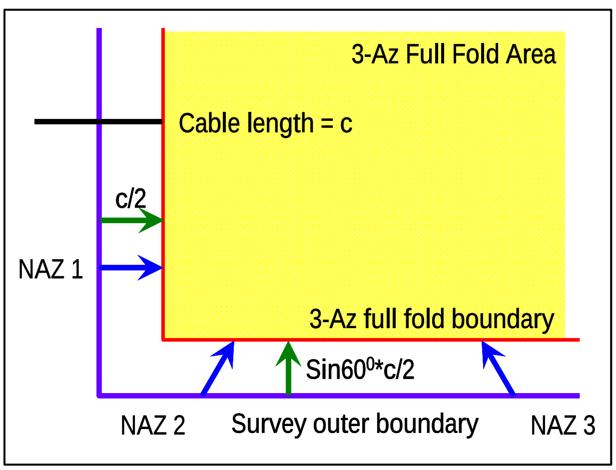

Figure **2b**: Coverage areas for a three-survey narrow azimuth.

An alternative technology for acquiring azimuth-rich data with a single vessel is a three-survey narrow-azimuth design, where the acquisition direction of each of the three surveys relative to each other is at 0, 60, and 120 degrees. Figure 2b illustrates the full-fold three-azimuth area of coverage for this azimuth-rich acquisition technique. The orientations of the three narrow-azimuth surveys are depicted by the three blue arrows. The area of three-azimuth full-fold coverage is bounded by the red line, and some coverage exists all the way out to the survey outer boundary (purple line).

The circle density for a coil survey is a function of the survey objectives, survey size, and circle radius, which, in turn, is a function of the number of cables, cable separation, and cable length being towed. The narrower the spread and the shorter the cables, the tighter the tuning circle can be. The specific objectives of the coil survey design, which is the subject of this paper, are: that the acquisition effort should be equivalent to that for a three-survey narrow-azimuth survey, and give essentially the same azimuth-rich area of coverage.

These objectives translate into:

a) The 180-degree area from the coil survey should be similar to the three-azimuth full-fold area for the three-survey narrow-azimuth survey. That is, the area bounded by the outer coil centreline in Figure 2a should be approximately the same as the area bounded by the three-azimuth full-fold boundary in Figure 2b.
b) The total sail kilometres from the coil survey should, to within a few percent, equal the total sail kilometres (including line turns) for the three-survey narrow-azimuth survey, assuming that both are acquired with the same acquisition configuration.

Figure 3a illustrates the source locations for a coil design that meets these objectives. Figure 3b is the corresponding fold of coverage. The various areas of coverage as described in Figures 1 and 2a are clearly identifiable. However, what is very apparent is that the fold of coverage is not uniform as it is in Figure 1a; rather, it exhibits a repeating rhombic pattern. Within the area of 360-degree azimuth coverage, the fold of coverage within a 25-m x 25-m bin varies between 600 and 750 in this example. Note, to generate this fold of coverage plot, a 25-m receiver interval, and a 25-m x 25-m bin size was used to satisfy the requirements of the plotting software. For a real survey, the receiver interval would be 12.5-m, in which case, the fold in a 25-m x 25-m bin would range from 1200 to 1500 in this area of 360-degree azimuth coverage; or from 300 to 375 if binned at 12.5-m x 12.5-m.

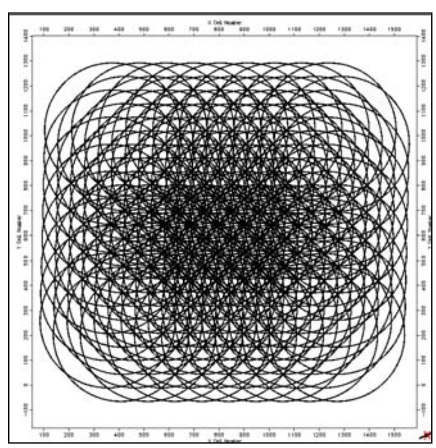

Figure **3a**: Coil survey shot locations

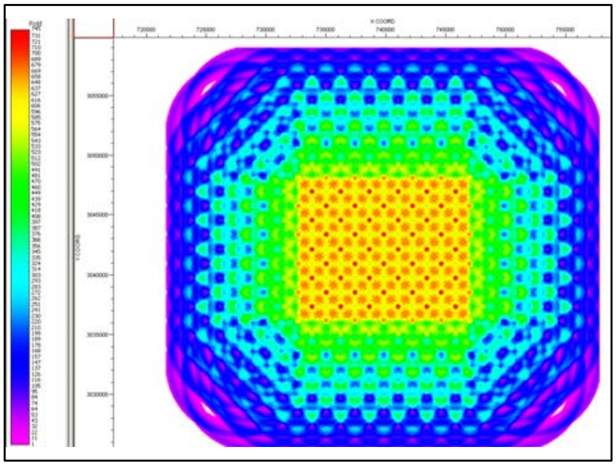

Figure **3b**: Corresponding coil surveys fold of coverage.

Figure 4 shows the number of populated offset groups as a function of four azimuth groups from the lower left corner of Figure 3b. Within the area bounded by the outer coil centreline (Figure 2a), all azimuths groups have continuous, but not uniform coverage. Within the area of 360-degree azimuth coverage, each azimuth group has from 50% to 100% of the offset groups populated. Annotated on Figure 4 are two sets of small squares in exactly the same position on each of the four azimuth plots. Within the solid black boxes, all four azimuths have a high percentage of the offsets populated. Within the dashed black boxes, two azimuths have a high percentage of offsets populated and the other two are not so well populated.

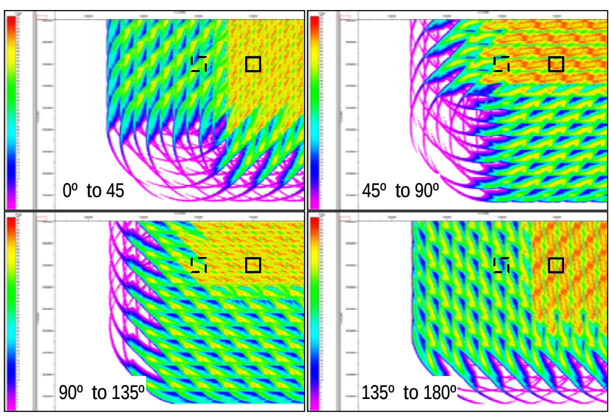

Figure **4**: Number of populated offsets for four azimuth groups.

If the fold of coverage is examined in more detail within the area bounded by the outer coil centreline (not illustrated here) then:

a) For any bin:
   a. For a given offset group, not all azimuths groups are populated, but azimuth gaps are rarely larger than one azimuth group.
   b. For a given azimuth group, not all offset groups are populated, but offset gaps are rarely larger than a few offset groups.

b) For a given azimuth/offset group, not all the bins are populated, but gaps are rarely larger than a few bins in either the x-direction or the y-direction.

Even though the fold of coverage from this particular coil survey design is not uniform, in the sense that the industry has come to understand in the context of the narrow-azimuth marine surveys, that where acquired historically. Within the repeating rhombic fold pattern, it is predictable and tractable. Consequently, conditioning the fold during the processing of these data in such a way as to achieve a regular distribution as a function of azimuth group, offset group, x-coordinate, and y-coordinate, is achieved by means of a four-dimensional compact Fourier interpolation (Moore and Ferber 2008).

Is the survey design illustrated in Figures 3 and 4 practical? During 2008 StatoilHydro conducted and extensive Wave Equation Extrapolation and Finite Difference Modelling exercise, simulating the acquisition and data processing of many azimuth-rich acquisition configurations, including the coil design illutrated in Figures 3 and 4, which, in turn, led to a field-test of this coil survey design (Houbiers et al. 2009).

An example of the results from that field test are illustrated in figures 5a and 5b, figure 5a shows a seismic section from an underlying conventional narrow-azimuth 3D acquisition through the centre of the coil test area, and 5b the corresponding seismic section from a small 3D pilot survey acquired using the coil design as described above.

Observations to note from the comparison of figures 5a and 5b are:

a) The multiples in the coil example are far better attenuated than in the narrow azimuth example. This is attributed to the fact that the coil data has continuous near offset coverage, with well-sampled azimuthal coverage. This makes these data ideal for the application of fully 3D surface-related multiple attenuation algorithms. (Moore and Dragoset 2008)
b) The fault imaging of the coil data is superior to that of the narrow azimuth data.
c) The subsurface illumination and hence structural definition of the coil data is superior to that of the narrow azimuth data.

Observations b) and c) where predicted as benefits of coil shooting over narrow-azimuth acquisition by the Wavefied Extrapolation Modelling performed as part of the modelling and feasibility study (Houbiers et al. 2009).

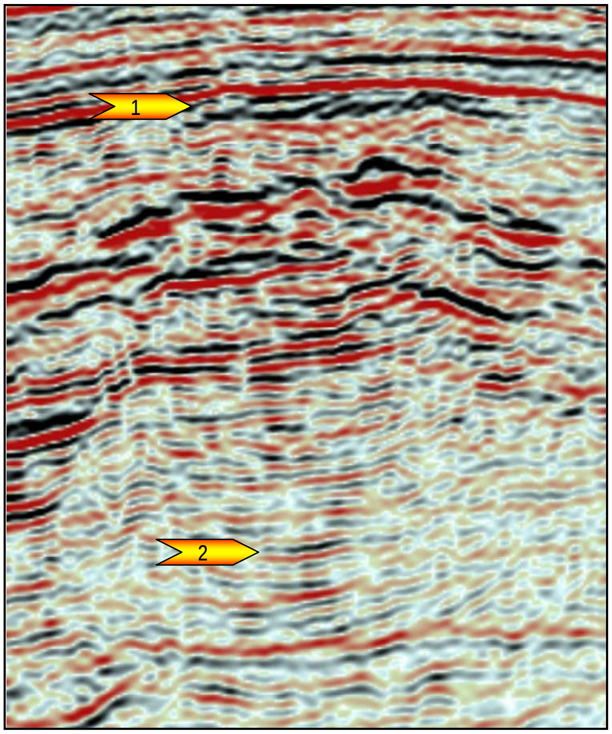

Figure **5a**: A narrow-azimuth seismic section taken from an underlying 3D survey. Arrows 1 & 2 highlight remnant multiple energy contaminating the narrow azimuth image not evident on the coil image.

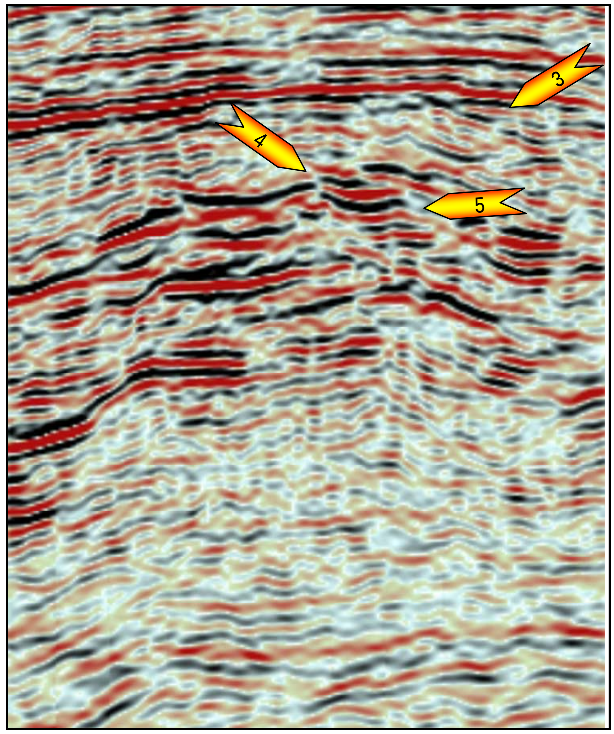

Figure **5b**: A coil seismic section taken from the 3D coil pilot survey. Arrow 3 highlights dipping primary energy. Arrow 4 highlights better fault definition. Arrow 5 highlights improved imaging of primary reflections. All illustrate imaging benefits of coil over a narrow azimuth acquisition configuration.

Conclusions

Coil surveys in general:

a. Require only a single acquisition vessel; hence, an azimuth-rich survey of this type can be acquired anywhere that a marine towed-streamer configuration can be deployed.
b. The dense shot coverage and full-azimuth coverage produces the ideal data type for application of true 3D surface-related multiple attenuation techniques.
c. Coil survey designs range from that illustrated in Figure 1 to that illustrated in Figures 3 and 4 and can be tailored to meet a range of geophysical and operational objectives.

The coil survey design illustrated in Figures 3 and 4:

d. Has the same acquisition effort as a three-survey narrow-azimuth, to within approximately 5%.
e. Delivers 180 degrees of azimuthal coverage over the same area that a three-survey narrow-azimuth delivers with three distinct azimuths.
f. Has very high fold when compared to a three-survey narrow-azimuth survey.
g. Is practical and delivers higher quality time and depth images than almost all other azimuth-rich acquisition techniques modelled (Houbiers et al. 2009).

Acknowledgements

We thank StatoilHydro and Heidrun unit partners for providing data and permission to publish the results and WesternGeco for permission to publish this work.

References

Houbiers, M. Arntsen, B. Thompson, M. Hager, E. Brown, G. and Hill, D. [2009] Full Azimuth Modelling at Heidrun. *EAGE Marine Seismic Workshop,* Extended Abstracts M04.

Moldoveanu, N. [2008] Circular Geometry for Wide-azimuth Towed Streamer Acquisition. *70th EAGE Conference & Exhibition*, Extended Abstracts, G011.

Moore, I. and Ferber, R. [2008] Bandwidth Optimization for Compact Fourier Interpolation. *70th EAGE Conference & Exhibition*, Extended Abstracts, G026.

[2007], Special section: Offshore Technology Conference and wide-azimuth seismic acquisition. *The Leading Edge*, 26.

Moore, I. Dragoset, B. [2008] General Surface Multiple Prediction: A Flexible 3D SRME Algorithm. *First Break 26.*