Minutes of the Seventh Meeting of the

Industry Steering Committee on Wellbore Survey Accuracy

Halliburton, Hwy 6, Houston
9 October 1997

Those present:

Hugh Williamson (Chairman and Minutes)	BP Exploration
John Turvill	Halliburton
Robert Wylie	Halliburton
Herb Illfelder	Halliburton
Brett Van Steenwyk	Scientific Drilling
Jim Towle	Scientific Drilling
Tim Price	Scientific Drilling
Koen Noy	Gyrodata
Tim Dallas	Gyrodata
Roger Ekseth	Statoil
Paul Rodney	Sperry-Sun Drilling Services
Wayne Phillips	Anadrill
Stewart Brazil	Anadrill
Philippe Theys	Anadrill
Robert Estes	Baker Hughes INTEQ
Andy Brooks	Baker Hughes INTEQ
Oddvar Lotsberg	Baker Hughes INTEQ
Steve Grindrod	Copsegrove Developments
Inge Manfred Carlsen	Saga Petroleum

1 Introduction

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

2 Basic MWD Error Model

2.1 Feedback on "Position Uncertainty Modelling" Document

No specific feedback had been received by the authors. The general consensus was that the document was made difficult to read by the poor arrangement of material. Some specific suggested additions were:

- a non-technical introduction, stating clearly what the document is trying to accomplish
- one or more worked examples
- a comprehensive list of references
- equation numbering

Andy Brooks reported a suggestion by John Thorogood (SPE) that the document be thoroughly peer-reviewed prior to publication. Hugh Williamson suggested that John de Wardt might be an additional or alternative reviewer.

Action: Hugh Williamson to pursue the suggested changes and additions to the document and distribute a new or alternative version prior to the next meeting.

2.2 Depth Errors

Hugh Williamson summarised how he Roger Ekseth had further developed Roger's work on depth error modelling since the previous meeting.

Roger had identified 20 separate error sources affecting both drillstring and wireline measurements, and had endeavoured to model each of them on physical principles. Given the variability in important parameters such as drill-pipe cross-section and mud weight, it was impractical to attempt to use this comprehensive physical model at the directional planning stage. As an alternative, a simpler model had been developed using the following process:

- choose typical values for each of the physical parameters in the detailed model.
- calculate the depth error from the detailed model for a variety of depths and well trajectories.
- select a small set of "weighting factors" to form a basic depth error model.
- find a set of error magnitudes for the basic model which closely match the results of the detailed model.

In this way, the following basic depth error model had been derived:

Name	Weight. fact.	Magnitude(*)	Physical justification
Depth reference error	1	0.35 m	summation of zero-reference errors, including drill-pipe above rotary and BHA deformation
Depth scale error	MD	0.225×10^{-3}	summation of scale errors, including all measuring tape errors and drillstring ballooning.
Depth stretch-type error	MD.TVD	$0.22 \times 10^{-6} m^{-1}$	summation of effects of elastic stretch, thermal expansion and hydrostatic compression.

(*) Magnitudes quoted are at 1-sigma level, but bias-type errors are included at a level which makes 2-sigma error estimates correct. The particular model quoted is for a bottom-founded rig.

Roger explained that some of the elements of the detailed model and their associated parameters had been derived from laboratory work performed by Rogalands Research, but that others were essentially best guesses from within Statoil.

John Turvill thought the quoted values rather low, especially the scale error, and quoted the high thermal gradients in Thailand as an example. He cautioned against publishing values which were known to be conservative in some areas, and suggested rather that “worst case” values should be given.

Andy Brooks thought the reference error might also be conservative, given that the length of drill-pipe above the slips was as likely to be ignored completely as estimated wrongly. Robert Estes stressed the need to make some allowance for human error, especially in drill-string taping.

It was agreed that the parameters used to derive the basic model should be reviewed to ensure they weren’t overly conservative, and that the model’s sensitivity to fundamental parameters such as thermal gradient and drill-pipe cross-section should be investigated.

Action: Hugh Williamson to complete this work and present results at next meeting.

Wayne Phillips pointed out that many of the error sources were of known sign, and should therefore be corrected for - the error model would then reflect the post-correction residual depth error. This was agreed in principle, but would not conform with the intent that the basic MWD model predict errors typical of today’s practices.

2.3 Drillstring Interference

Oddvar Lotsberg described some recent work performed by INTEQ in Norway to investigate the permanent and induced magnetisation of drill-string components.

Each component was laid horizontally north-south, and the total magnetic field measured with a proton magnetometer at 2, 4, 6, 8 and 12 metres from the end. The component was then flipped over, and the measurements repeated. Measurements of the ambient field were also made. In this way, it was possible to distinguish between induced and permanent magnetism.

Pole strengths at the box and pin ends of each component were calculated individually, with a single parameter being fitted to each set of five measurements. This parameter represented the pole strength of equal monopoles (ie. field strength falls off as inverse square of distance from pole), the poles being assumed to lie 50cm within each end of the component. More weight was given to the more distant measurements, since these were more typical of non-magnetic spacings used in the field. Several dozen components of a range of types and sizes had been examined in this way.

The results indicated that the total range of pole strength values was largely independent of component diameter, but there were indications that average values were larger for larger diameter components. Some drill collars were found to have particularly high pole strengths, possibly resulting from the strong magnetic fields used in inspection testing.

There was no evidence of induced magnetism in the components tested. Oddvar had calculated that a relative permeability of 4000 would generate a pole strength of about 800 micro-Webers. Wayne Phillips thought that the geometry of the components would reduce the relative permeability to perhaps 100, which would explain the apparent absence of induced magnetism.

In addition to these direct measurements, INTEQ had calculated pole strengths indirectly for several BHAs used in the field. The calculation was based on the average correction applied for axial drillstring interference, and assumed two monopoles arranged such that their effect on azimuth was additive.

Oddvar concluded that reliable non-magnetic spacing requirements could only be based on the results of a large number of experimental measurements. In addition, making azimuth corrections based on measuring the magnetisation of components at surface was problematic due to the unknown changes to the magnetisation of components downhole.

Hugh Williamson had used the experimental data presented by Graham McElhinney at the previous meeting to calculate strengths for monopoles assumed to be 50cm within the end of the components (80cm from the point of measurement). The results were in good agreement with both the direct and indirect determinations of pole strength made by INTEQ. Combining all the data together gave a population of about 100 steel components. A histogram of pole strengths showed a roughly gaussian distribution, with an RMS value of 400 micro-Weber. The maximum pole strength was 1150 micro-Weber, and there seemed to be little overall relationship between component diameter and magnetic pole strength.

It was noted that Graham’s slides had contained an error, giving the relationship between magnetic field strength and distance for dipoles and monopoles as inverse square and inverse cube respectively. This error had been repeated in the minutes of the previous meeting.

Hugh noted a useful “rule-of-thumb” stating that an X micro-Weber monopole created an X nano-Tesla magnetic field at a distance of 9 metres.

2.4 Sensor Calibration Data

The Group discussed the request for sensor calibration and performance data made by Hugh Williamson and Roger Ekseth subsequent to the previous meeting.

Wayne Phillips reported that calibration data "five cycles deep" would take several years to compile if it were not already available, and might be of no greater value than data one or two cycles deep. Paul Rodney agreed with this. John Turvill thought that he could access such data, but both he and Robert Estes thought that older data was likely to be of a lesser quality.

Roger Ekseth stressed that he wanted to see at least some data that was more than one cycle deep in order to demonstrate that changes in calibration don't accelerate over time. Once this had been demonstrated, the vendors could concentrate on amassing "broad" datasets. John Turvill showed the successive jumps in calibration values for two tools over a five-year period. They showed no systematic ageing effects. Paul Rodney added that he had gathered similar data for five tools, and that he had seen no acceleration in calibration variability with age - except immediately prior to tool failure.

Wayne Philips and Paul Rodney pointed out that there are two separate error sources which need to be distinguished:

- residual errors resulting from fitting thermal model curves to calibration values determined at discrete temperatures.
- jumps in calibration values between successive calibrations.

Wayne pointed out that the difference between successive thermal models could be interpreted in several ways, and that the Group should standardise by always reporting the difference between the models interpolated at 125°C.

Actions: Paul Rodney and John Turvill/Robert Wylie to investigate the added value (if any), of "deep" datasets over "broad" datasets using their small historical datasets (5 tools).
Meanwhile, all vendors to gather "broad" datasets (100 tools, 1 cycle deep) and to perform separate evaluations of:

- residuals from fitting thermal model for single calibration (average value for entire temperature range)
- differences between successive calibrations (at 125°C).

2.5 General

Hugh Williamson showed the progress to date of the basic MWD error model, and highlighted the three most significant gaps:

- BHA radially symmetric misalignment
- cross-axial magnetic interference
- conversion from axial magnetic pole strength to axial interfering field.

If was agreed that S.I. units (with angles in degrees) should continue to be used by the Group.

Hugh also reviewed the standard nomenclature. B was preferred to H for magnetic field strength, and Ω was preferred to ω for Earth rate (angular velocity).

Action: Hugh Williamson to include latest version of basic MWD model and nomenclature when distributing minutes for future meetings.

3 In-Field Referencing - A Geophysicists's View

Jim Towle gave a presentation on the time and space variations in the Earth's surface magnetic field. He highlighted the importance of the subject in a number of applications, particularly those involving long electrical conductors such as power lines and telephone cables, in which magnetic disturbances can induce currents of hundreds of amps.

Spatial incoherence of geomagnetic disturbances is caused by:
- variations in ionospheric source morphology
- geomagnetic induction in open water
- geomagnetic induction in local geology.

Rapid changes in the magnetic field due to ionospheric disturbances induce electric currents in the oceans and conductive geology, which in turn set up magnetic fields which can be as large as 50% of the source field strength. These effects are concentrated near coastlines and conductive features in the Earth's crust and will be greatest at high latitudes. In these areas, some of the assumptions underlying the use of interpolated in-field referencing (IIFR) may be difficult to uphold.

It is theoretically possible to attempt a correction for these induced fields by means of "transfer functions". These rely on Fourier transforms to generate the phase and magnitude shifts in the field variations between two locations as a function of the time period of the disturbance.

4 Error Modelling of Gyroscopic and Inertial Systems

Roger Ekseth summarised his work on developing error models for gyroscopic tools. The main application of the models would be in well planning, and in investigating the performance variations between different tools. It was important for the maintenance of the software which will incorporate the models that they be as simple and as logical as possible. It must also be straightforward to introduce new tools. For this reason, Roger wanted to limit the number of different modules required for error modelling and preferred to fit the gyro tools into the existing error propagation framework.

Roger had identified the main sources of instrument error in the (north-seeking) gyro tools in most common use and had derived "weighting functions" which express their effects on the tools' measurements of inclination and azimuth. For continuous tools, Roger had made use of the error accumulation scheme outlined in the minutes of the sixth meeting. He was in the early stages of applying the method to inertial systems, but was optimistic that it was practical to do so.

Roger recognised that characterising the performance of continuous gyro and inertial tools with this scheme would present some problems, but believed these could be overcome. He explained that there will be a different set of equations for each tool and that each term will require "tuning" once the models have been implemented in software.

Tim Price asked how it was proposed to validate the behaviour of the models, and recommended the approach taken by Shell, where use of a particular model required the use of a particular set of standardised procedures. Hugh Williamson suggested that the behaviour of the models could be validated by comparison with the vendors' own "black box" models.

It was generally accepted that error models for gyroscopic and inertial tools, being more dependent on the instrumentation than on the environment, would require more intensive field validation than error models for MWD. Wayne Phillips was concerned that field comparison data sufficient for rigorous model validation would be difficult to source.

5 Establishing New Error Models

Hugh Williamson introduced the discussion by dividing the process of establishing new error models into four phases: development, validation, approval and review. He then showed how each phase required a different level of knowledge, authority, or access to data.

Note: the phases may be summarised by,

Development:	*Choice and/or definition of the error terms in the model based on knowledge of the tool and its operating environment. Defining the applicability of the model and the minimum operating procedures its use implies.*
Validation:	*Compilation of sufficient evidence to reasonably establish the validity of the error model, including results from the test stand, test wells, and operational wells. Summarising the results.*
Approval:	*Decision to use error model in well operations.*
Review:	*Analysis of the continued validity of the error model as a result of new field data, or changes to the tool, operating conditions or procedures.*

Tim Price asked how the Committee could expect to reach agreement on the approval of any error model. Hugh thought that the Committee was probably the wrong body to approve error models, as approval inevitably implied the acceptance of some risk.

Philippe Theys made a comparison with ISO standards - companies could insist that error models had met standards set by the Committee before they would be used. Robert Estes preferred an analogy with Wolff and de Wardt - their method had been adopted across the Industry without the authors even recommending its use. The same could be expected of the work of the Committee.

Hugh Williamson suggested the Group compile a list of items which they would want to see in an “Error Model Validation Report” should they be in a position involving the approval of models. The suggestions were:

- Statement of the error model
- Limits of the model’s applicability
- Standard operating procedures
- Quality measures and specifications
- Experimental data
- Standard worked examples

Stewart Brazil thought the Committee had spent too much time defining the first entry on the list when it could have been making progress on several of the others. Wayne Phillips suggested that the Committee could work on compiling a list of standard examples (well profiles) against which to test error models.

Action Hugh Williamson to seek input from participants on the features to be included in a list of standard examples. Results to be summarised and discussed at the next meeting.

Herb Illfelder asked when the Committee was planning to publish the results of its work. Hugh Williamson thought that the method for computing positional uncertainty and the basic MWD error model should not be published until they had been implemented in software and reality checked. This was likely to take at least 6 months. He felt that two more meetings would be required in order to finalise the content of the first paper, which meant it might be published in a little over a years time.

6 Next Meeting

Roger Ekseth offered to host the next meeting. It will be held at Statoil's R&D facility in Trondheim on Thursday 19th February 1998.

Action: Hugh Williamson and Roger Ekseth to confirm date and venue to participants.