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Wide-Tow Streamer 3D Acquisition: Fundamentals

Summary

Overall, the operational constraints of certain vessels should not deter operators from considering wide-tow streamer configurations in pre-survey planning. The restriction on total streamer spread width (**not** the number of streamers, as that is not the key factor) should be based on geophysical considerations. Pre-survey planning and modelling is proven as robust and reliable (in Nucleus™), enabling all geophysical considerations to be quantitatively examined prior to the actual survey. Provided that the shallowest target is not unacceptably affected by any acquisition footprint, the streamer spread width should be increased as much as possible in pursuit of the most cost-effective acquisition.

Introduction

3D streamer configurations should always be customized to the specific geophysical requirements of each survey location. In some cases the emphasis will be upon large exploration-scale parameterization where coarse cross-line sampling is deemed to be acceptable and survey efficiency is the key priority. In such cases the width of the streamer spread (and the sail line separation) will be large.

Many modern seismic vessels can tow eight (8) streamers at 100 m separation with dual-source shooting, yielding a total spread width of 700 m, and a nominal sail line separation of 400 m. Due largely to the operational constraints prohibiting many seismic vessels to a maximum spread width of about 700 m, that figure has become a de-facto criteria for "wide tow" multi-streamer acquisition. In other words, any streamer spread with a width of 700 m or greater is classified as "wide-tow", sometimes with undesirable connotations. In some cases, such connotations originate as part of commercial bidding efforts by service companies with limited operational capabilities, and have no geophysical foundation.

In general terms, the streamer spread width will translate to the following operational and geophysical outcomes:

- Analogous to painting a wall with a wider brush or mowing a lawn with a wider lawnmower, a wider streamer spread will result in a 3D survey area being completed with less total sail lines.
  - Less sail lines means less total survey duration and less total cost.
  - Less survey duration means less exposure to technical, operational, HSE and weather downtime. The seismic products will thus be delivered quicker to the operator, with cascading benefits of longer interpretation time available between data delivery and drilling, better prospect management, etc.
  - Larger streamer spreads will incur a marginally longer line turning time, and a marginally increased cost for equipment wear and tear. Nevertheless, the increased efficiency provided by wider tow significantly outweighs the small increase in line change times (**refer to Figure 2**).

- In the case of shallow water bottom and/or shallow (less than 1 s TWT) targets, very large streamer spreads can create an "acquisition footprint". This effect is most obvious on time slices as "stripes" of degraded amplitudes along the sail line boundaries (**refer to Figure 1**). The geophysical cause and nature of the acquisition footprint is described later.
  - The general law is that "**Provided that the shallowest target is not unacceptably affected by the acquisition footprint, the streamer spread width should be increased as much as possible in pursuit of the most cost-effective acquisition**".
  - In certain cases of specialized amplitude analysis, footprint effects

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Introduction

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on the seafloor may interfere with certain AVO calibration schemes, although this is not common. In severe cases (notably shallow water) the seafloor event may be missing on stacked images of the outermost CMP sublines from a given sail line, due to the outer trace muting used in processing. The footprint effect upon event continuity and amplitude **decreases** with **increasing depth** (or TWT).

- Footprint effects do not typically interfere with the interpretive mapping of target surfaces, even for shallow surfaces.
- Several processing schemes are now offered by most service companies to reduce the effects of any acquisition footprint.

The Issue of Wide Azimuths

Wide-tow multi-streamer acquisition will not necessarily provide a platform for "wide-azimuth" reservoir characterization. As the source and streamers are "coupled" in a fixed manner, multi-streamer acquisition cannot offer the complete range of source-receiver azimuths potentially available to land or seafloor 3D acquisition. Even when very large streamer spreads are towed, and the range of source-receiver azimuth at near offsets is in the range of $\pm 80^0$, the azimuth range will quickly taper off to less than $\pm 10^0$ at typical far offsets (e.g. 4000+ m). Consequently, wide-tow acquisition can typically only enable "wide azimuth" processing for quite a small offset range. This restriction therefore precludes all but quite shallow targets.

The Cross-Line Acquisition Footprint

Several factors can contribute to affecting the amplitude and signal-to-noise characteristics of imaged cross-line stack traces within a swath of multi-streamer acquisition. The cross-line acquisition footprint (hereafter referred to as the "footprint") is typically observed as decay in amplitude and/or signal-to-noise quality, increasing in severity outwards from the centre of the sail line to the sail line boundaries, and generally diminishing with increasing depth. It is important that the trade-off between the efficiency of towing a large streamer spread and any potential footprint issues be understood prior to a new 3D survey. A common threshold for "acceptable" footprint is 2 – 3 dB amplitude variation in the cross-line stack direction.

The footprint is the cumulative effect of azimuthal fold variations across the near offsets, source-receiver directivity, cross-line AVO variations, and subsurface imaging irregularities. The significant source-receiver offset variation across a typical 3D streamer configuration will result in strong shallow fold and signal-to-noise variation for cross-line stack traces, often resulting in notches of no data between adjacent sail lines for arrival times less than about 1 s TWT. Short near offsets are missing at sail line boundaries, a problem also well known in seafloor and land 3D acquisition. The restricted offset range at sail line boundaries is often compounded when longer offsets are removed by the mute used in data processing. A physically large source array will yield high energy output, with large peak-to-bubble (P/B) ratio, if the array is properly tuned. A reduction in the dimensions of the array (by either using fewer sub-arrays, reducing sub-array separation, or using shorter sub-arrays) can, however, improve the symmetry of energy output (i.e. improve the directivity) at the expense of output, P/B ratio and low frequency content in the source wavelet. After fold and sampling irregularities, source directivity is the next greatest contribution to the footprint. AVO variation in the cross-line direction (shallow targets are recorded with a large range of incidence angles over relatively small offset ranges) is the next greatest contribution to the footprint. Collectively, source directivity and AVO can easily contribute 1 – 2 dB of cross-line (DMO) stack amplitude variation (footprint) for shallow targets (less than about 1 s TWT).

The choice of shooting direction, combined with the choice of shooting method (single-source vs. dual-source, parallel vs. anti-parallel, no streamer overlap vs. streamer overlap, etc.), have a direct influence upon the nature of both severe and subtle imaging artefacts arising during processing. Any acquisition effort to optimize the fundamental pursuit of: 1. Uniform target illumination, and 2. Tight 3D spatial sampling of the recorded wavefield, will minimize any footprint artefacts arising in processing. Dip shooting yields significantly greater illumination irregularities than strike shooting when very large streamer spreads are used. As shooting in the strike direction is associated with more regular illumination, shooting in the dip direction will typically be associated with increased DMO instability and footprint problems. In all cases, the footprint is exaggerated by decreasing depth, increasing target dip, increased source array directivity, increased AVO behaviour at the target interface, and increased streamer spread width. Post-stack migration will reduce any footprint effects observed on DMO stack data. Pre-stack time and depth migrations (PSTM and PSDM) typically yield a reduced footprint in comparison to that observed on DMO stack, due to the larger and more symmetric operator used.

Note that the number of streamers used is not the critical factor that influences footprint – spread width is the issue. PGS experience demonstrates that target depths larger than about 1 s TWT will have negligible PSTM footprint effects when streamer spread widths of 900 m are used, provided that dips do not exceed about 15^0. Larger dips and/or shallow targets must be properly examined by pre-survey planning and modelling before the maximum acceptable streamer spread width is fixed.

Figure 1 shows the results of an elastic 3D modelling and processing exercise, where pre-survey modelling results were quantitatively calibrated against post-survey data analyses. The PGS Nucleus™ package was used for all modelling. Within a standard deviation of the measured amplitude variations, the modelled and real results were shown to compare favourably, despite the inherent approximations during modelling related to generalization of the Earth model and modelling of the AVO behaviour for the target interfaces. In conclusion, the rigorous attention given to pre-survey modelling of wide-tow streamer scenarios in Nucleus™ is very accurate. World-wide experience, where similar post-survey calibration exercises have been completed, also confirms the robustness of the methods described here.

Cost Efficiency of Wide-Tow Acquisition

Survey cost is essentially a function of line lengths and sail line separation. More than a decade of industry 3D experience worldwide has reinforced the cost-effectiveness of acquiring large 3D survey areas, preferably with the shooting direction along the long axis of the survey area:

- The relative area of “prime acquisition” vs. the buffer for full fold run ins/outs and migration aperture increases as the total survey area increases.
- The relative time shooting “prime lines” vs. line turns increases as the line length increases. Shooting in the short-axis direction of elongate 3D surveys (large aspect ratio) results in significant survey inefficiencies.

As vessel technology has improved, streamer counts have increased. The current record held by Ramform vessels is sixteen streamers at

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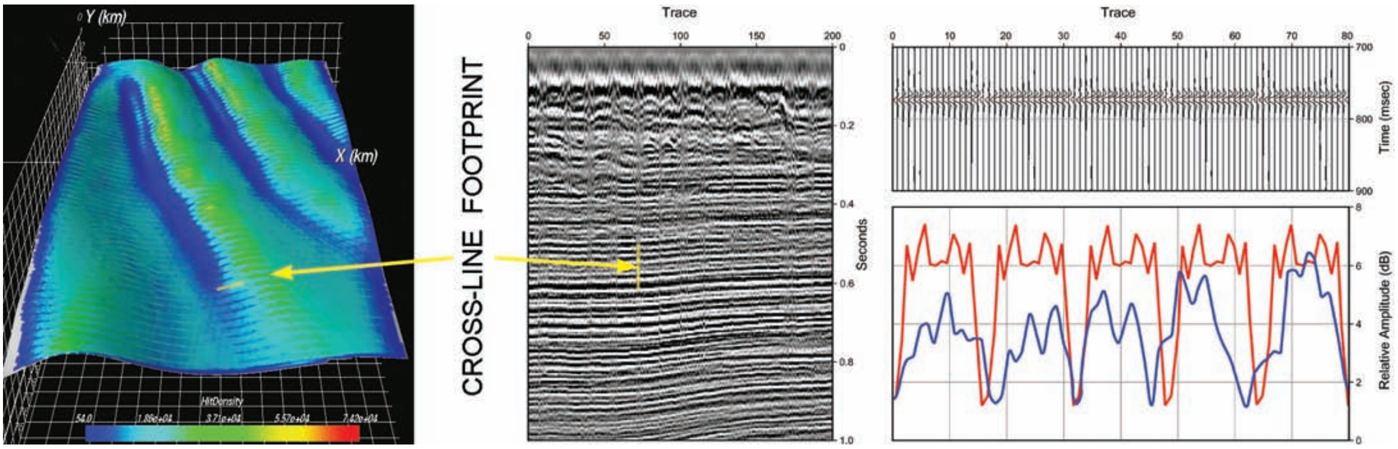

Figure 1: The cross-line acquisition footprint appears as linear bands of degraded amplitudes on horizon/time slices (left) and vertical bands of degraded amplitudes on time sections (middle). The artefact decreases in severity as time/depth increases. In this example of pre-survey modelling calibration the synthetic cross-line DMO stack event at the upper-right represents the result of 3D ray tracing and processing in Nucleus™. PSTM and PSDM results can also be simulated. The 3D dipping plane-layer model used was based upon a survey location in offshore Indonesia. An actual cross-line from the production DMO stack cube (middle) was then used to quantitatively interrogate the footprint amplitudes. An event at ~ 0.7 s TWT was auto-tracked, and compared at the bottom right with the predicted footprint amplitude (80 cross-line stack traces equates to five nominal sail lines). As expected, the modelled footprint (red) slightly overestimates the actual footprint (blue), but the match is good. The modelled amplitudes are asymmetric because 2^0 feathering is used in modelling. The real amplitudes are irregularly periodic because vessel steering varies from line-to-line. Note that the cross-line acquisition footprint in the left figure is a minor artefact compared to the fundamental illumination irregularities associated with overburden structure.

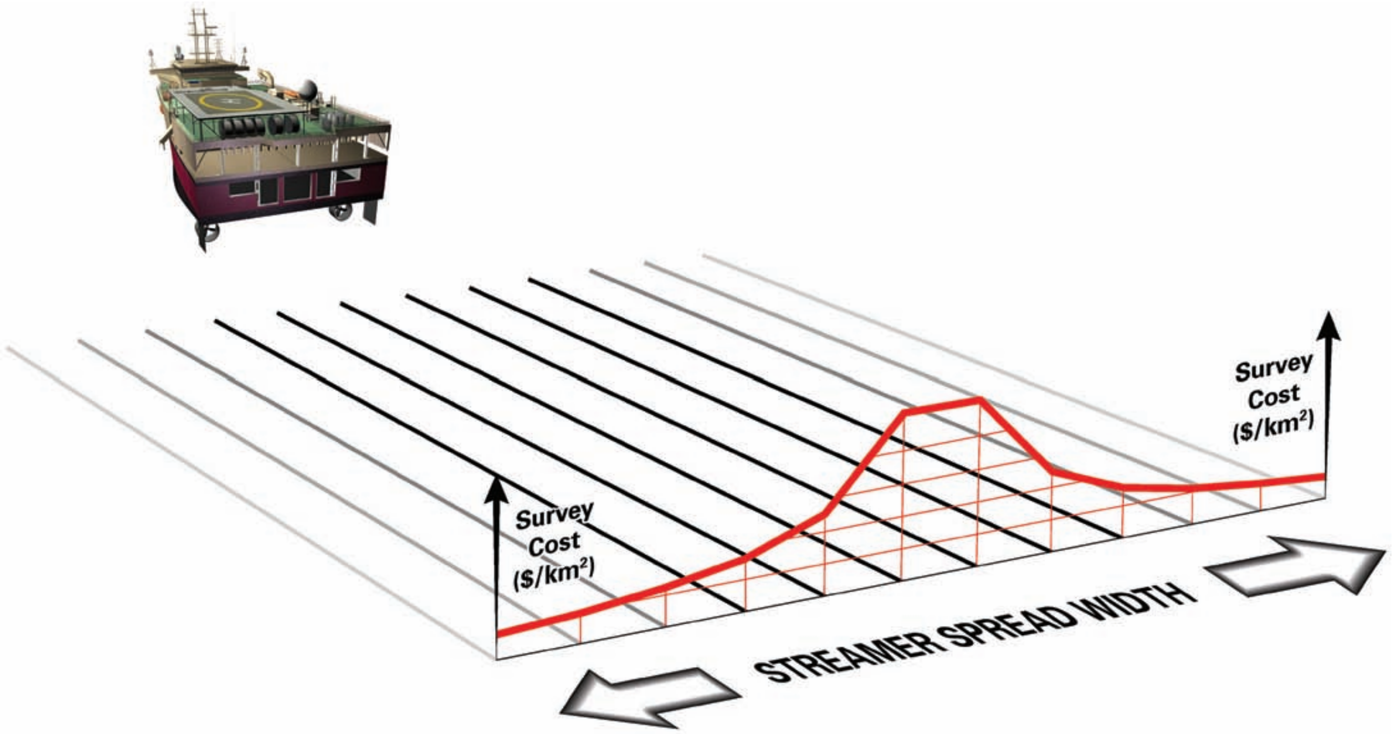

Figure 2: Schematic illustration of the cost benefits of wide-tow multi-streamer acquisition. The number of sail lines required to complete a 3D survey is a direct function of the sail line separation, and therefore, the total streamer spread width.

Cost Efficiency of Wide-Tow Acquisition

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50 m separation. Note that this HD3D configuration has a total streamer spread width of 750 m, and a nominal sail line separation of 400 m. These parameters are equivalent to eight streamers at 100 m separation (700 m spread width, and a nominal sail line separation of 400 m). The standard non-HD3D configuration for Ramform vessels is ten streamers at 100 m separation (900 m spread width, and a nominal sail line separation of 500 m). Modern paravane and towing system technology allows twelve streamers to be towed at 100 m separation (1,100 m spread width, and a nominal sail line separation of 600 m), but maximum streamer length is restricted to 6,000 m in this scenario.

Overall, significant survey efficiencies can be achieved with Ramform vessels. Current daily production records exceed 100 km² of prime acquisition per day. Deployment or recovery of the entire streamer spread can be completed in less than one day, thereby minimizing exposure to environmental or HSE factors.

Conclusions

Wide-tow streamer geometries between 700 and 1,100 m spread width are now commonplace, and should be considered on their merits for any given survey. Pre-survey modelling and planning is quantitatively reliable (in Nucleus™), and is a robust means to investigate all potential geophysical implications of any acquisition scenario. Once it is established that a wide-tow streamer spread is geophysically acceptable at all target depths it then makes obvious sense to minimize cost and exposure to weather, HSE and operational downtime by deploying the most efficient acquisition configuration possible.

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