A Calculated Approach for Nudge Optimization

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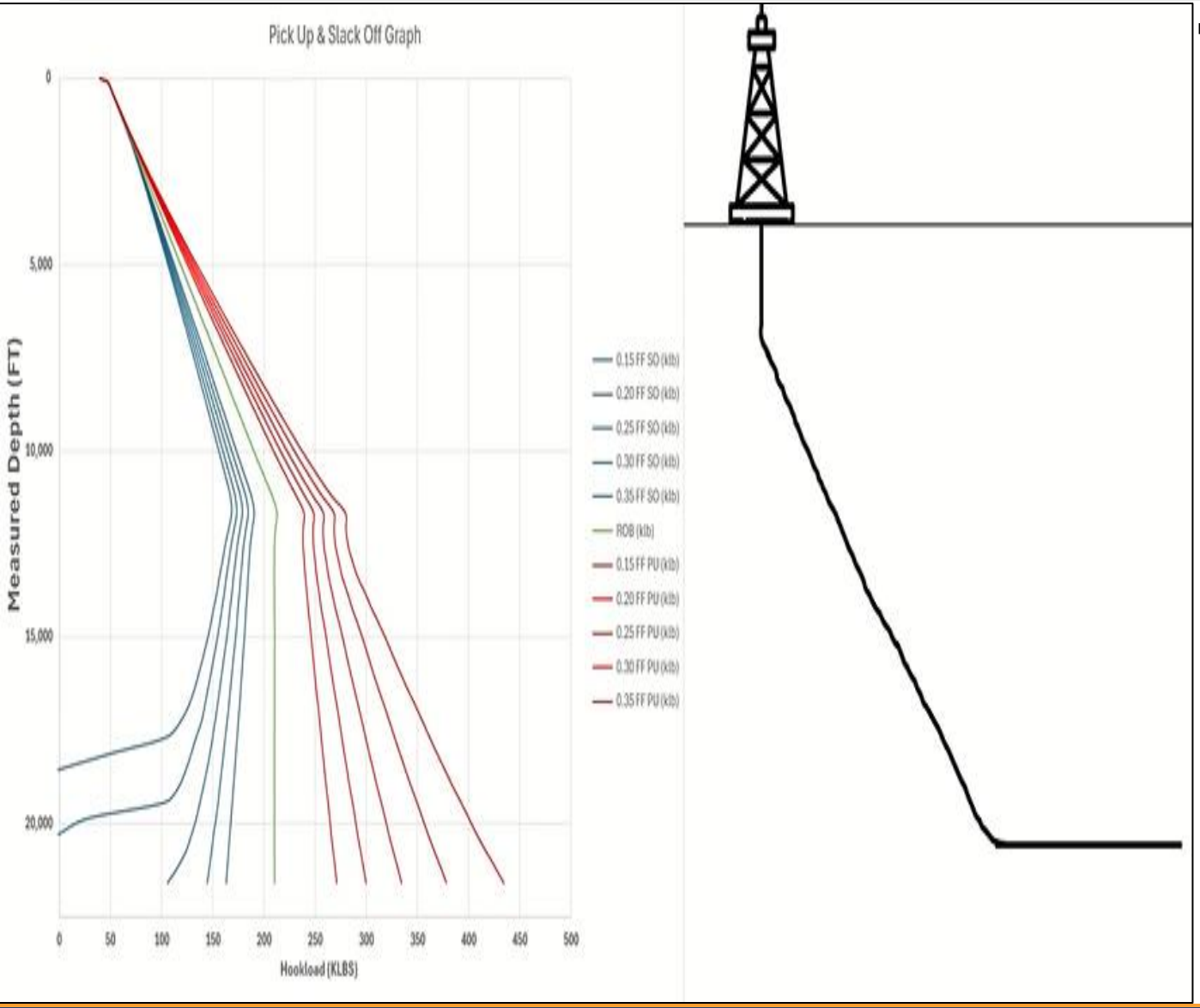
Wellplan Modeling Different Nudge Designs



- ***Higher Inclination Nudges***
  - ***PROS***
    - **Faster Sliding At Shallower TVD**
    - **Drop Back To Vertical Sooner For Maximum Rotating Footage**
  - ***CONS***
    - **Increasing Pick Up Hookload**
    - **Decreasing Slack Off Hookload**
      - In Some Cases, S/O Hookload Will Increase with Higher Inclination
    - **Increasing Torque with Higher Nudge Inclination**

Is there a point of diminishing returns for drilling performance?

At what nudge inclination does the faster drilling begin to diminish?

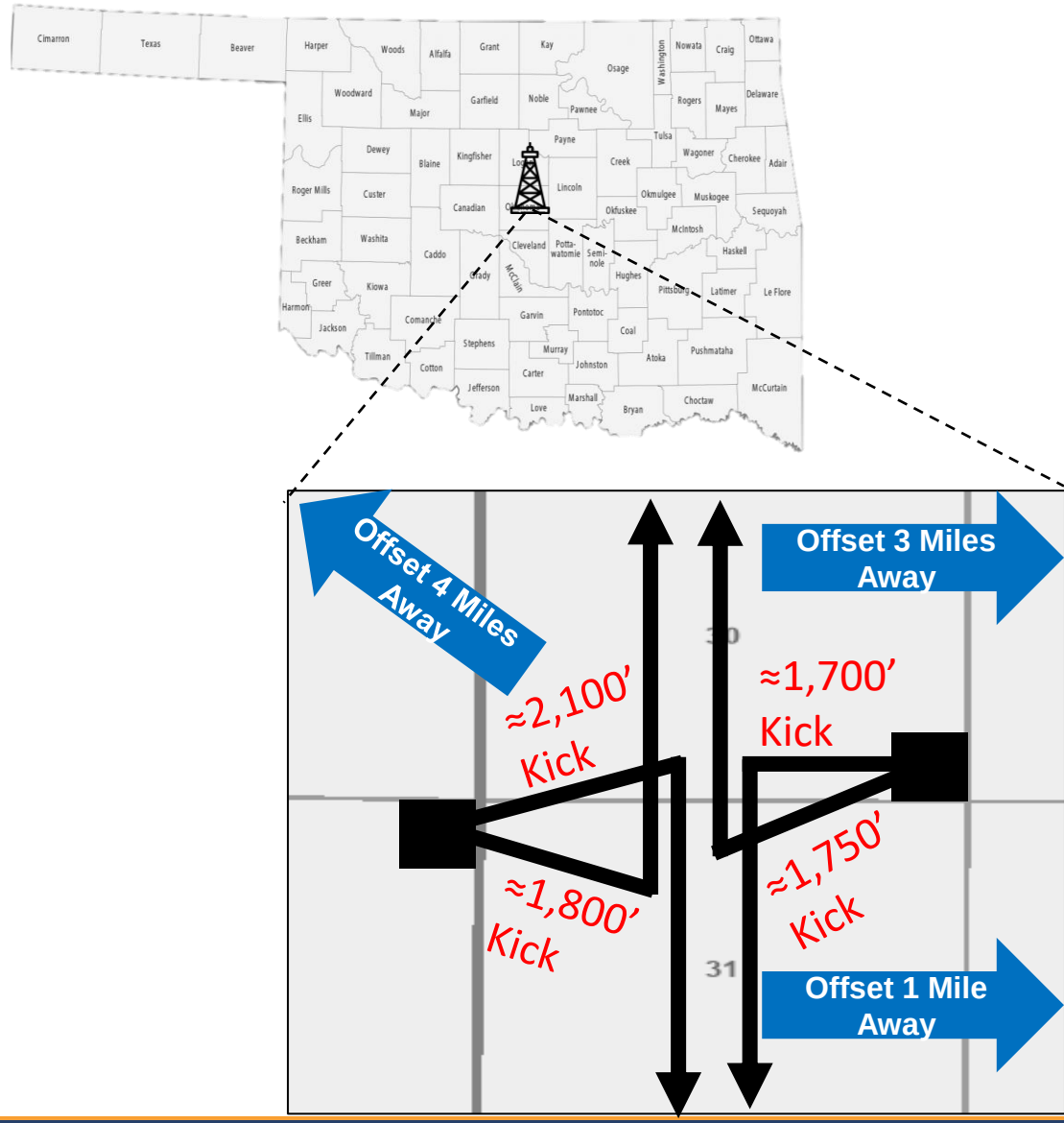
Is There An Optimal Inclination For Fastest Drilling Performance?

- Strategy

  - ROP vs Depth
    - Sliding vs Rotating
      - Are There Optimal Spots to Slide?
      - Are There Optimal Spots to Rotate?

  - BHA Rotational Tendency
    - How Fast Will It Drop Inclination?
      - Function of Inclination Angle?
      - Function of Formation?

  - Motor Yields
    - How Much Sliding Is Necessary to Hold Angle?



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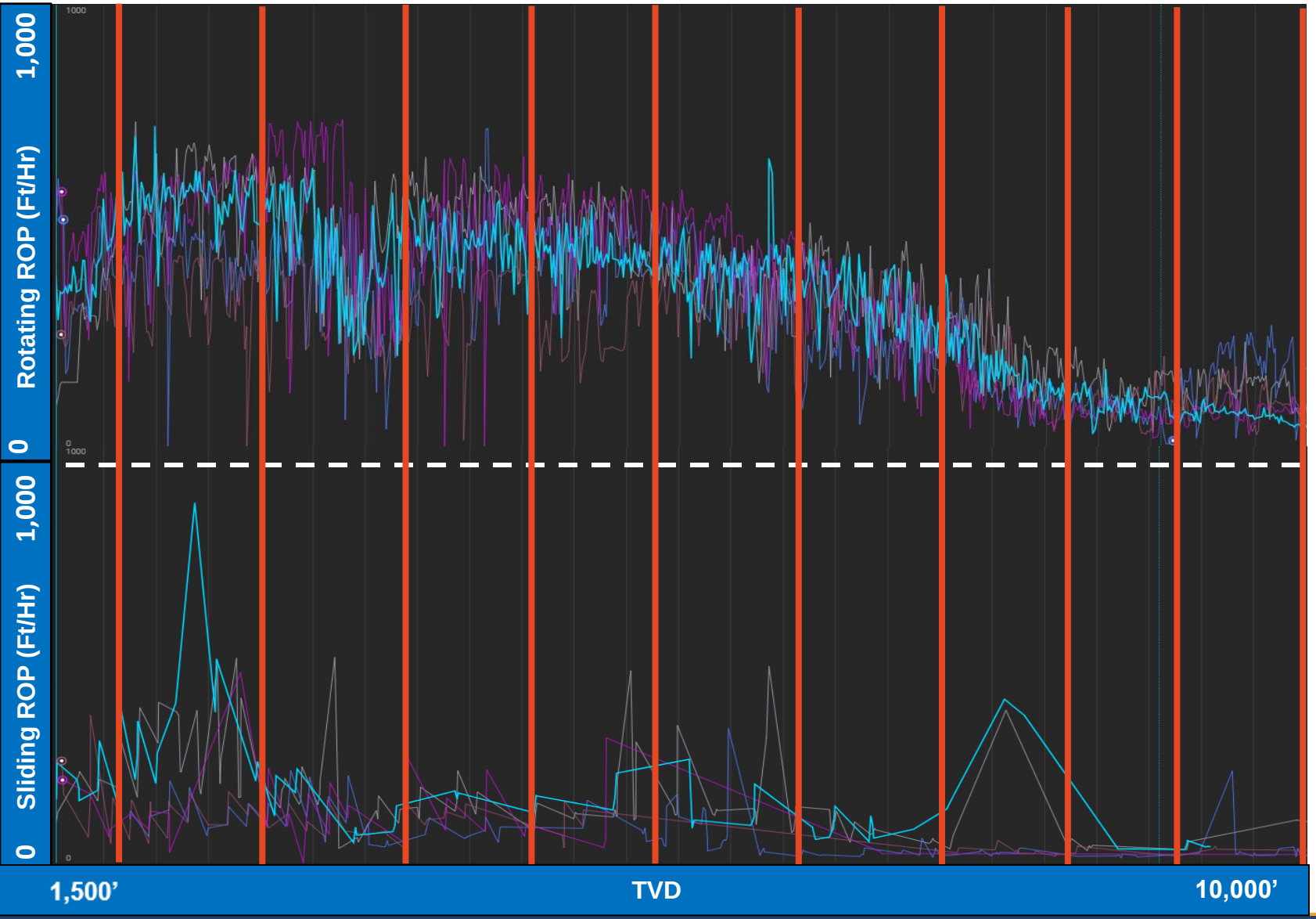

- ROP vs Depth
  - Sliding vs Rotating
    - Are There Optimal Spots to Slide?
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TVD	Rotating ROP	Sliding ROP
1,600 - 3,000	480	160
3,000 - 4,000	418	88
4,000 - 5,000	404	74
5,000 - 6,000	292	53
6,000 - 7,000	145	27
7,000 - 8,000	108	13
8,000 - 9,000	63	11
9,000 - 10,000	79	49

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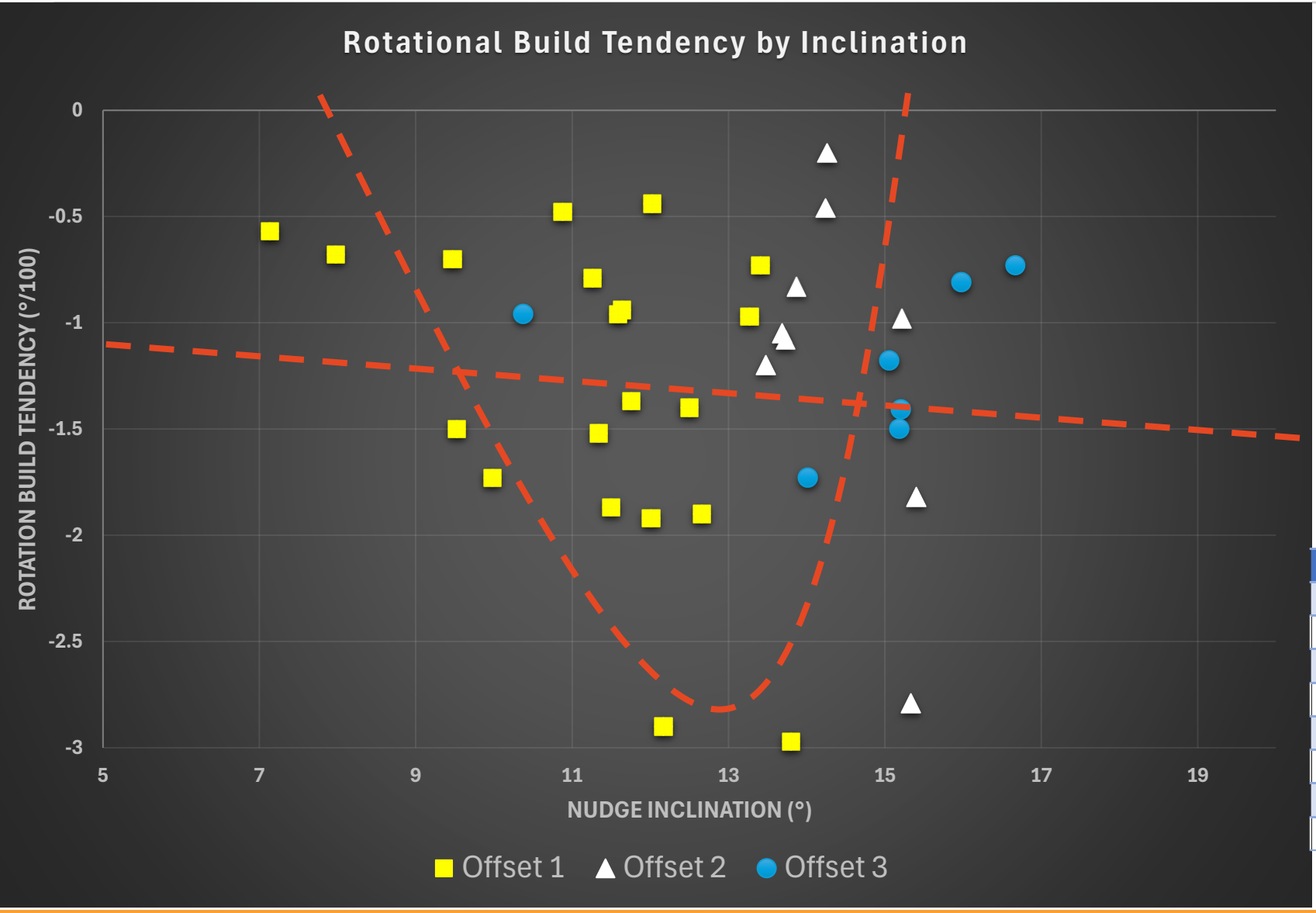

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  - How Fast Will It Drop Inclination?
    - Function of Inclination Angle?
    - Function of Formation?

No Significant Correlation with Inclination

Strong Correlation with Drop and TVD

TVD	Rotating ROP	Sliding ROP	Drop Trend
1,600 - 3,000	480	160	0.3°
3,000 - 4,000	418	88	1.8°
4,000 - 5,000	404	74	3.0°
5,000 - 6,000	292	53	2.0°
6,000 - 7,000	145	27	0.3°
7,000 - 8,000	108	13	0.3°
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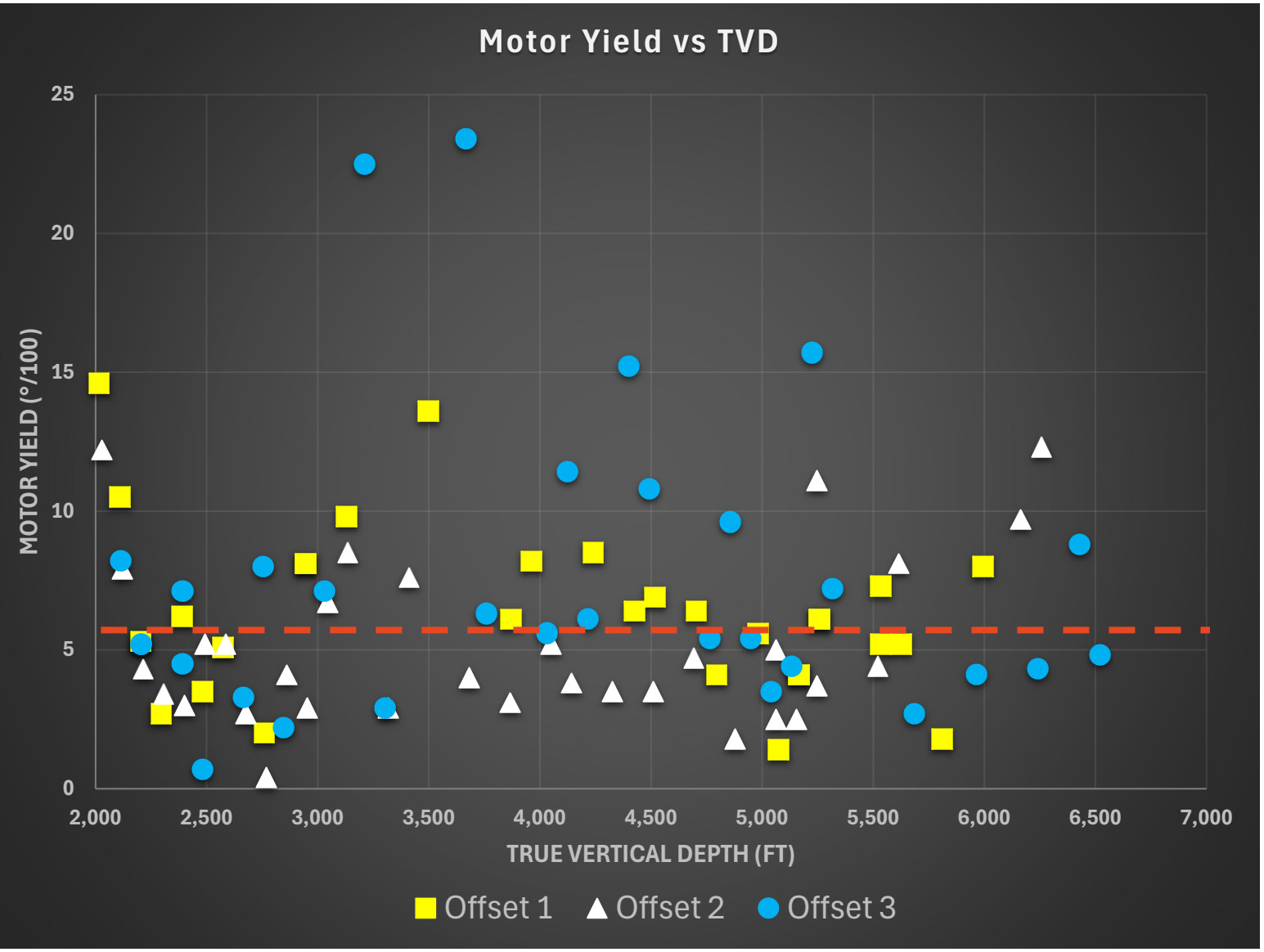

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Okay, So Now What?

MD (usft)	Inc (°)	Azi (°)	CL (usft)	TVD (usft)
5,900.0	25.00	0.00		5,601
6,000.0	25.00	0.00	100	5,692

$$Slide\ Footage = \frac{Drop\ Tendency}{Motor\ Yield + Drop\ Tendency} * CL$$

$$Slide\ Footage = \frac{2.0°}{6.0° + 2.0°} * 100' = 25'of\ Sliding$$

$$Rotating\ Footage: 100'CL - 25'Slide = 75'of\ Rotation$$

$$Time\ to\ Drill: \frac{25'Slide}{53\ ft/hr} + \frac{75'Rotation}{292\ ft/hr} = 0.72\ Hours$$

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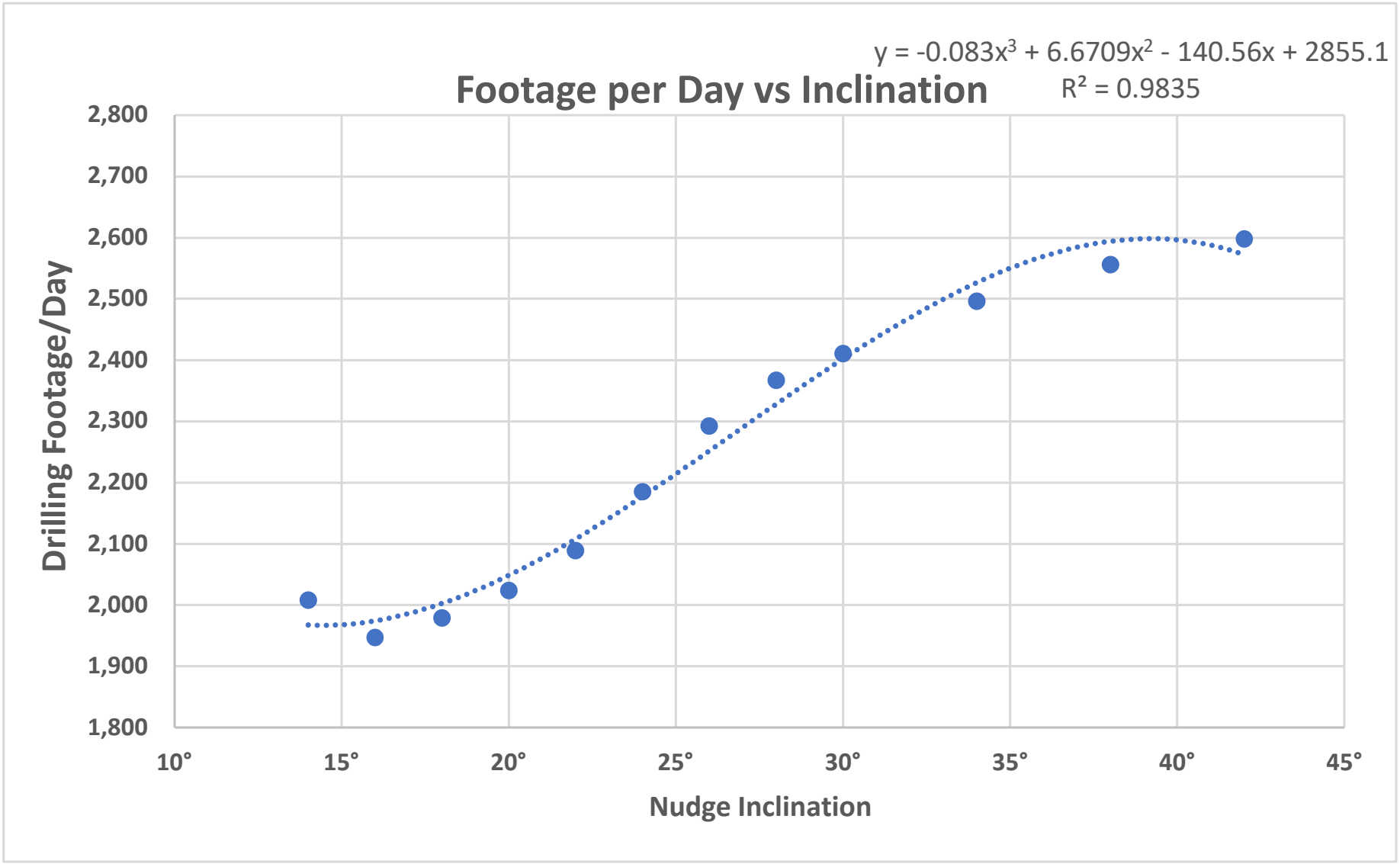
Other Calculations Include

- Toolface Accuracy vs TVD
- Additional Time to Find Toolface
- Connection Times
- Target Window Size

Simulation Results



What is the Optimal Inclination?

Calculus Refresher

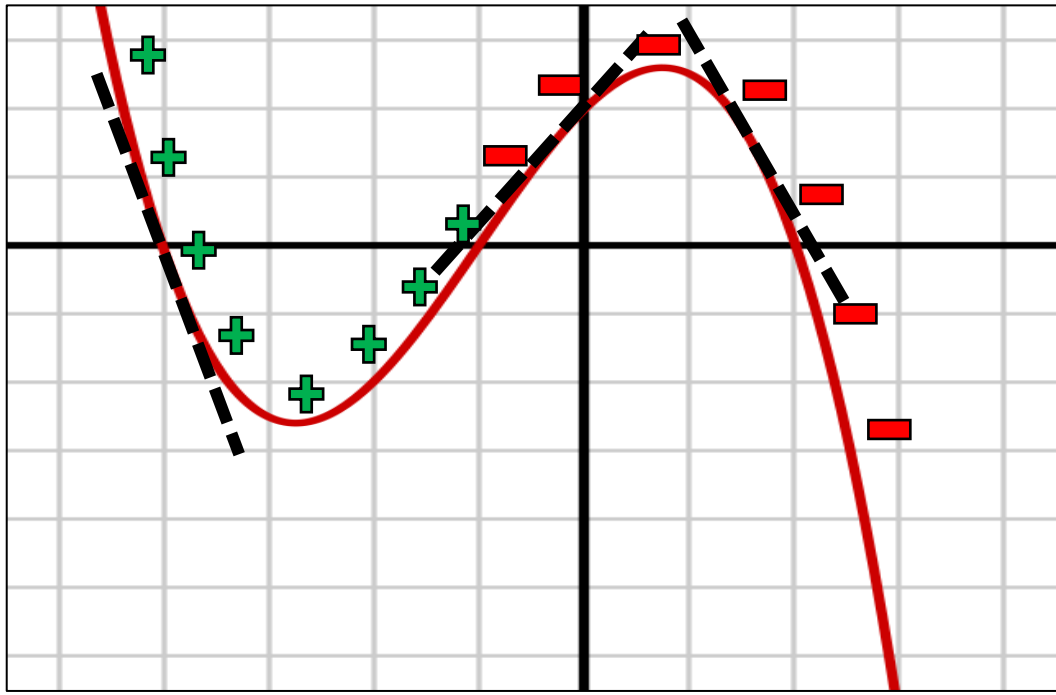
$$y = Ax^3 + Bx^2 + Cx + \mathrm{D}$$

$$\frac{dy}{dx} = 3Ax^2 + 2Bx + C = \text{Slope}$$

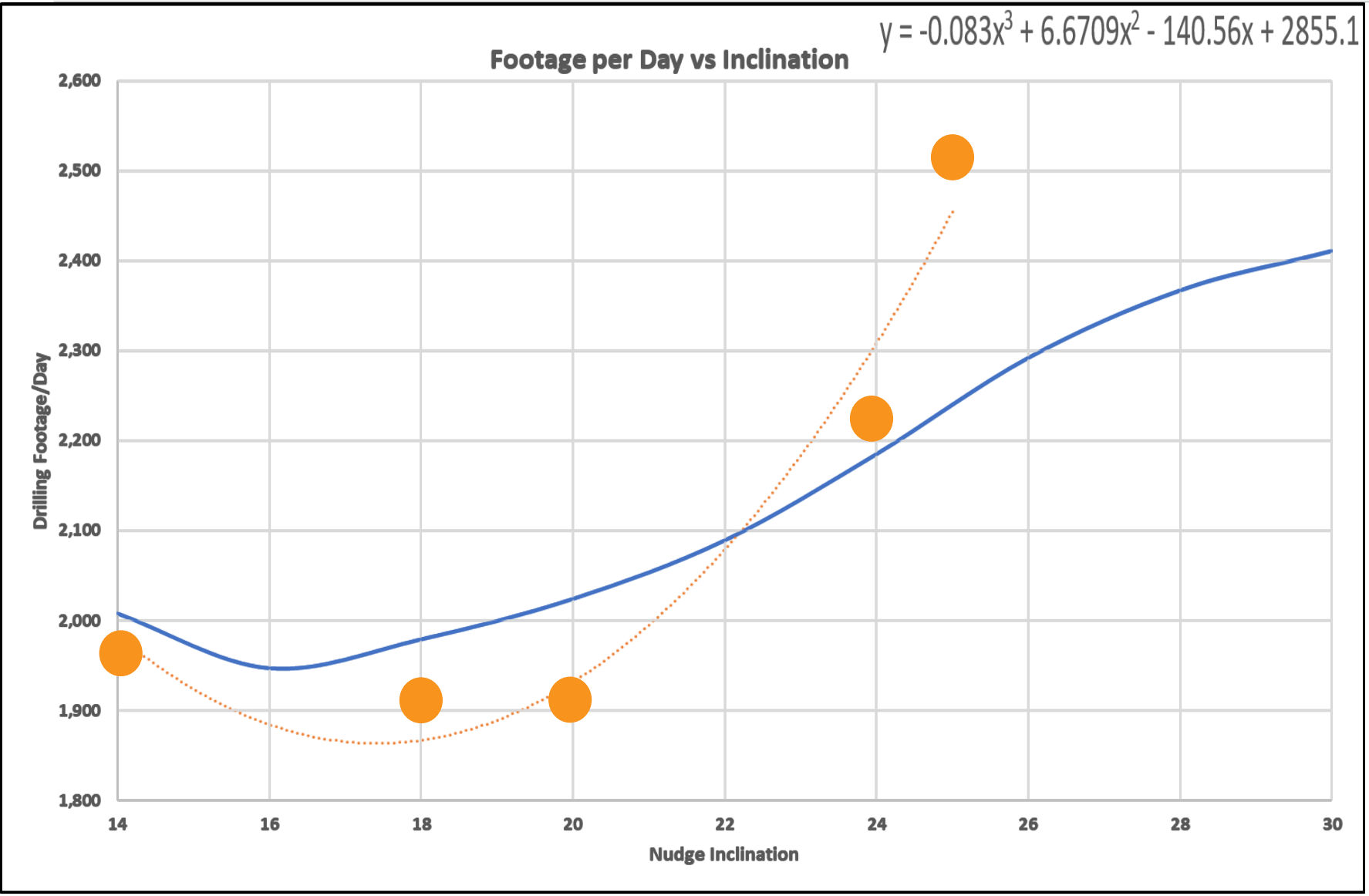
$$\frac{d^2y}{dx^2} = 6Ax + 2B = Rate\ Slope\ Changes$$

$$6Ax + 2B = 0$$

$$x = \frac{-B}{3A} = Point\ of\ Dimenishing\ Returns$$



Model vs Actual Results



$$x = \frac{-B}{3A}$$

$$x = \frac{-6.67}{3 * (-0.083)}$$

$$x = 26.8°$$

Optimal Nudge Angle

= Actual Footage/Day