Minutes of the Sixth Meeting of the

Industry Steering Committee on Wellbore Survey Accuracy

Hotel Sofitel, Vienna
24-25 June 1997

Those present:

Hugh Williamson (Chairman and Minutes)	BP Exploration
Graham McElhinney	Halliburton
Brett Van Steenwyk	SDC/Applied Navigation Devices
Eric Wright	Gyrodata
David Roper	Sysdrill
Adam Henly	Sysdrill
Leif Jensen	Statoil
Roger Ekseth	Statoil
Patrick Knight	Sperry-Sun Drilling Services
Anne Holmes	Sperry-Sun Drilling Services
Dave McRobbie	Sperry-Sun Drilling Services
John Weston	Sperry-Sun Drilling Services
Stewart Brazil	Anadrill
Philippe Theys	Anadrill
Philip Gurden	Baker Hughes INTEQ
Andy Brooks	Baker Hughes INTEQ
Torgeir Torkildsen	IKU
Rita Helen Sveen	IKU
Steve Grindrod	Copsegrove Developments
Inge Manfred Carlsen	Saga Petroleum
Odd H. Inderhaug	Norsk Hydro
Gerard Höhner	SEG
Wulf Luther	SEG

1 Introduction

Hugh Williamson welcomed those present and outlined a proposed agenda for the meeting.

2 Proposed Standard Format for Error Models

David Roper circulated a copy of the latest documentation to all participants, and described their structure and status.

2.1 Document Structure

As far as possible, the document has been divided into independent sections to facilitate its use and further development.

Part 1: *Introduction,* defines terms and outlines the general model for position error.
Part 2: *Error Propagation Model,* states the assumptions underlying the model and shows how position uncertainty propagates from measurement errors.
Part 3: *Error Term Definitions,* lists particular error sources and their behaviour, and is further divided into sections covering specific tool/error types. Part 3(a), *Error Terms for Solid State Magnetic Tools*, covers MWD and EMS tools.
Part 4: *Well Trajectory Models*, shows how the propagation equations change according to the choice of survey calculation method.
Part 5: *Error Term Parameters*, will give the magnitudes and correlation coefficients to be used for particular error sources. It will also be divided into sections covering specific tool and error types.

The document is a development of the approach recently described by Andy Brooks and Harry Wilson in SPE 36863.

2.2 Document Status

The content of the document cannot yet be considered in the public domain. It will, until its formal publication, remain the intellectual property of the four companies who collaborated in its production (Sysdrill, Statoil, BP, INTEQ). Until then, the document may be circulated within the companies participating in the Steering Committee providing certain conditions, detailed within the document, are met. Requests for further copies should be made to David Roper.

2.3 Feedback

Feedback of several types is expected:

- identification of typographical errors in equations
- questions on (physical) correctness of equations
- identification of missing error terms
- requests for clarification
- fundamental concerns about the approach

All feedback will be welcomed by the authors and should be directed to them by e-mail.

Actions:

Participants to review document, critically assess it as a proposed standard for the Industry and send comments to authors.
Authors to discuss all feedback, agree revisions as appropriate and present summary at next meeting.

2.4 Publication

Several options for dissemination of the material were suggested and discussed.

SPE Paper There are several problems associated with this format:
- the equations could not be presented in full due to lack of space
- the novelty of much of the material is questionable
- getting survey error papers accepted for conferences is difficult

SPE Monograph It was felt the more extensive treatment offered by the monograph format might better suit the material. However, it was recognised that such a document would require substantial work, and ought to include yet-to-be-completed work on gyroscopic systems.

IMS Publication The IMS has published several technical documents which have been well received. The likelihood of these reaching a wide audience is, however, questionable.

API Recommended Practice An API RP would formalise the material, and could help its adoption by the industry as a whole. However, the administrative effort required to produce and maintain such a document, and the lack of contacts between members of the Committee and the API were regarded as significant drawbacks.

Action: Authors of the document to discuss options for publication with senior SPE representatives.

3 Input Parameters for Basic MWD Error Model

At the Amsterdam meeting, participants had committed to share their knowledge of the size and behaviour of MWD errors sources with the previously identified “focal points”. The results, as presented by the focal points, were as follows:

3.1 Sensor Errors

Perhaps not surprisingly, Anadrill had not received any alternatives to the values they had presented at the Denver meeting.

Stewart Brazil reviewed these values, explaining that they were derived from a number of sources, but were intended to be representative of typical tool performance in the field. In particular, the values were 1.3 to 1.6 times larger than those characteristic of tools leaving Anadrill’s calibration facility.

Estimates had been made of the contribution of “sensor” errors and “electronic” errors to each error source. It was agreed that, provided it was reasonable to assume statistical independence, a total value could be estimated from the root-sum-square of these contributions.

Details of the estimates are given in "Compilation of Basic MWD Error Sources - Preliminary Version 1"

There was agreement that for estimates of sensor performance to be truly comparable, more clarity was needed on when and how the performance is assessed, and how typical values are derived from them.

Important Note. Subsequent to the meeting, Roger Ekseth and Hugh Williamson agreed to request, on behalf of the Operators, and with an assurance of confidentiality, specific sensor error information from each of the four major directional companies. The information to be supplied is as follows:

A value for bias and scale factor for both accelerometers and magnetometers with, if appropriate, differentiation between axial and cross-axial sensors, and between different models of sensor. Each value to be calculated as the standard deviation of a sample of the observed changes between consecutive calibrations of a sensor. The sample to consist of at least five update values for at least twenty-five sensor packages from tools which have been used in the field and have been subject to a standard calibration cycle. The following provisions also apply:
- calibrations subsequent to or made as a result of sensor faults are to be excluded from the sample.
- the values supplied must be traceable to individual calibration records.
- either sensor misalignment within the tool is to be documented as insignificant in comparison to sensor biases and scale factor errors, or specific values for misalignment are to be supplied derived in the same way as the values for bias and scale factor error.

Actions:
- Anadrill, Halliburton, Sperry-Sun and INTEQ to provide above information to Hugh Williamson and Roger Ekseth
- Hugh Williamson and Roger Ekseth to use values received to derive values suitable for inclusion in basic MWD error model.

3.2 Drillstring Interference

Graham McElhinney presented the results of his recent researches into (axial) drillstring interference. With the aid of a hand-held electronic compass, the compass deflection near the ends of many drillstring components had been measured. These measurements had shown that the vast majority of magnetic poles lie within 30cm of the end of the component.

Theoretically, a magnetic pole may be either a monopole or a dipole. The field strength associated with a monopole will fall off with the cube of the distance away from it. For a dipole, the field strength falls off with the square of the distance.

Most of the compass deflection measurements had been made 30cm from the end of the component. The compass deflection to be expected at 5m, 10m, and 15m from the end of the component when oriented horizontally in an east/west direction had been calculated under the "worst case" assumptions that (a) the pole behaved like a dipole and (b) the pole was 30cm from the end of the component.

The results showed that:
- the variance in pole strength was so great, even amongst similar components, that it was not possible to make sensible error predictions based solely on the make-up of a BHA.
- a significant number of supposedly non-magnetic components exhibited appreciable magnetisation (>¼° azimuth error at 5m distance).

- the measurements of compass deflection for some components, particularly steel stabilisers, were “saturated”, so that the expected deflections calculated for greater distances were probably underestimates.

It was Graham’s view that the permanent magnetism found in drillstring components resulted from the large fields to which they are exposed during inspection. These fields are typically 50,000 to 100,000 times the strength of the Earth’s field.

There followed a discussion on whether the magnetic properties of drillstring components change downhole. Steve Grindrod stated that Shell Expro had observed that the magnetic properties of motors and jars do indeed change. Graham McElhinney pointed out that “before and after” measurements would settle the issue and stated his intention of making such measurements for some of the components he had already studied.

Andy Brooks mentioned that INTEQ were in the process of making similar measurements, and that he expected to have some results by the next meeting.

3.3 BHA Misalignment

Phil Gurden had received estimates of BHA deflection errors only from BP Exploration. These values, which are treated as due to sag under gravity, were in broad agreement with those currently in use by INTEQ.

3.4 Magnetic Field Errors

Hugh Williamson presented some estimates of magnetic field uncertainty. He thanked Baker Hughes INTEQ for their permission to use a report commissioned by them, “Error Estimates for Geomagnetic Field Values Computed from the BGGM” as a primary source of information.

Five sources of error were identified:

1. Errors in fit of main field model to actual main field (at base epoch)
2. Errors in prediction of secular variation
3. Regular daily variation (due to electrical currents in the ionosphere)
4. Irregular variation in time (due to electrical currents in the magnetosphere)
5. Irregular variation in space (due to magnetic properties of crustal rocks)

The likely magnitudes of these five errors were estimated individually, often from sparse or otherwise restricted data. In particular, several estimates known to be realistic in the region of the North Sea were extrapolated to cover the rest of the globe.

The general assumption was that errors 1, 2 and 5 were correlated between all surveys in the same field, and that errors 3 and 4 were correlated between adjacent survey stations but not between surveys in the same well. Correlation coefficients for these latter errors were highly dependent on the mean time between surveys, with estimates bing made from data collected from two UK fields.

Patrick Knight pointed out that the magnitude of the daily variation was frequently observed to increase following solar flare activity. Hugh Williamson thought that since an entire year’s data had been used in the estimates of this error source, this effect could be considered to have been incorporated within the values presented.

David Roper expressed some doubt over the values presented for the error in the main field model. He thought aliasing of the data could lead to larger actual errors than were suggested by the goodness of fit of the data to the model.

3.5 Measured Depth

Roger Ekseth presented some recent work he had done on evaluating drillstring measured depth errors. He stressed that the work had not yet been fully checked and therefore that the conclusions should be treated with caution.

Roger felt that the usual assumption of a linear increase of error with depth was too simplistic. By contrast, a complete analysis of the drillstring was complex and impractical given the usual lack of information available at the planning stage.

As a compromise, the following process had been undertaken to give a set of fit-for-purpose error estimates:

1. List all known sources of error (12 separate sources were identified)
2. From a knowledge of the physical causes of each error term, write down an equation for its size in terms of the relevant physical parameters (drillstring length and cross-section, mud density, etc.)
3. Choose typical values for each physical parameter
4. Evaluate the combined effect of all the error sources for a number of different well shapes and sizes
5. Find a simplified expression for the total depth error in terms of a small number of parameters which closely approximates the values found in (4).
6. Modify the expression in (5) to fit the proposed standard definition for error sources.

Completion of this work had led to the following conclusions:

- Due to the widely differing offset errors, it is necessary to differentiate between surveys taken on floating rigs and those drilled from rigs sitting on land or on the seabed.
- The total bottom-hole depth error predicted for any well can be satisfactorily approximated by the sum of three terms:
  (i) a constant term
  (ii) a term proportional to measured depth
  (iii) a term proportional to the square of the true vertical depth
- Although the most significant sources of error are known to behave as biases (that is, they always affect the measurements in the same sense), it is more convenient, at least in the short-term, to treat them as having mean zero. To achieve this, it is necessary to treat the calculated bias values as if they were random values at some fixed confidence level. A confidence level of 95% (2 standard deviations) was suggested as the most suitable.

Roger had also performed a similar analysis for wireline depth errors, where eleven separate error sources had been identified.

3.6 Post-Correction Residual Errors

Andy Brooks discussed the errors remaining after the application of corrections for BHA sag and axial drillstring interference.

He identified 4 sources of error associated with BHA sag corrections:

1. Errors in the model. For example, results from software which allows the modelled drillstring to lie outside the borehole wall will clearly be unreliable.
2. Incorrect application of the model. For example, application of the correction with the wrong sign.
3. Inappropriate use of the model. For example, applying a correction where no significant sag deflection should have been expected.
4. Imprecision in the calculated correction.

The first three of these, although significant, must be classified as gross errors and are therefore outside the scope of an error model. A value of 0.08°sin(Inc) (at 1 standard deviation) had been suggested by BP as typical of the fourth error source. The sin(Inc) dependency resulted from the expectation that the error would be proportional to the component of gravity acting perpendicularly to the drillstring.

David Roper was of the opinion that perhaps 90% of the sag error could be removed by a detailed finite element analysis of the drillstring, but that this was rarely carried out in practice.

Andy gave a diagrammatic explanation of the dependency of conventional axial magnetic interference corrections on the assumed values of magnetic dip and field strength. He referred to his recent paper SPE 36863 which contains mathematical expressions for this dependency. These expressions can be further simplified under the assumption that the uncertainties in the horizontal and vertical components of the earth's magnetic field are the same.

It was important to note that the use of such corrections introduced a dependency on the absolute scale factor of the magnetometers. There is no such dependency when all 6 sensors are used to compute the well azimuth.

Actions:
- Hugh Williamson to summarise and circulate the current best estimates of error magnitudes within a single document.
- Participants to continue to contribute empirical and anecdotal evidence to help finalise basic error model.

Note: Accompanying these minutes is a document, "Compilation of Basic MWD Error Sources - Preliminary Version 1" which contains a summary of the figures presented by participants to date.

4 Gyroscopic and Inertial Systems

Gerard Höhner gave a brief introduction to his company, SEG, and described two programs for simulating errors in gyro and inertial systems, both of which could be used in oil well applications. The two programs, one commercially available through Navstar, and one developed in-house by SEG, could model both strapdown and gimballed systems. About 50 separate error sources were included in the models, and the effects of rig motion, different well trajectories and the use of different Kalman filtering techniques could be properly accounted for.

Hugh Williamson asked if, from what they knew of their mechanisation, the performance of gyroscopic and inertial tools currently in use in the oil field could be predicted using these programs. Wulf Luther thought that they could.

There followed some discussion on the applicability of the proposed standard error model formulation to gyro systems. The main drawback of the currently proposed model was its inability to incorporate errors which accumulate down the well. Brett van Steenwyk confirmed that any system which "remembers" its own orientation is bound to be subject to such errors.

Note: In discussion subsequent to the meeting, a straightforward modification to the error propagation equations was suggested which would remove this difficulty.

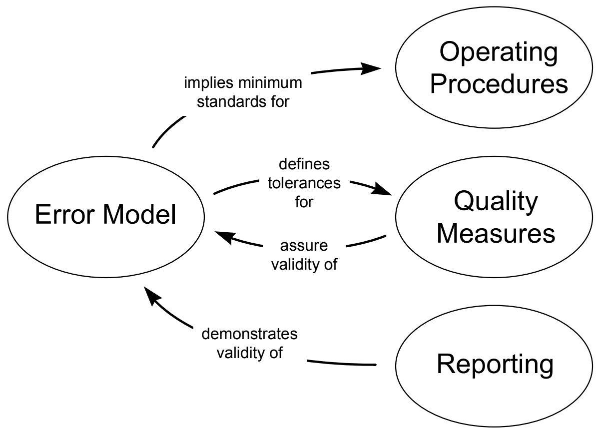
If the ith error source is systematic within a survey (that is, its magnitude is constant within a survey) then its magnitude in the kth survey is a random variable ε_i^k *with standard deviation* σ_i^k.

In the current model, the resultant error in azimuth (say) at the pth station is $\delta A_{k,p} = \left.\frac{\partial A}{\partial \varepsilon}\right|_{k,p} \varepsilon_i^k$.

In the proposed model, this becomes $\delta A_{k,p} = \left.\frac{\partial A}{\partial \varepsilon}\right|_{k,p} \varepsilon_i^k + C\delta A_{k,p-1}$ *where* C *= 0 or 1 depending on whether the error source is "memoryless" or not.*

5 Improving Quality

Hugh Williamson opened the discussion on quality by emphasing the links between an accepted error model on the one hand, and standard operating procedures, quality measures and reporting requirements on the other. He argued that knowledge of the occurrence, behaviour and "acceptable" size of each individual error source could be used to derive and define standards for the above three elements of every survey service.



Philippe Theys cited the multi-level records maintained by Schoeller-Bleckmann as a demonstration of traceability bing a prerequisite of quality. He contrasted this with the poor level of data collection and traceability typical of many survey services. There were several contributory causes:

- multiple sets of requirements for different clients
- lack of awareness of possible sources of error
- lack of process control
- too much unjustified human intervention in the handling and processing of data

In addition, there was the problem of data storage:- customers were not routinely interested in receiving non-essential data channels, but service providers couldn't commit to store this data themselves indefinitely.

It was pointed out that quality certification, such as the ISO9000 series, did not demonstrate the use of best practices, only of standardised practices.

Hugh Williamson then asked the general question: "What can the Committee do to improve quality?". Many of the responses related to raising the awareness of oil companies of the importance of survey quality and the possible impact of well positioning errors on their business.

Since the majority of members came not from oil companies but from the service sector, this led to the question: "Why does the Committee want to improve quality?". The responses to this could be divided into two groups:

Operator benefits:
- improved production
- greater safety
- reduction in lost time

Service Sector benefits:
- conformance to a standard makes life easier and more economic
- fewer penalties for poor performance
- establishment of a standard would help leverage other Operators into paying more for higher quality services.

The majority conclusion was that the Committee needed to attract more Operators to take an active interest in its work. This would give the participants from the Service Sector both increased motivation to champion quality initiatives, and an increased likelihood of receiving support for such initiatives from within their own companies.

It was pointed out that representatives of the Service Sector often have a broader network of contacts with oil companies than do the Operators themselves. Responsibility for attracting other Operators to the Committee should therefore be shared equally amongst all its current participants.

Actions:
- all participants committed to take some specific action to involve one or more new Operator representatives in the work of the Committee.
- Philippe Theys will pursue the inclusion of a session devoted to directional survey accuracy in the programme of the SPWLA Topical Conference on Log Data Quality (Taos, 12-16 Oct).

6 Next Meeting

Given the wish to attract representatives of other oil companies, it was suggested that the next meeting include a seminar-style discussion of:
- the value to the Operator of quality directional surveys.
- the most common errors affecting directional surveys.

- case studies of good (value adding) and poor (costly) survey quality delivery.

Thursday 9th October in Houston (following the SPE Annual Technical Conference and Exhibition in San Antonio, 5th-8th Oct) was agreed as a provisional date and venue. Graham McElhinney kindly offered to host the meeting. The meeting may be planned to extend into Friday 10th, depending on the program.

Action: Hugh Williamson to suggest program for meeting, request contributions from members, and confirm its date and location.