Minutes of the Eighth Meeting of the

Industry Steering Committee on
Wellbore Survey Accuracy

Statoil R&D Facility, Trondheim
19 February 1998

Present:

Hugh Williamson (Chairman and Minutes)	BP Exploration
John Turvill	Halliburton
Brett Van Steenwyk	Scientific Drilling
John Barlow	Scientific Drilling
Tim Dallas	Gyrodata
Roger Ekseth	Statoil
Torgeir Torkildsen	Statoil
Leif Jensen	Statoil
Paul Rodney	Sperry-Sun Drilling Services
Anne Holmes	Sperry-Sun Drilling Services
Dave McRobbie	Sperry-Sun Drilling Services
Alewyn van Asperen	Shell International
Jack Emmen	Shell International
Angus Jamieson	Tech 21 UK
Chris Chia	Anadrill
Philippe Theys	Anadrill
Harry Wilson	Baker Hughes INTEQ
Andy Brooks	Baker Hughes INTEQ
David Roper	Sysdrill
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 Sensor Calibration Data

Paul Rodney presented the results of Sperry-Sun's investigation into time variation in calibration results. Of 417 sensor packages for which calibration data were available, only 28 had 3 or more sets of data.

Trends in sensor bias and scale factor over time had been searched for by curve-fitting consecutive calibration results. On a very few sensors, the regression coefficients were significant, but in general no time effect had been found. Paul speculated that degradation of sensor performance was more closely related to type of service (hot hole, high vibration etc.) than to elapsed time.

Paul again put forward the idea of using residual errors to estimate field performance of sensors. Residual errors are the errors (expressed as angles or biases) which the sensors exhibit in the test stand after correcting for calibration parameters. Calculating residual errors prior to re-calibration would give an estimate of field performance.

Harry Wilson noted that MWD sensors have very stable performance and rarely fail their calibration checks. In contrast electronic multishot sensors, which receive rougher treatment, tend to drift gradually out of calibration. This observation was supported by Dave McRobbie.

Andy Brooks summarised INTEQ's approach to calibration checking. Tools are acceptance tested in the local service base's test stand after every job. The inclination and azimuth measured by the tool are recorded at a series of inclinations, azimuths, toolfaces and temperatures. If any measurement exceeds a pre-defined threshold (0.25° for inclination, an inclination-dependent step-function for azimuth), the tool is recalibrated. The results of 5,000 to 10,000 such acceptance tests performed on each type of tool at the Lafayette base were used to derive the sensor performance parameters for INTEQ's own error models.

John Turvill had found more than 30 sensors with a history of at least 5 calibrations. He showed summary statistics for two such, one of which showed indications of a change in the magnetometer scale factors over time. One sensor package showed the biggest change in calibration over the smallest time interval. In summary, there appeared to be no consistent time-related behaviour.

2.2 Depth Errors

Hugh Williamson showed a breakdown of the error budget for drillstring depth errors predicted by Roger Ekseth's physical model. The two most significant errors were drillstring stretch and drillstring thermal expansion, the effect of the latter being about half as much again as the former.

Several members commented that this was the reverse of the expected result, and that stretch would in most circumstances exceed thermal expansion.

Action: Hugh Williamson to check calculations and critical parameters used in this calculation:

Follow-up: *In a frictionless vertical well, the theoretical errors should be :*

Thermal Expansion	=	$\frac{1}{2}.D^2.Ct.Gt$
Stretch	=	$(p.g/E).\{ \frac{1}{2}.D^2 + L.(D - L)(X-1) \}$

where

D	=	*depth of well (m)*
Ct	=	*coefficient of thermal expansion of steel (/degC)*
Gt	=	*geothermal gradient (degC/m)*
p	=	*density of steel in mud (kg/m³)*
g	=	*acceleration due to gravity (m/s²)*
E	=	*Young's modulus of steel (N/m²)*
L	=	*length of drill-collars (m)*
X	=	*ratio of drill-collar cross-section to drill-pipe cross-section*

In the example, the values used were:

D	=	*3500 m*
Ct	=	*0.000012 /degC*
Gt	=	*0.04 degC/m*
p	=	*6250 kg/m³*
g	=	*9.81 m/s²*
E	=	*212,000,000,000 N/m²*
L	=	*120 m*
X	=	*7.15*

which gives	*Thermal Expansion*	=	*2.94 m*
	Stretch	=	*2.49 m*

The global average geothermal gradient is, in fact, nearer

Gt = *0.025 degC/m*

which would give Thermal Expansion = 1.84 m

Likewise, 9"/3" drill collars with 5½" drill pipe would give:

X = *8.94*

and hence Stretch = 2.70 m

The conclusion must be that either error source can be greater, depending on the particular circumstances of the well.

Hugh outlined a point of discussion that had arisen in the error propagation Working Group concerning depth errors. The problem, which concerns the distinction between uncertainty in the wellbore position and uncertainty in the depth of the survey tool along the well, was first raised by John Thorogood in 1990 in a critique of Wolff and de Wardt's approach. Expressed another way, the discussion distinguishes between the uncertainty in the well's location at a fixed along-hole depth, and the uncertainty in the position of the survey tool when it came to rest.

Follow-up: Preparatory mathematical work by Andy Brooks and others, and a meeting of the Working Group on Friday 20th, established that the two methods of depth error propagation produce results which differ only by an along-hole component. Elements of both methods are required in the solution of all but the simplest positional uncertainty problems. The topic will be fully discussed in the paper describing the error propagation mechanism.

Steve Grindrod mentioned a case where mis-matches of between 12ft - 40ft had been seen when tying wireline depths to a gamma-ray tag at 10,000ft measured depth. Tim Dallas felt much of this difference would be attributable to gross error, particularly as wireline operators are likely to be less careful when they know they will be re-zeroing the depth at a tag.

2.3 Cross-Axial Drillstring Interference

Hugh Williamson showed a slide summarising some data collected by Anne Holmes. The data comprised estimates of the bias affecting the X and Y magnetometers in 78 MWD surveys. The surveys came had a wide geographical distribution, and included cases where magnetic spacing was both good and poor. The bias estimates are calculated by Sperry-Sun's magnetic survey processing algorithm.

Anne noted that several outliers, indicative of magnetic hot-spots, had been eliminated from the dataset, and stated her intention to continue gathering this data.

The root-mean square of the remaining bias values was 57 nT. This value represents the combined effect of sensor biases and magnetic interference caused by the drill-collar. A crude estimate of the latter can be made by subtracting the Group's best-estimate of the former from the total:

1-sd cross axial interference (X & Y axes) = $\sqrt{(57^2-50^2)}$ = 27 nT

This value is consistent with the inspection tolerance of 40-50 nT for hot-spots within non-magnetic drill collars.

It was pointed out that contrary to the entry on Hugh's summary slide, cross-axial interference should behave like radial misalignment and be uncorrelated between survey stations.

Follow-up: I don't agree with this any more. Surely cross-axial interference is indistinguishable from magnetometer bias and therefore, like sensor bias, systematic between stations. If there is any doubt, it is whether radial misalignment is correlated between stations.

3 Analysing Poor Quality Survey Data

Angus Jamieson highlighted some of the more common errors that afflict old and poorly managed survey data. He then described some techniques which he had developed to analyse wellbore survey data for quality and possible errors. The suite of techniques form part of the ADVISE service offered by his company.

A document describing the service and some of the theory underlying it accompanies these minutes.

4 Standard Well Profiles

Several members had contributed examples of well profiles they had used in analysing error models and error propagation software.

Brett van Steenwyk described a “geological intercept” profile which reverses back on itself in plan view, which causes some errors to reduce with depth. He also showed a “corkscrew” profile, useful for examining the behaviour of gyroscopic tools. The azimuth turn at low inclination provides a good test for the sensitivity of the error model to misalignment of the gyro sensors.

Steve Grindrod showed a number of simple profiles which he uses for testing different implementations of the Wolff and de Wardt error model. The most basic test is to examine the errors generated over straight well sections in different quadrants.

Chris Chia described a total of 10 well profiles which he uses to examine the behaviour of survey companies’ models for their own tools, and to generate simplified models which can be used in their stead. He also uses them for predicting the errors to be expected with particular BHA configurations.

Angus Jamieson described two special well shapes which he had developed. The first involved the azimuth varying continuously about North, and then turning 90° East. This profile is rotated in 10 degree increments around the compass. The second was a corkscrew profile, generated by adding successive segments at incremental toolface angles. The resultant wellpath takes the shape of a spiral on a travelling cylinder projection.

David Roper drew the distinction between profiles for testing software (his particular area of interest) and those for testing error models. For the former, he recommended testing individual error terms over straight line sections.

Hugh Williamson requested that the Group divide into to two syndicates, and that each attempt to define:

- at most three profiles suitable for testing the implementation of error modelling software
- at most three profiles suitable for examining the behaviour of different error models

John Turvill suggested that a worked example generated by the Group and circulated in the Industry, if properly conceived, could act as a “wake-up-call”, drawing attention to the size of the errors to which MWD is subject. This was added as an additional requirement for the syndicates.

Andy Brooks explained that his group had listed 4 “pathological” hole directions, 6 profile types which would reveal particular behaviour of some error terms, and 5 other tests of error calculation and propagation:

Pathological directions

1. Vertical
2. Horizontal, E-W
3. Along the magnetic field vector
4. Along the Earth’s spin vector

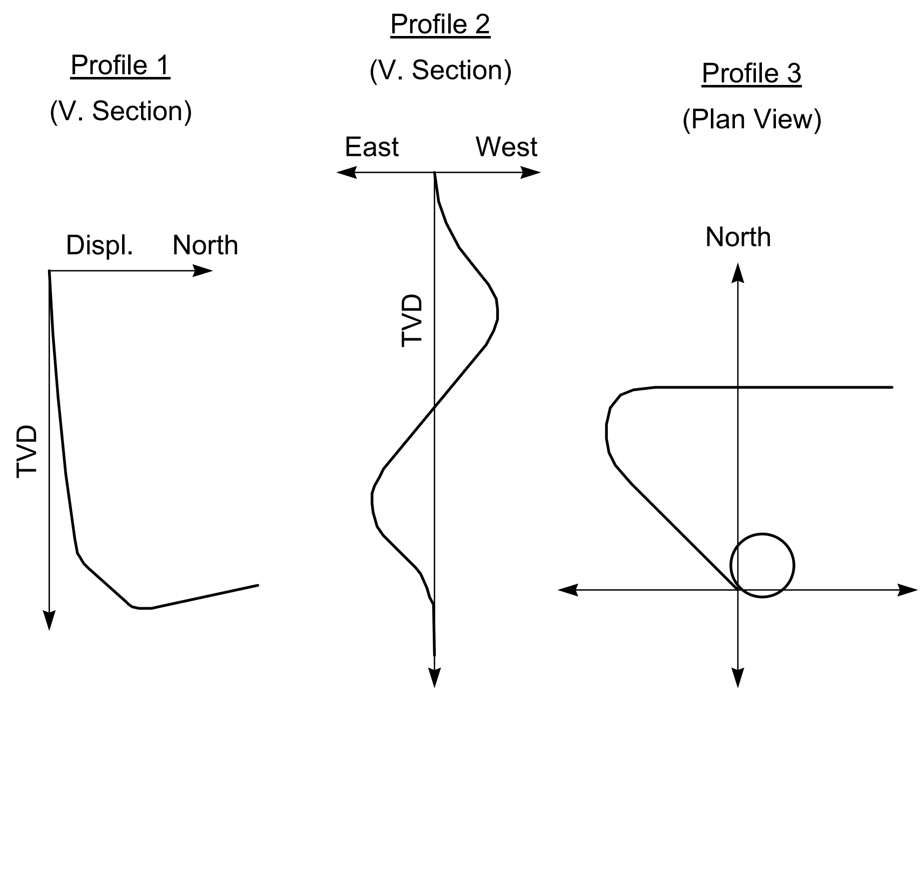
Illustrative profile types

1. >90° inclination
2. Corkscrew
3. “Pregnant Lady” (or “Fat Man”!), a build-drop-reverse build-drop profile
4. Any Southern hemisphere well
5. Fish-hook
6. 180° turn

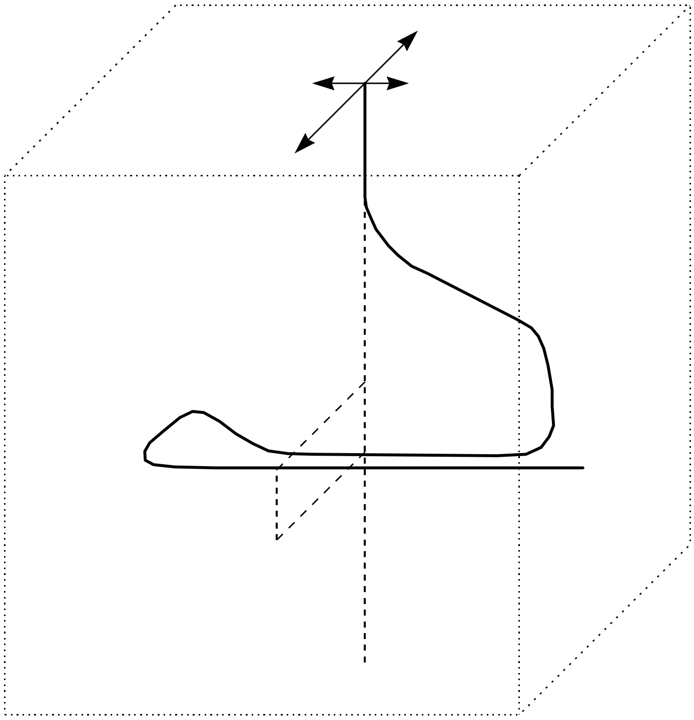
Tests of error propagation

1. Random vs. systematic errors
2. Errors correlated vs. uncorrelated between surveys
3. Sliding vs. rotating (ie. toolface constant or varying)
4. High latitude well
5. High tortuosity well

Andy then described three well profiles which together could be made to cover all these cases. The first is confined to the north-south plane, and includes low-angle and high-angle sections. The second crosses under itself twice, once at angle and once vertically. The third includes a low-angle corkscrew and then builds and turns to horizontal east-west.



David Roper's group had devised the single profile illustrated below.



The well starts vertical, builds and drops to the East, returns back underneath the wellhead, builds above horizontal, then turns through 180° and finishes horizontal due East.

For use as a worked example, the uncertainty would be calculated at several critical points down the well (kick-off-point, end-of-build, end-of-drop etc.). This would aid software companies in tracing the source of disagreement.

David added that considerable supporting information would be required to fully specify any worked example - survey station depths, correlation across tie-ins etc. He was of the opinion that achieving matching results for a small number of standard profiles ought not to be the sole basis of acceptance testing, and that compiling a fully documented acceptance testing suite was beyond the capabilities of the Group. He felt that two separate implementations of the equations would be required to assure the standard worked examples were correct.

Hugh Williamson explained that BP would accept software only if it both reproduced standard worked examples and could be shown to have undergone extensive system testing. On it's own, successful duplication of the worked examples would be a significant milestone in testing any software.

Alewyn van Asperen thought a series of look-up-tables at different inclinations and azimuths would be useful, whereby discrepancies between implementations could be traced easily.

Steve Grindrod said that his experience with testing implementations of the Wolff and de Wardt equations had shown that the same errors and misinterpretations tend to arise again and again. He expected implementation of the new equations to be no different.

Action: Hugh Williamson to propose standard profiles based on the Group's discussions.

5 Error Parameters and Running Conditions

Hugh Williamson introduced the topic with two questions for the Group:

- What assumptions/conditions underlie our basic MWD error model ?
- Between which cases ought we to distinguish ?

Alewyn van Asperen was concerned about the dependency of some error terms on running conditions, particularly magnetic interference and misalignment. He asked the Group what evidence there was to support the current estimates of these effects.

Hugh Williamson reviewed the magnetic pole strength data presented at the previous meeting. Alewyn was still concerned about the detection of outliers due to "hot" motors for example, and wanted to ensure such case, where the modelled values were greatly exceeded, were clearly flagged in the field.

Harry Wilson felt that these cases could, and ought, to be caught through standard quality control. He pointed out that axial magnetic interference error is unique amongst those in the model in that it is entirely dependent on magnetic spacing. He explained that INTEQ assume the BHA has been made up with reference to standard spacing calculations, and therefore currently model the azimuth error as 1° at "90° E/W". For critical situations, details of the actual BHA are used, and the applicable model parameter is changed.

Alewyn also asked about the value of 0.2° used for sag misalignment. Harry Wilson explained that INTEQ's value of 0.2° for sag was the result of a study of the output of their sag correction program. When a sag correction has been applied, a somewhat arbitrary figure of 0.1° is used. The figures are supported by comparisons of RIGS surveys and MWD surveys run in the Rogalands test well.

Dave McRobbie agreed with the general magnitude of these numbers. Using Sperry-Sun's 3D BHA modelling program, inclination corrections of 0.2°-0.3° are seen. Azimuth corrections rarely, if ever, exceed 0.12°

Harry made the distinction between radial misalignment, which is properly part of the tool specification, and sag misalignment, which is dependent on running conditions. John Barlow pointed out that this did not apply to radial misalignment caused by a bent element on the BHA. Hugh Williamson thought that in general, running conditions were the result of choices made at the rigsite while tool specifications were the result of standard running gear or procedures and were universally applicable.

Action: All members to consider how best to gain experimental or theoretical information on the size of the last remaining "blank" in the basic MWD error model: radial misalignment.

6 Error Models and Survey Acceptance Criteria

Alewyn van Asperen pointed out that the QA tolerances commonly used for B-Total and Dip allow for much more error in the sensors than is predicted by error models. He requested that a fixed relationship be established between QA parameters and the error model, such that the error model predicted worst-case errors which it could be demonstrated were not exceeded in practice.

Angus Jamieson pointed out that the laws of Gaussian distribution were unreliable beyond 2-3 standard deviations from the mean.

Hugh Williamson supported Alewyn's idea in principle, but also wanted to take economic advantage of the fact that most surveys have small errors.

Roger Ekseth did not like the idea of worst case errors - there was no theoretical maximum possible error. A single error source subject to a strict acceptance/rejection criterion would not be Normally distributed. However, the combination of several such errors would, by the Central Limit Theorem, approach Normality. It was thus desirable to establish strict acceptance criteria related to each error source.

Later in the day, Hugh Williamson identified two distinct approaches to error modelling:

1) error models should represent the worst possible performance consistent with passing strict QA criteria. There should be a direct relationship between pass/fail criteria and predicted error magnitudes.
2) error models should predict the statistical distribution of normal tool performance. This could be done whether or not pass/fail criteria were related directly to appropriate error terms.

He suggested that the approaches could be reconciled by re-defining the pass/fail criteria for each QA measure at the same number (R) of standard deviations from the mean. The percentage of surveys rejected under each QA measure would be monitored to check the relationship between the pass/fail criterion and the 1-sd error.

The 1 standard deviation error could be used for statistical purposes and the R standard deviation error could be used for "worst case" predictions.

Harry Wilson agreed that surveys ought to be rejected at some statistical level, the only question was whether this level should be 2-sd, 3-sd or some other level. He suggested that whatever number was adopted, it could be promulgated within the industry as a best practice. This would improve the understanding of QA measures in general.

Angus Jamieson suggested the relationship between model parameters and pass/fail criteria should be monitored not by calculating the percentage of surveys rejected, but by expressing the pass/fail criterion in terms of standard deviations of the QA measure. Pass/fail criteria (and model parameters) could be revised on this basis.

Hugh Williamson listed four questions, the answers to which would help advance this topic:

- what QA measures are currently is use for MWD surveys ?
- what are the current pass/fail criteria ?
- what should they be based on the Basic Error Model (at 3-sd) ?
- what is the currently observed 1-sd value of each ?

Action: Alewyn van Asperen and Harry Wilson to complete a worked example based on current QA measures and to circulate amongst the Group. Members to respond to this, comparing their own procedures and results.

7 Next Meeting

Paul Rodney offered to host the next meeting. It will be held at the Dresser's facility in Houston on Thursday 7th May 1998.

Action: Hugh Williamson and Paul Rodney to confirm date and venue to participants.