Borehole Positioning and Tortuosity Standard Calculation Methods "Where we are now and where we are going"

Darren Aklestad

Speaker Information

- Darren Aklestad
- Principal Surveying Engineer
- Schlumberger
  - 25 yrs Drilling & Measurements experience
  - Specialized in: Well Planning, Anti-Collision, Error Modelling, Survey Corrections, Cartography, Drilling Automation (Software Solutions)

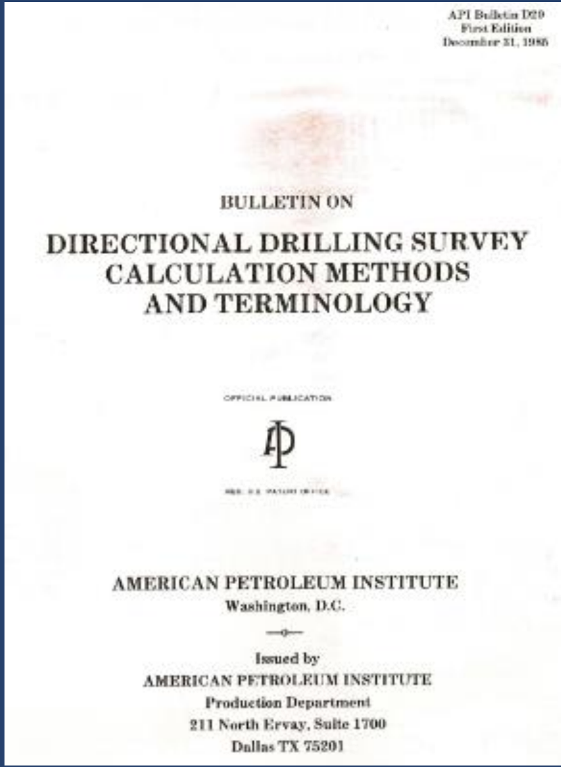
Presentation Agenda

- **Borehole Position Calculation Methods – "Where We Are & Have Been"**

- **Hole Condition "Shape" Indicators**
  - **Dogleg / Severity**
  - **Tortuosity**
  - **Rugosity**

- **Borehole Position Calculation Methods – "Where We Are Going"**
  - **High frequency surveys**
  - **Computation Problems**
  - **New Model Methods**

Trajectory Calculation Models API Bulletin D20 (1985)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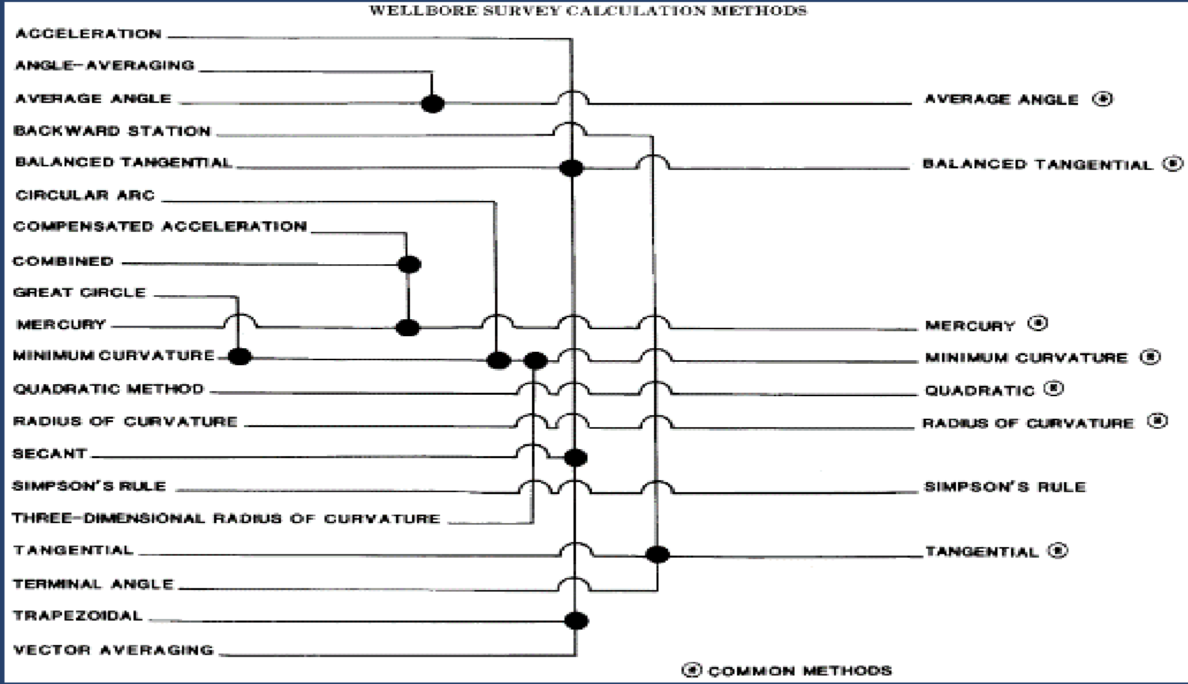
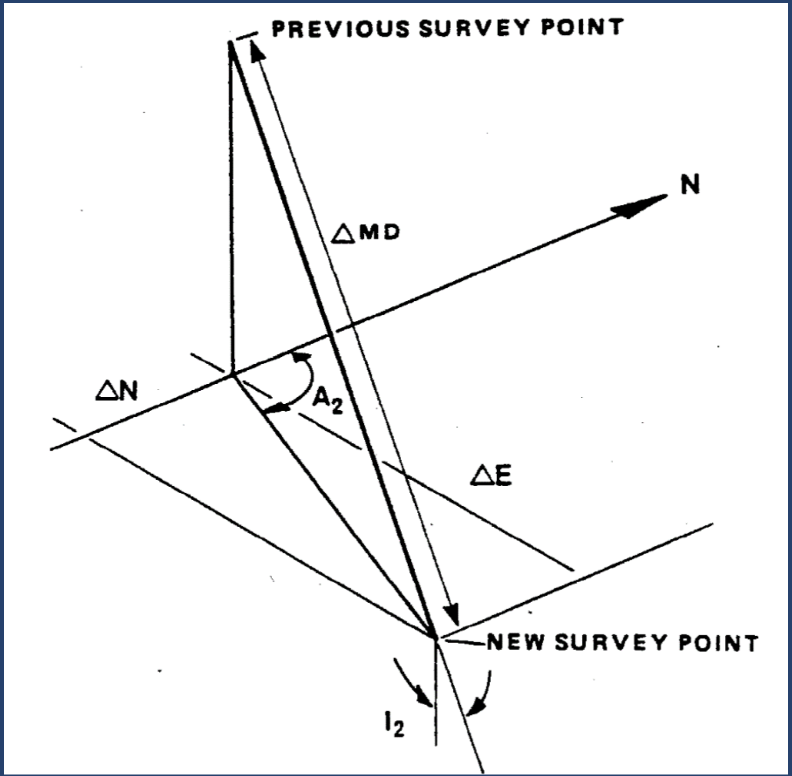


Tangential Method



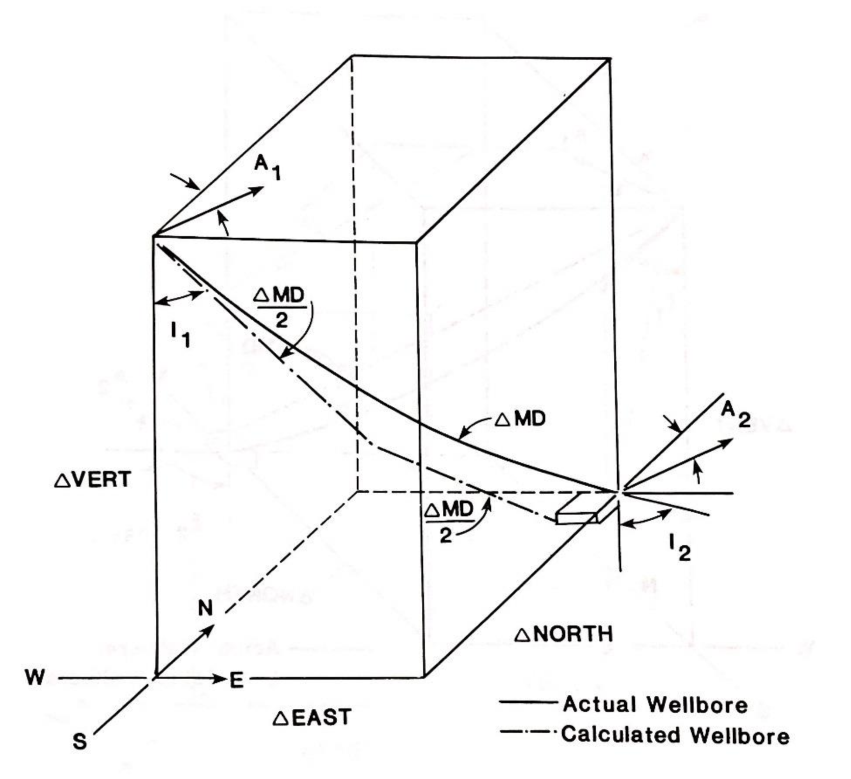
Δ North $= \Delta MD \cdot \sin I_2 \cdot \cos A_2$

Δ East $= \Delta MD \cdot \sin I_2 \cdot \sin A_2$

Δ Vertical Depth $= \Delta MD \cdot \cos I_2$

Δ Course displacement $= \Delta MD \cdot \sin I_2$

Balanced Tangential Method



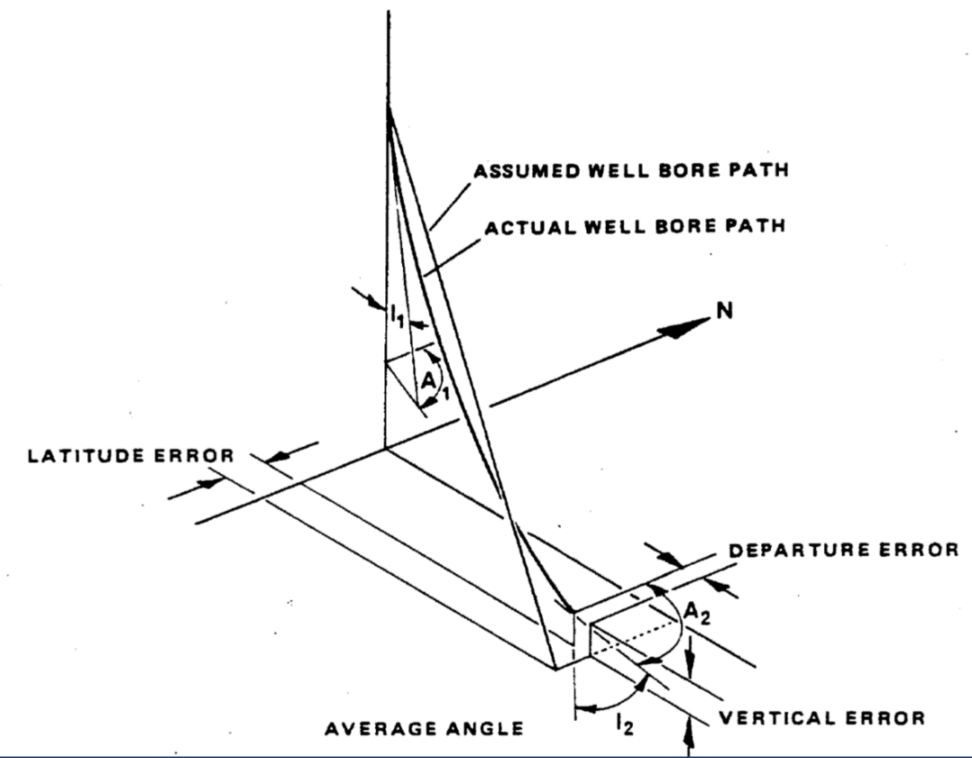
$$\Delta North = \frac{\Delta MD}{2}\left[\sin I_1 \cos A_1 + \sin I_2 \cos A_2\right]$$

$$\Delta East = \frac{\Delta MD}{2}\left[\sin I_1 \sin A_1 + \sin I_2 \sin A_2\right]$$

$$\Delta Vertical\ Depth = \frac{\Delta MD}{2}\left[\cos I_1 + \cos I_2\right]$$

$$\Delta Course\ Displacement = \frac{\Delta MD}{2}\left[\sin I_1 + \sin I_2\right]$$

Average Angle Method



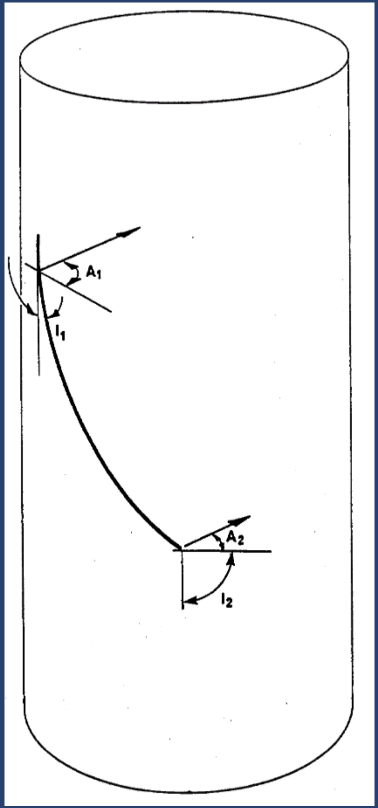
$$\Delta\, North = \Delta\, MD \cdot \sin\left[\frac{I_1 + I_2}{2}\right] \cdot \cos\left[\frac{A_1 + A_2}{2}\right]$$

$$\Delta\, East = \Delta\, MD \cdot \sin\left[\frac{I_1 + I_2}{2}\right] \cdot \sin\left[\frac{A_1 + A_2}{2}\right]$$

$$\Delta\, Vertical\ Depth = \Delta\, MD \cdot \cos\left[\frac{I_1 + I_2}{2}\right]$$

$$Course\ Displacement = \Delta\, MD \cdot \sin\left[\frac{I_1 + I_2}{2}\right]$$

Radius Of Curvature



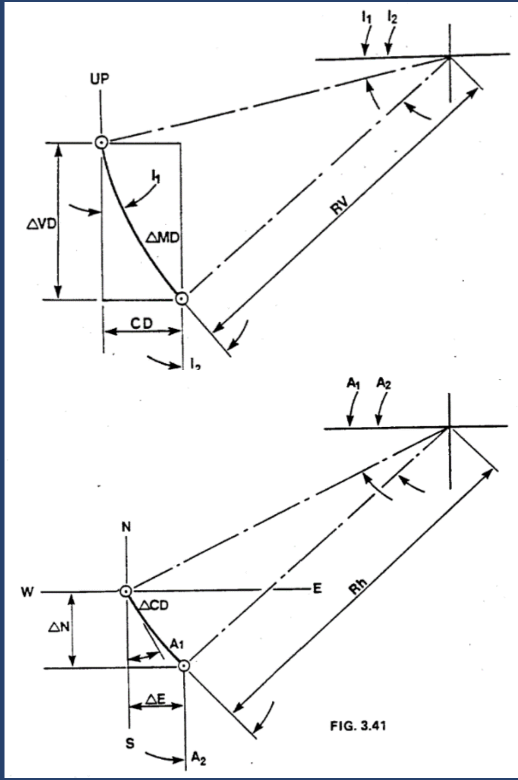


FIG. 3.41

$$R_v = \frac{180 \cdot \Delta MD}{\pi \, (I_2 - I_1)}$$

$$R_h = \frac{180 \cdot \Delta CD}{\pi \, (A_2 - A_1)}$$

$$\Delta VD = R_v \sin I_2 - R_v \sin I_1$$

$$= R_v (\sin I_2 - \sin I_1)$$

$$= \frac{180 \cdot \Delta MD}{\pi} \frac{(\sin I_2 - \sin I_1)}{(I_2 - I_1)}$$

$$CD = R_v \cos I_1 - R_v \cos I_2$$

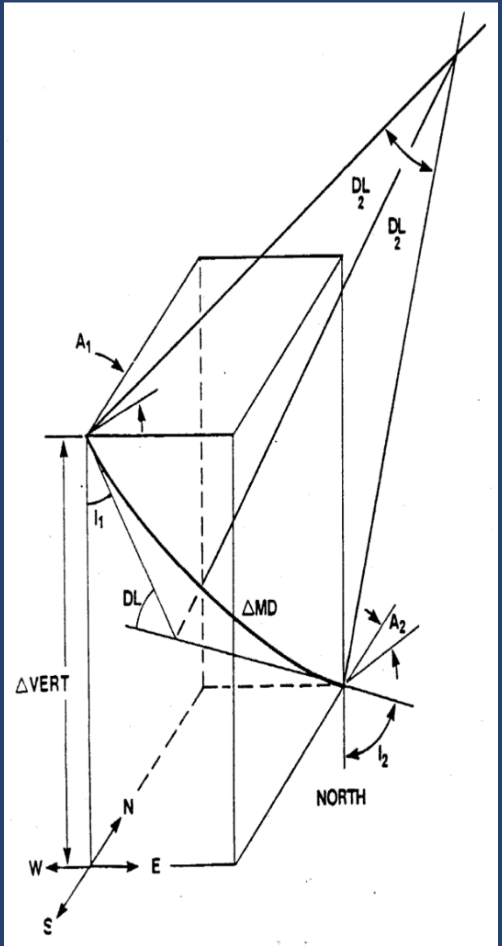
$$= \frac{180 \cdot \Delta MD}{\pi} \frac{(\cos I_1 - \cos I_2)}{(I_2 - I_1)}$$

$$\Delta North = R_h \sin A_2 - R_h \sin A_1$$

$$= \frac{180^2 \Delta MD \, (\cos I_1 - \cos I_2) . (\sin A_2 - \sin A_1)}{\pi^2 (A_2 - A_1) . (I_2 - I_1)}$$

$$\Delta East = \frac{180^2 \Delta MD \, (\cos I_1 - \cos I_2) . (\cos A_1 - \cos A_2)}{\pi^2 (A_2 - A_1) . (I_2 - I_1)}$$

Minimum Curvature



$$DL = Cos^{-1}\left[Cos(I_2 - I_1) - Sin\, I_1 . Sin\, I_2 \left(1 - Cos(A_2 - A_1)\right)\right]$$

$$RF = \frac{360}{DL . \pi} . tan\frac{DL}{2}$$

or,

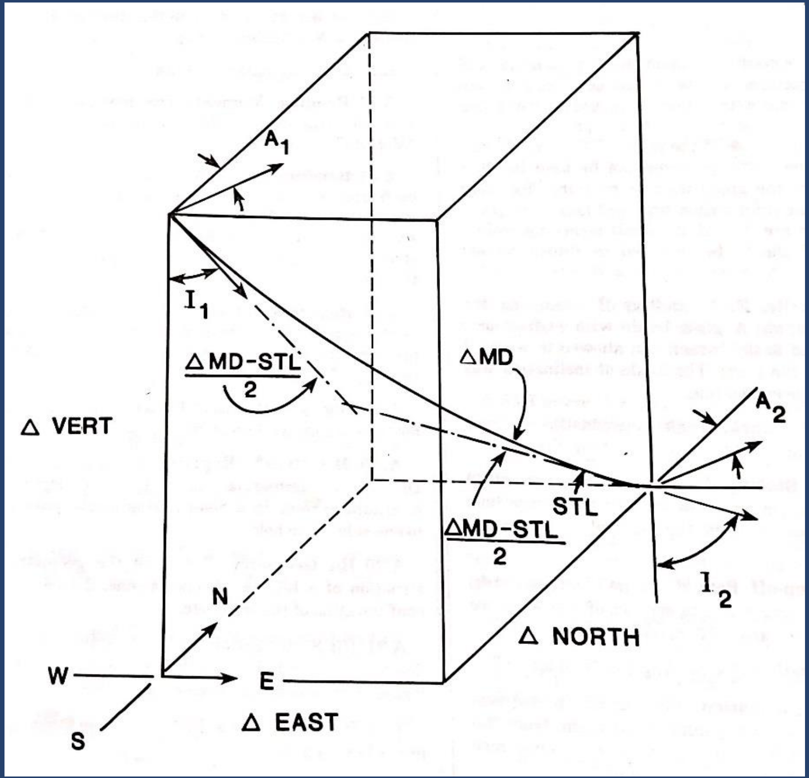
$$RF = \frac{360}{DL . \pi} . \frac{1 - Cos\, DL}{Sin\, DL}$$

$$\Delta VD = \frac{\Delta MD}{2} . (Cos\, I_1 + Cos\, I_2) . RF$$

$$\Delta N = \frac{\Delta MD}{2} . (Sin\, I_1\, Cos\, A_1 + Sin\, I_2\, Cos\, A_2) . RF$$

$$\Delta E = \frac{\Delta MD}{2} . (Sin\, I_1\, Sin\, A_1 + Sin\, I_2\, Sin\, A_2) . RF$$

Mercury Method



Mercury, Nevada Nuclear Test Site

$$\Delta N = \left[\frac{\Delta MD - STL}{2}\right]\left[\text{Sin } I_1 . \text{Cos } A_1 + \text{Sin } I_2 . \text{Cos } A_2\right] + STL . \text{Sin } I_2 . \text{Cos } A_2$$

$$\Delta E = \left[\frac{\Delta MD - STL}{2}\right]\left[\text{Sin } I_1 . \text{Sin } A_1 + \text{Sin } I_2 . \text{Sin } A_2\right] + STL . \text{Sin } I_2 . \text{Sin } A_2$$

$$\Delta VD = \left[\frac{\Delta MD - STL}{2}\right]\left[\text{Cos } A_2 + \text{Cos } A_1\right] + STL . \text{Cos } A_2$$

Where STL is the survey tool length.

Borehole Condition Indicators

- **Dogleg**
  - **Lubinski – pipe bending**
  - **Wilson – Tangential Method / Radius of Curvature**
  - **Mason and Taylor – Minimum Curvature**

- **Tortuosity – Cumulative Dogleg – can be normalized**

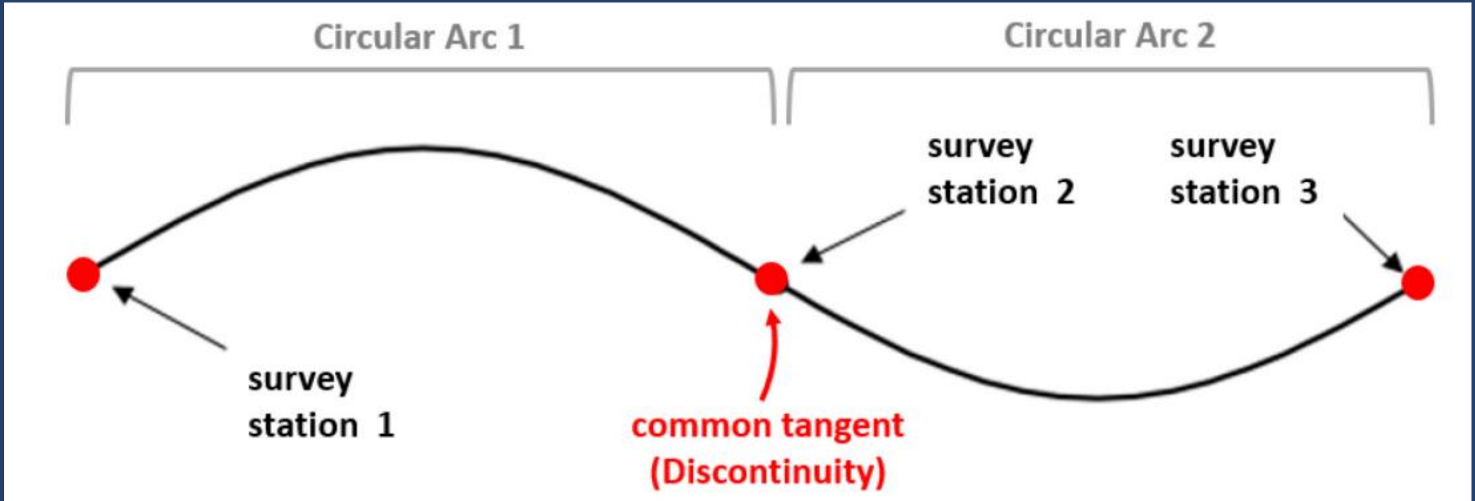
- **Rugosity – Wellbore diameter irregularity**

High Frequency Surveys

- **Continuous Surveys – Gyro & MWD**
  - **Gives better indication of the "true" shape of the well path**
  - **Shows and corrects for "Stockhausen Effect"**
  - **Short intervals can magnify angular changes when shown as rates, e.g. large DLS values**

Advanced Spline Curve (ASC) model

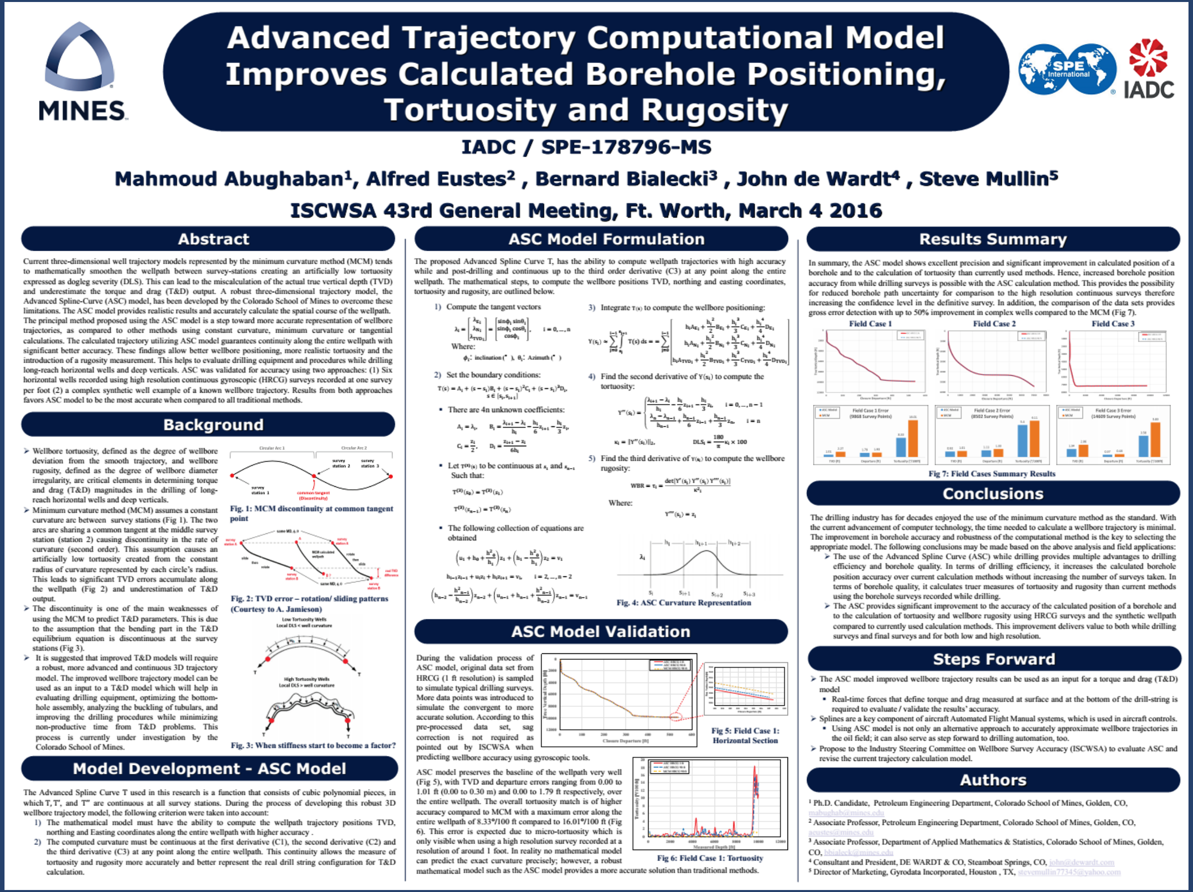
IADC/SPE-178796 • Advanced Trajectory Computational Model • Mahmoud F Abughaban



Advanced Spline Curve (ASC) model

IADC/SPE-178796 • Advanced Trajectory Computational Model • Mahmoud F Abughaban

- Current trajectory method has an invalid assumption (constant curvature arc) proven by high resolution surveys in slide/rotation pattern modes:
  - Causes artificially low tortuosity
  - Significant TVD error accumulation
  - Underestimates torque and drag output
- A robust three dimensional wellbore trajectory model (The ASC Model) has been developed:
  - Based on Cubic polynomial piece-wise continuous functions
    - Solving system of liner equations
  - Continuous at all survey stations up to the third derivative
  - Requires no assumptions / definite solution
- The ASC characteristics allow:
  - More accurate wellbore positioning, tortuosity and rugosity with less number of surveys taken than current trajectory methods while drilling and post-drilling


MINES
Advanced Trajectory Computational Model Improves Calculated Borehole Positioning, Tortuosity and Rugosity
SPE International
IADC
IADC / SPE-178796-MS
Mahmoud Abughaban¹, Alfred Eustes², Bernard Bialecki³, John de Wardt⁴, Steve Mullin⁵
ISCWSA 43rd General Meeting, Ft. Worth, March 4 2016
Abstract
Current three-dimensional well trajectory models represented by the minimum curvature method (MCM) tends to mathematically smoothen the wellpath between survey-stations creating an artificially low tortuosity expressed as dogleg severity (DLS). This can lead to the miscalculation of the actual true vertical depth (TVD) and underestimate the torque and drag (T&D) output. A robust three-dimensional trajectory model, the Advanced Spline-Curve (ASC) model, has been developed by the Colorado School of Mines to overcome these limitations. The ASC model provides realistic results and accurately calculate the spatial course of the wellpath. The principal method proposed using the ASC model is a step toward more accurate representation of wellbore trajectories, as compared to other methods using constant curvature, minimum curvature or tangential calculations. The calculated trajectory utilizing ASC model guarantees continuity along the entire wellpath with significant better accuracy. These findings allow better wellbore positioning, more realistic tortuosity and the introduction of a rugosity measurement. This helps to evaluate drilling equipment and procedures while drilling long-reach horizontal wells and deep verticals. ASC was validated for accuracy using two approaches: (1) Six horizontal wells recorded using high resolution continuous gyroscopic (HRCG) surveys recorded at one survey per foot (2) a complex synthetic well example of a known wellbore trajectory. Results from both approaches favors ASC model to be the most accurate when compared to all traditional methods.
Background
Fig. 1: MCM discontinuity at common tangent point
Fig. 2: TVD error – rotation/ sliding patterns (Courtesy to A. Jamieson)
Fig. 3: When stiffness start to become a factor?
Model Development - ASC Model
ASC Model Formulation
Fig. 4: ASC Curvature Representation
ASC Model Validation
Fig 5: Field Case 1: Horizontal Section
Fig 6: Field Case 1: Tortuosity
Results Summary
In summary, the ASC model shows excellent precision and significant improvement in calculated position of a borehole and to the calculation of tortuosity than currently used methods. Hence, increased borehole position accuracy from while drilling surveys is possible with the ASC calculation method. This provides the possibility for reduced borehole path uncertainty for comparison to the high resolution continuous surveys therefore increasing the confidence level in the definitive survey. In addition, the comparison of the data sets provides gross error detection with up to 50% improvement in complex wells compared to the MCM (Fig 7).
Field Case 1
Field Case 2
Field Case 3
Fig 7: Field Cases Summary Results
Conclusions
The drilling industry has for decades enjoyed the use of the minimum curvature method as the standard. With the current advancement of computer technology, the time needed to calculate a wellbore trajectory is minimal. The improvement in borehole accuracy and robustness of the computational method is the key to selecting the appropriate model. The following conclusions may be made based on the above analysis and field applications:
The use of the Advanced Spline Curve (ASC) while drilling provides multiple advantages to drilling efficiency and borehole quality. In terms of drilling efficiency, it increases the calculated borehole position accuracy over current calculation methods without increasing the number of surveys taken. In terms of borehole quality, it calculates truer measures of tortuosity and rugosity than current methods using the borehole surveys recorded while drilling.
The ASC provides significant improvement to the accuracy of the calculated position of a borehole and to the calculation of tortuosity and wellbore rugosity using HRCG surveys and the synthetic wellpath compared to currently used calculation methods. This improvement delivers value to both while drilling surveys and final surveys and for both low and high resolution.
Steps Forward
The ASC model improved wellbore trajectory results can be used as an input for a torque and drag (T&D) model
Real-time forces that define torque and drag measured at surface and at the bottom of the drill-string is required to evaluate / validate the results' accuracy.
Splines are a key component of aircraft Automated Flight Manual systems, which is used in aircraft controls.
Using ASC model is not only an alternative approach to accurately approximate wellbore trajectories in the oil field; it can also serve as step forward to drilling automation, too.
Propose to the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA) to evaluate ASC and revise the current trajectory calculation model.
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Improved Wellbore Quality Using a Novel Real-Time Tortuosity Index

IADC/SPE-178869 • Yang Zhou • Danden Zheng • Pradeepkumar Ashok • Eric van Oort

- Tortuosity Density Index

Documentation / Reference Updates

- Add borehole quality definitions to Lexicon
- Add new section to bibliography for hole condition and

Questions / Comments

THANK YOU