Your Wellbore Isn't Telling You The Hole Truth

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Drilling Uncertainly Prediction TS Webinar
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Speaker Information

- Mahmoud Abughaban – BSc: KFUPM, MSc: Heriot-Watt, Ph.D: Colorado School of Mines
- Research Scientist, Upstream Advanced Research Center
- Saudi Aramco
  - 10 years Drilling experience
  - Specialized in: Drilling Optimization and Automation, Well Planning, Survey Modelling

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Outline

- Background
- Improved Wellpath Tortuosity Model
- Model Validation
- Applications
  - Torque and Drag Prediction
  - Beyond Drilling Applications

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The Perfect Wellbore

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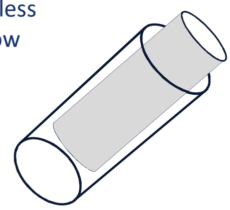
- Perfect wellbore: a flawless three-dimensional hollow cylinder with a smooth surface



Has the property to allow casing or completion to run within it

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Do we have a perfect wellbore?

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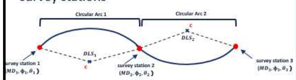
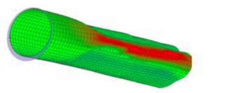
Yes

The Minimum Curvature Method [MCM]: based on a piecewise approximation assuming a constant curvature arc between survey stations



In our models, YES!

No



In reality, drilling a perfect well is against mother nature

Robust model can do a better job than MCM

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My Ph.D. Journey

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Extending the Reach of Drilling

- Limitations
- Borehole Trajectory Model
- Torque and Drag [T&D] model

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My Ph.D. Journey

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Extending the Reach of Drilling

Limitations | Borehole Trajectory Model | Torque and Drag [T&D] model

What Limits the Horizontal Departure?

- Borehole stability – time exposure, geomechanics, drilling fluids interaction or pressure differential
- Hole Cleaning – hydraulic flow, annular and slip velocity, mud rheology, filter cake quality
- Excessive drag – friction exceeds the force available to push the bit
- Excessive torque – friction exceeds the torque available to rotate the bit

How to improve torque and drag [T&D] predictions from current models?

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Improved Borehole Trajectory Model

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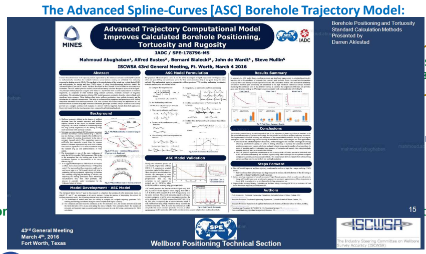
The Advanced Spline-Curves [ASC] Borehole Trajectory Model:



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The ASC Borehole Trajectory Model Validation Process

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- Five wells were provided with survey data recorded every one foot using the high resolution continuous gyroscopic [HRCG] survey tool
  - This data is effectively the **"Ground Truth"**
- Original data set (1 ft resolution) is sampled to simulate:
  - Typical 90 ft survey interval resolution
  - 45 ft and 30 ft survey interval resolution

More data points were introduced to simulate the convergence to a more accurate solution

Calculation error analysis

Measured Depth [ft]	Inclination [°]	Azimuth [°]
9000	57.4	18.75
	20 ft interval resolution	
9020	57.49	18.48

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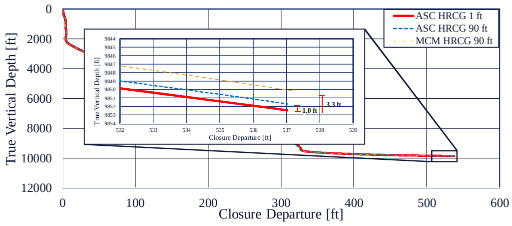
Vertical Section – Field Case 1



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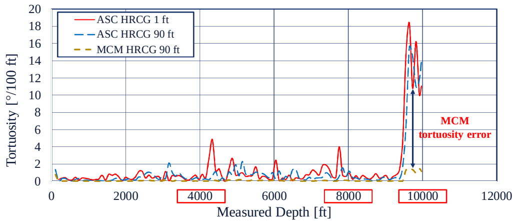
Tortuosity Results – Field Case 1



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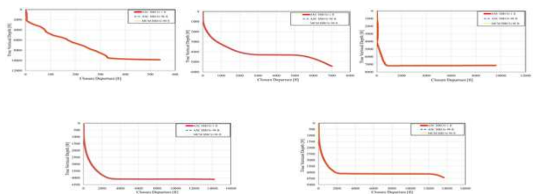
Results – Well Profiles *



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Results – Calculation Methods Vs. Ground Truth *

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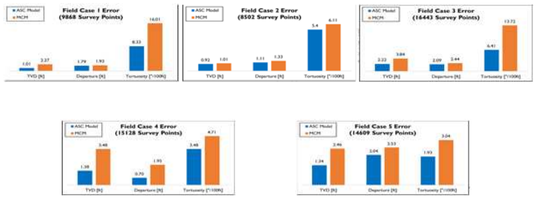

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Torque and Drag Applications

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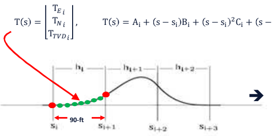
1. The ASC Model Interpolated Surveys – Semi-Analytical Solution

Spline general equations for TVD, Northing and Easting are known between survey points:

$$T(s) = \begin{bmatrix} T_{E\,i} \\ T_{N\,i} \\ T_{TVD\,i} \end{bmatrix}, \qquad T(s) = A_i + (s - s_i)B_i + (s - s_i)^2 C_i + (s - s_i)^3 D_i, \qquad s \in [s_i, s_{i+1}]$$



Interpolated surveys:

$$MD_i = s_i$$

$$\phi_i = \cos^{-1}(T_{TVD\,i})$$

$$\theta_i = \tan^{-1}\left(\frac{T_{E\,i}}{T_{N\,i}}\right)$$

Note:
Increasing the survey resolution to small intervals – one survey per foot – the error of not including the bending stiffness in current T&D model is minimal

Pseudo high resolution (PHR) Surveys

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Torque and Drag Applications

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2. The Advanced Spline-Curve [ASC] Torque and Drag Model:

SPE-184611 MS

- Uses a stiff-string model, extended for a non-constant curvature trajectory [The ASC model] that includes: Geometric torsion [τ], change in the rate of curvature [$d\kappa$ / ds], stiffness, bending moment
- Has the ability to predict a more accurate contact forces between the drillstring and wellbore
- Can solve T&D parameters from surface to total depth in reasonable time using standard engineering computer

More accurate prediction of drillstring to wellbore wall contact forces for basic drilling operations

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Torque and Drag Applications

2. The Advanced Spline-Curve [ASC] Torque and Drag Model:

- Uses a stiff-string mo… …ry [The ASC model] that includes: Geometric to… …ss, bending moment
- Has the ability to pre… …rillstring and wellbore
- Can solve T&D param… …e using standard engineering computer

Basic drilling operations:
- **Rotating off Bottom**
- **Pickup (pulling out of the hole)**
- **Slackoff (Running in hole)**
- **Rotary Drilling**

More accurate prediction of drillstring to wellbore wall contact forces for **basic drilling operations**

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Model Validation Process

The testing and validating procedure of the model accuracy consists of two approaches:

A. Using an industry approved T&D software [Program A] with the following survey inputs:
   1. Actual survey data recorded at the typical 90 ft interval [Program A (90 ft)]
   2. Interpolated survey data generated from the ASC borehole trajectory model at a high resolution of one survey per foot [Program A (1 ft)] – Semi analytical approach

B. Using the ASC T&D model; extended for a non-constant curvature trajectory model
   3. Actual survey data recorded at the typical 90 ft interval [Program A (90 ft)]

All three results will be tested against a field case with real-time T&D measured at the surface

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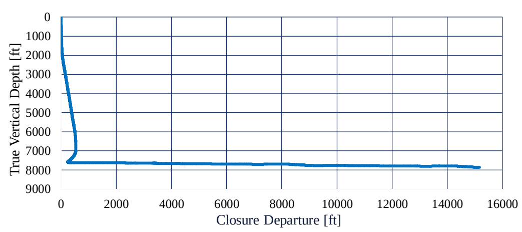
Vertical Section – Field Case 1



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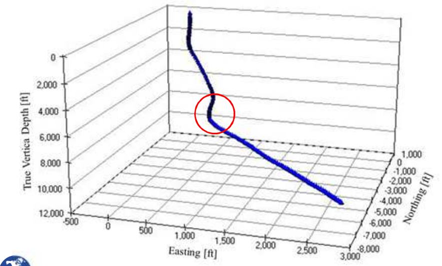
3D Horizontal Section – Field Case 1



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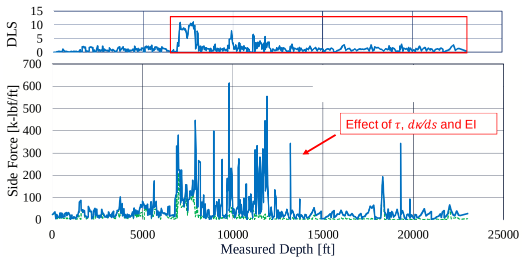
Side Force – Field Case 1



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Downhole Weight on Bit and Torque on Bottom Prediction

- Step 1: Calculate the forces acting on the bottom of the drillstring
- Step 2: DWOB and TOB are an iterative process, i.e. different downhole values will be estimated until the measure and calculated hookload reaches a tolerance level less than 1%

$$tolerance \left| \frac{HL_{measured} - HL_{calculated}}{HL_{measured}} \right| \leq 1\%$$

- Final estimated DWOB and TOB values are reported

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Beyond Drilling: Subsurface correlations from wellbore data

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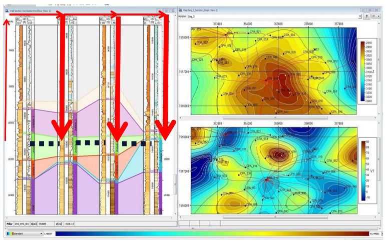
- Exploration can correlate on well logs tied to seismic
- Assets must correlate on well logs tied to True Vertical Depth



This is a long route with many error sources that accumulate
Assets require high accuracy

Courtesy: John de Wardt
Source: Paridigm

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ESP Placement Application

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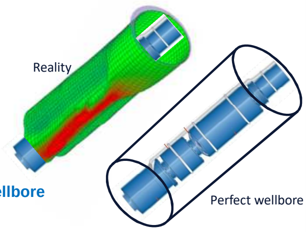
- Simulation/ Placement plan is based on MCM
  - Smooth wellbore
  - Low tortuosity
- Failure occurrence
  - Root causes??
  - Review plan??



Further Investigation on Wellbore Tortuosity

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Liquid Loading Phenomena

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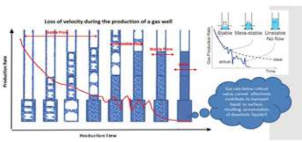
- Liquid loading is a phenomena where actual velocity of gas is below critical velocity of gas
- When this occurs some of the liquid accumulates at the bottom of the well instead of being produced

Objective: Examine variables impacting liquid loading phenomena and determine significance of wellbore trajectory



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Liquid Loading Variables

- Wellbore trajectory/Tortuosity– Higher cumulative dogleg = Earlier Liquid Loading
- Undulation Amplitude – Larger undulation amplitude = Earlier Liquid Loading
- Wellhead pressure - Higher pressure = Earlier Liquid Loading
- Liquid flowrate – Higher liquid flowrate = Earlier Liquid Loading
- End of Tubing location – Higher md EOT = Later Liquid Loading
- End of Tubing angle – Higher EOT angle = Later Liquid Loading

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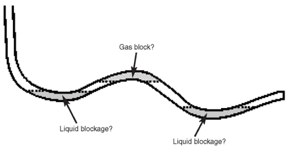
Liquid Loading Prediction

- The ASC model is applied to identify the production performance from the accurate results of wellbore tortuosity and its effects on fluid flow patterns.



More accurately calculation of wellbore curvature and tortuosity

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Conclusion

- Drilling problem prediction and mitigation requires clear understanding of the downhole condition
- Wellbore Tortuosity (Tortuosity is a property of curve being tortuous (twisted; having many turns – in boreholes) has multiple effects from T&D to fluid flow
- ASC borehole trajectory model can fill the gap where there are no sensors

Wellbore Telling You PART of The Hole Truth

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Questions

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