54th General Meeting
6 & 7 of October 2021
Virtual Conference

Wellbore Positioning Technical Section

The Industry Steering Committee on
Wellbore Survey Accuracy (ISCWSA)

Real-Time Wellbore Placement Improvement with High-Fidelity Trajectory Estimation and Dual-Sensor MWD Packages

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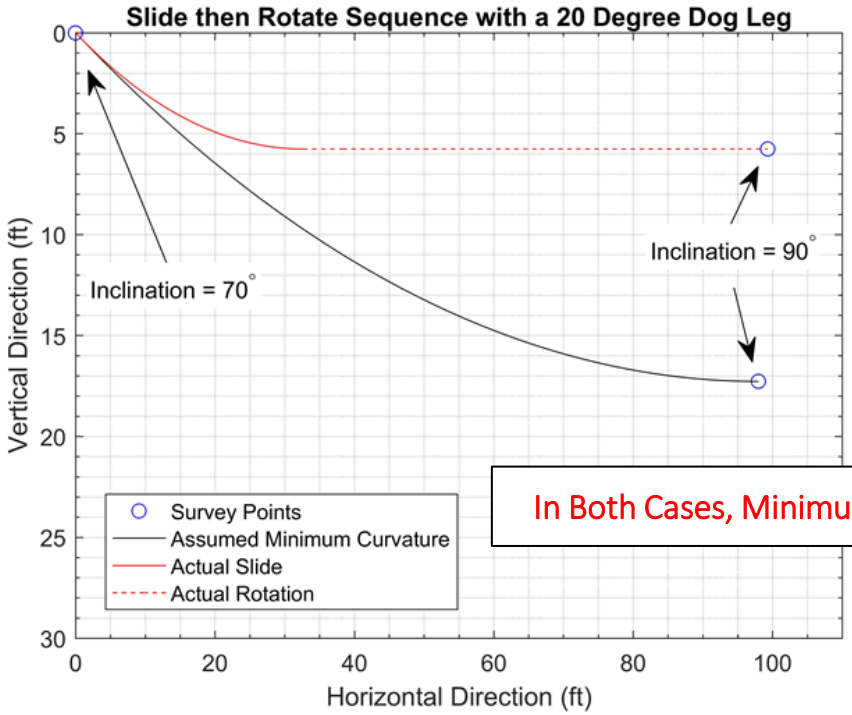
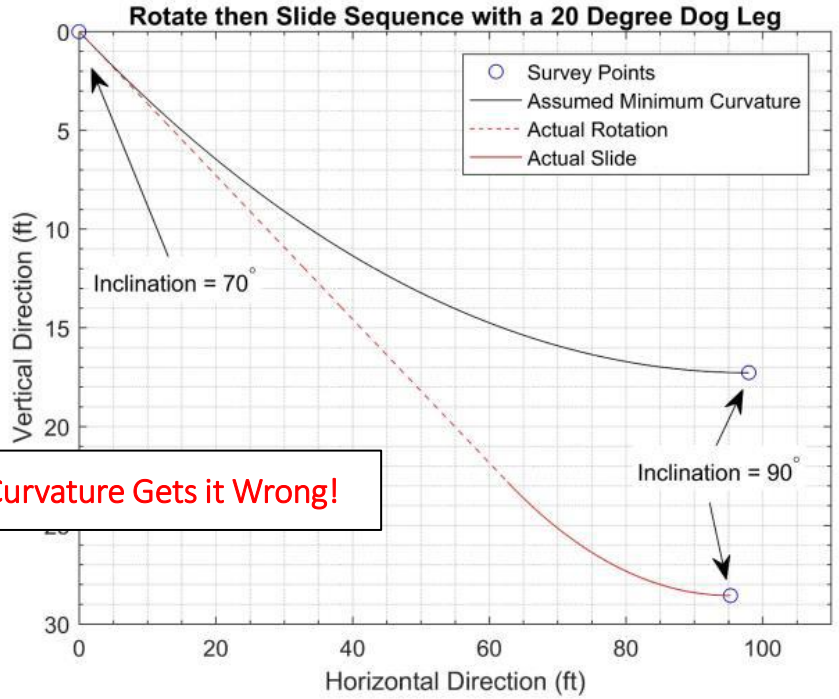
Agenda

- The Challenge to the Industry
- Dual-Sensor Packaging
- Navigation vs. Sensing
- High-Fidelity Trajectory Estimation
- Dual-Sensors with High-Fidelity Trajectory Estimation
- Lab Testing / Field Trial Methodology & Results

The Industry Challenge

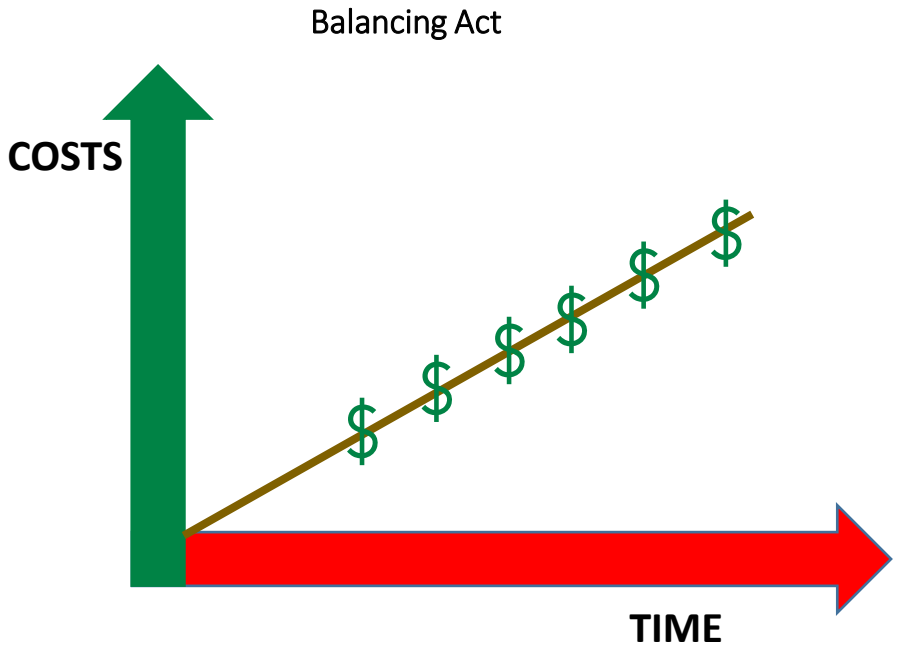




In Both Cases, Minimum Curvature Gets it Wrong!

How Do We Fix this?

- Take more Surveys!
- Change How We Drill!
- Change Minimum Curvature!
- Do Nothing



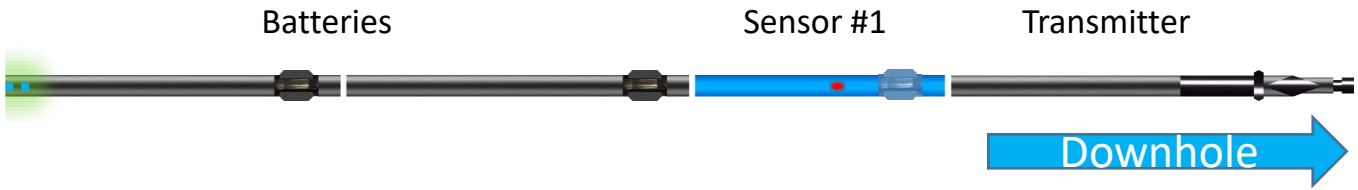
Economic Challenge of Taking More Surveys

Most Drilling Operations Survey every 90 ft. (30 meters)

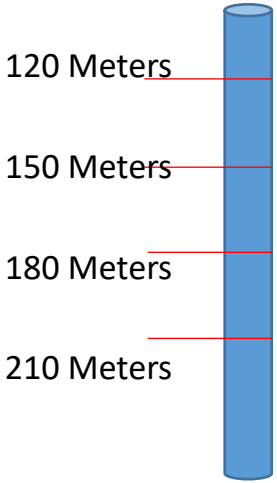
Lines up with pipe connections. (Survey on Connection).

1. Stop Drilling. Shut off Pumps
2. Sit Still (30-45 seconds)
3. Turn Pumps On
4. Detection (2-5 minutes)

Single Sensor MWD Tool

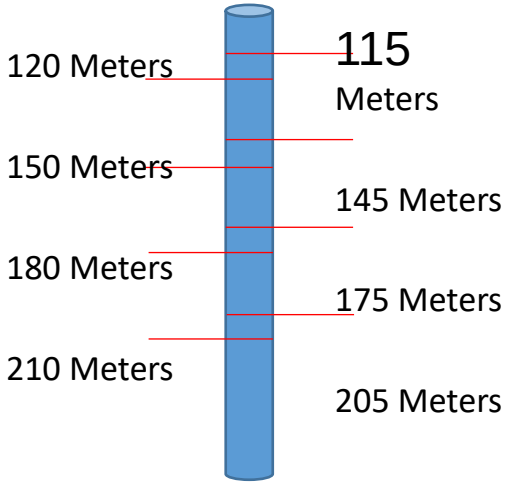


Send two sets of survey data each PUMPS OFF cycle at the same time

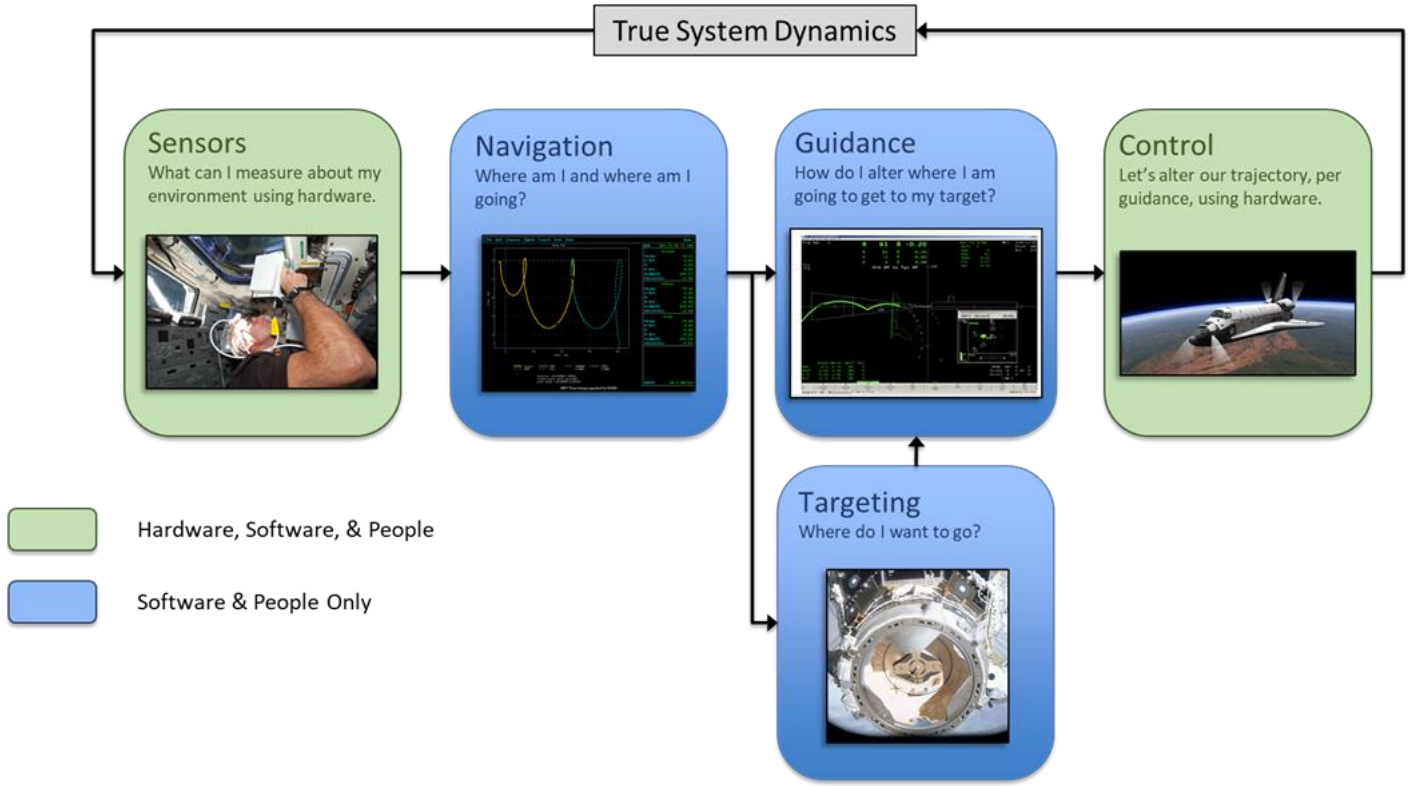


It's a Data Challenge!

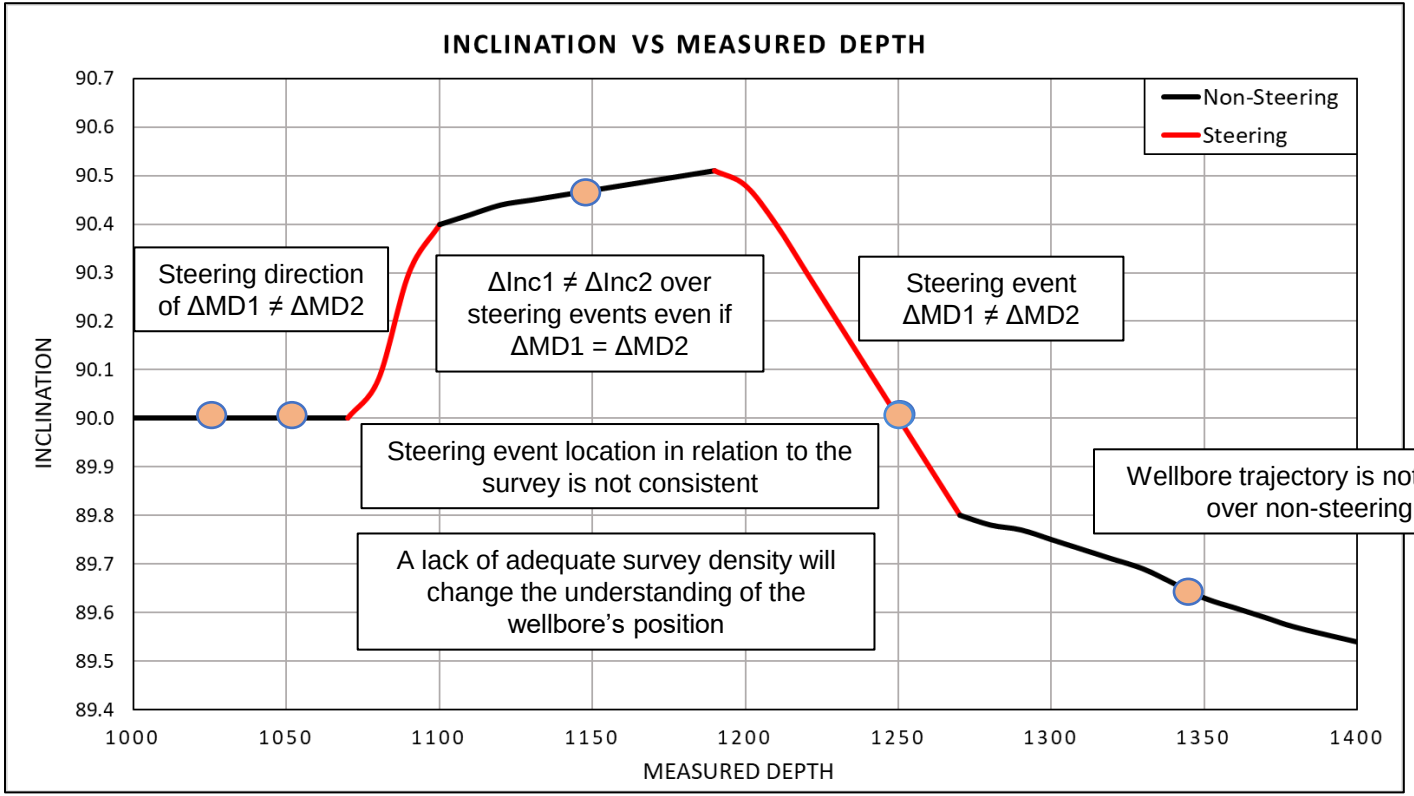
Direct API Connections Fix It!



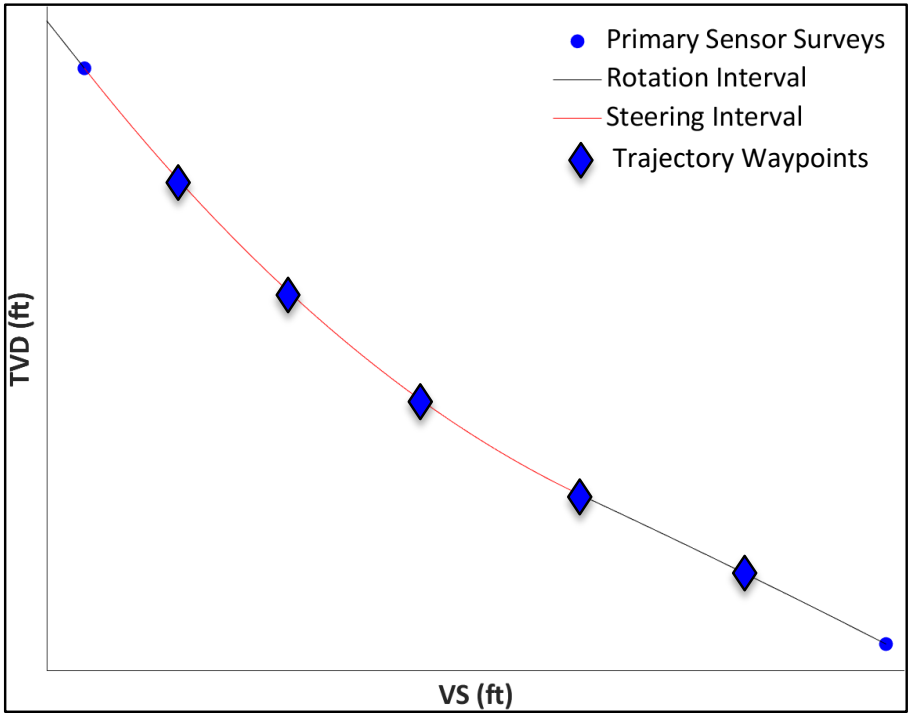
Sensing Vs. Navigation –> An Aerospace Application Analogy



Variables to Consider in High-Fidelity Trajectory Estimation

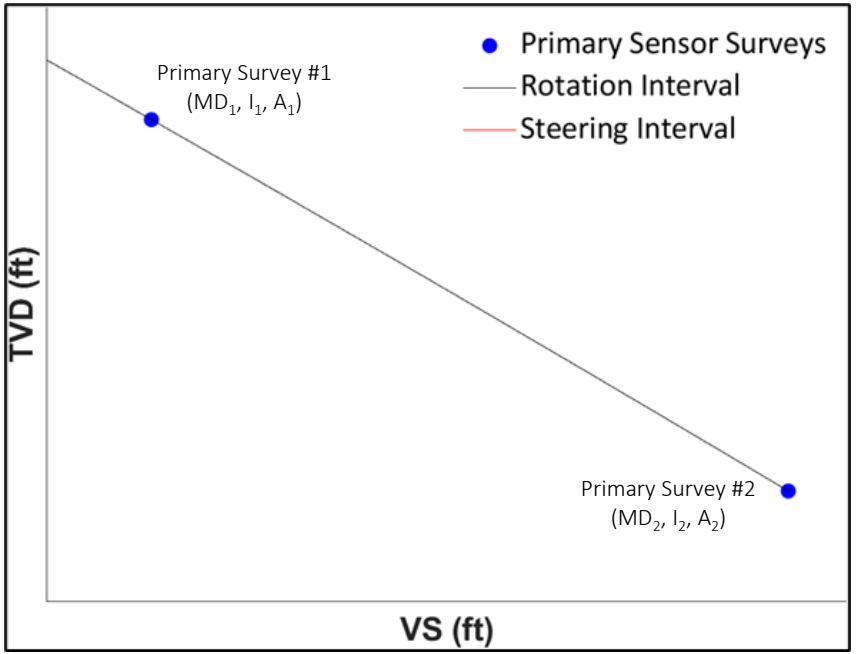


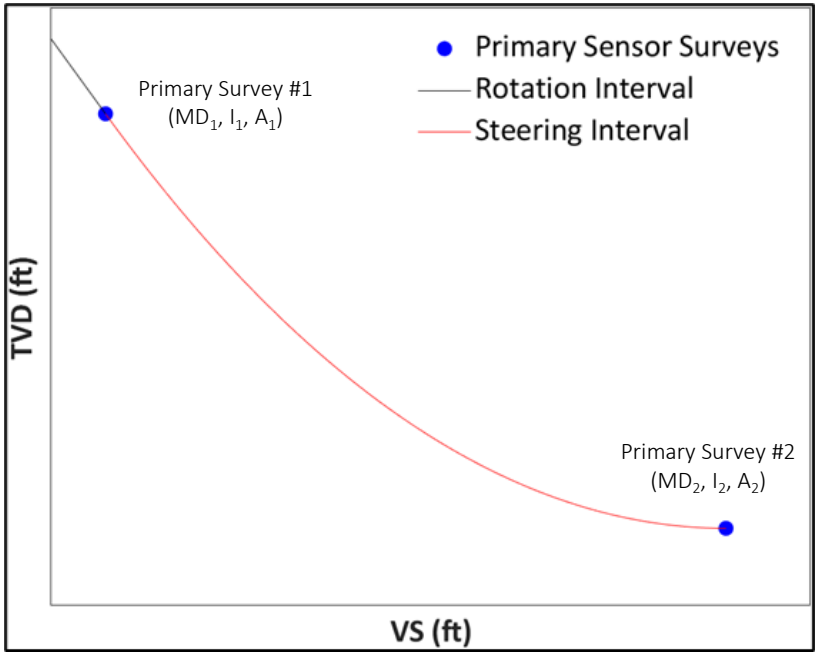
Using Trajectory Waypoints to Capture Wellbore Characteristics



- Trajectory Waypoints are modeled MD, INC, AZI datapoints at 15ft intervals to account for:
  - Steering/Non-Steering Transitions
  - Rotary Tendency Estimations
  - Refined Insights Provided by Continuous Inclination
- Maintain Minimum Curvature as means to calculate well path trajectory

Quantification of Rotary Tendencies & Motor Yield (Single-Sensor)

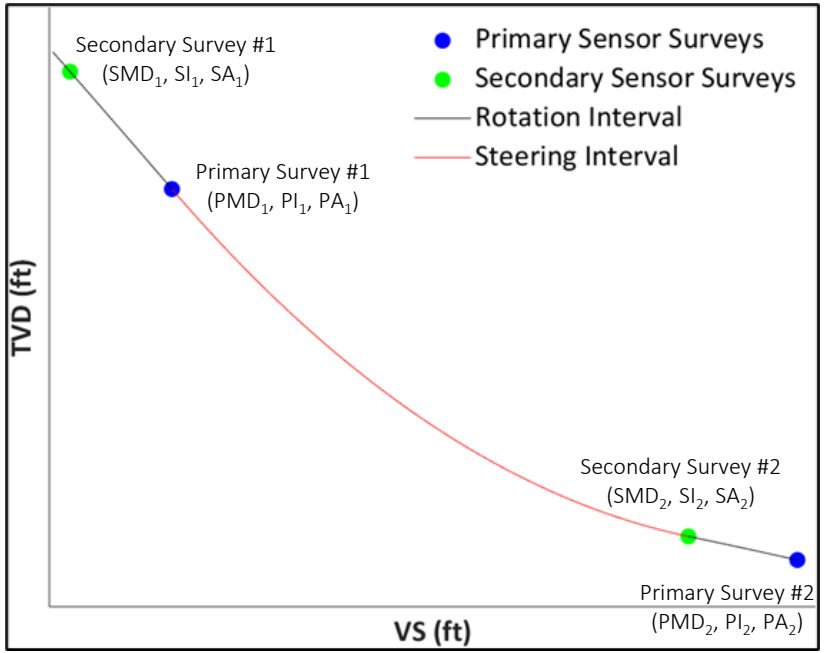


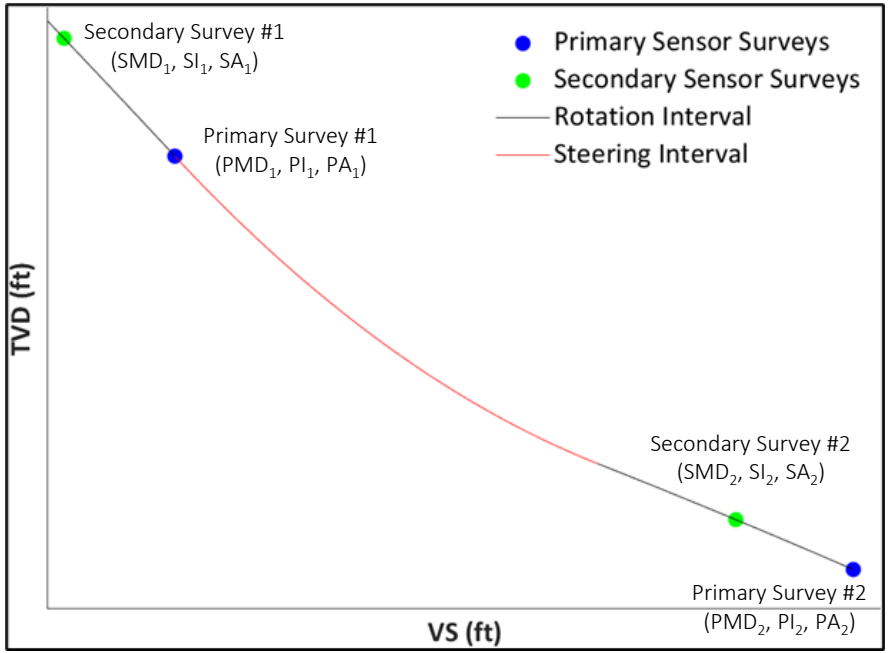


$$RBDR = \frac{I_2 - I_1}{MD_2 - MD_1}$$

$$MY = \left(\frac{1}{SE}\right) x \left(\frac{I_2 - I_1}{MD_2 - MD_1}\right)$$

Quantification of Rotary Tendencies & Motor Yield (Dual-Sensor)

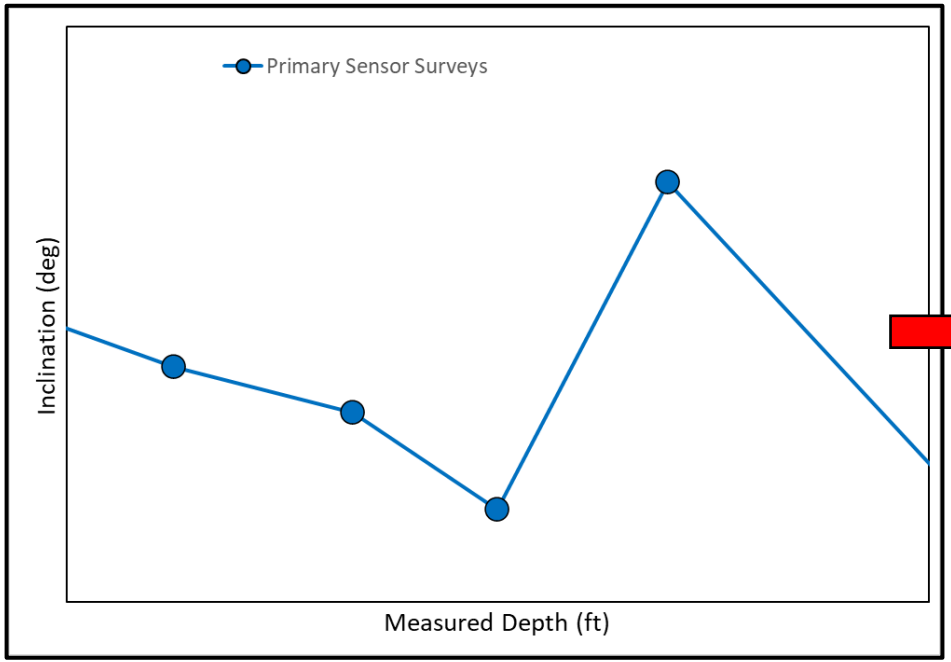


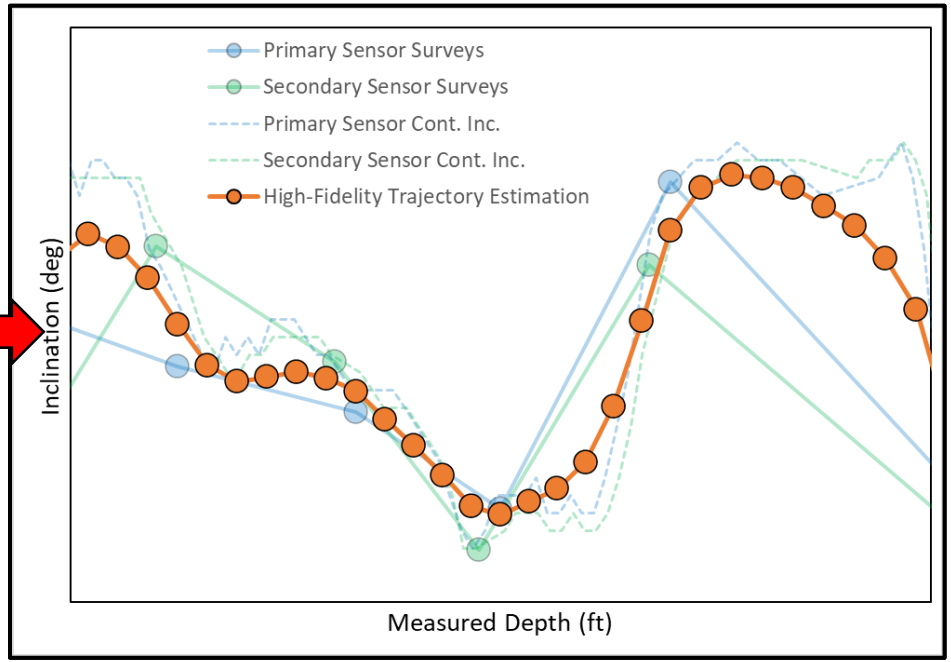


$$RBDR = \frac{PI_2 - SI_2}{PMD_2 - SMD_2}$$

$$MY = \left(\frac{1}{SE}\right) x \left(\frac{(SI_2 - PI_1) - (RBDR \ x \ \Delta MD_{Rot})}{\Delta MD_{Slide}}\right)$$

Statistical Synthesis of Multiple Measurements





Lab Testing Configuration & Methodology

- Data simulation module for 6-axis dual-sensor configuration
  - Deviated, horizontal well with 10,000ft lateral
  - Simulated at 0°, 45°, 90° vertical section direction
- Random number generator used to inject unknown levels of MWD sensor errors
- Corrupted dataset processed through high-fidelity trajectory estimation algorithm
- Resulting position and uncertainty output compared to the uncorrupted position (true wellbore position)
- The size of the post-fit EOU was compared against the EOU size of the tightest, widely accepted gyroscopic surveying tools in the industry

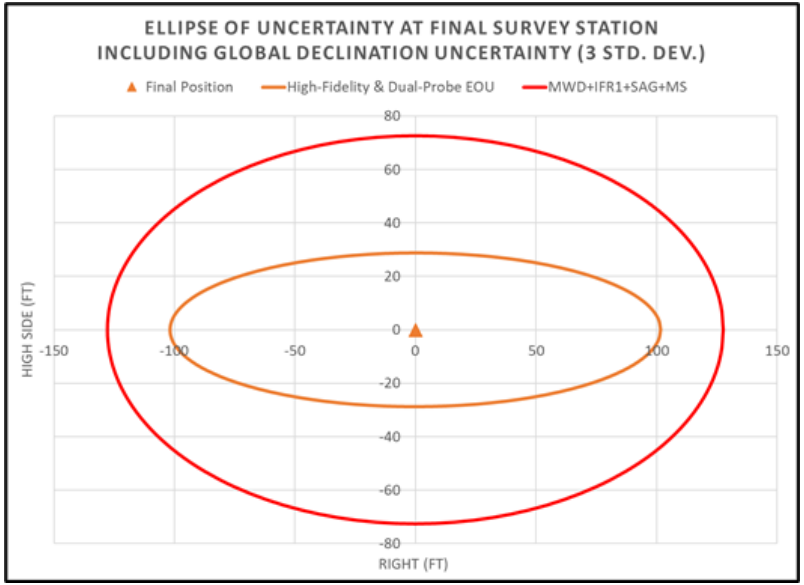
Lab Testing Results

Vertical Section Direction	Lateral Length (ft)	Survey Type	EOU Half-Width Horizontal (ft)**	EOU Half-Width Vertical (ft)**
0°	10,000	Dual-Sensor & High-Fidelity Trajectory Estimation*	108.9	59.6
		Gyro A	129.8	116.1
		Gyro B	60.1	56.7
45°	10,000	Dual-Sensor & High-Fidelity Trajectory Estimation*	106.4	59.9
		Gyro A	111.2	116.1
		Gyro B	62.1	56.8
90°	10,000	Dual-Sensor & High-Fidelity Trajectory Estimation*	116.6	60.0
		Gyro A	88.4	116.5
		Gyro B	64.2	56.6

*Including Global Declination Uncertainty (Dual-Sensor & High-Fidelity)
**3-Sigma Values

Field Trial Description & Target Expectations

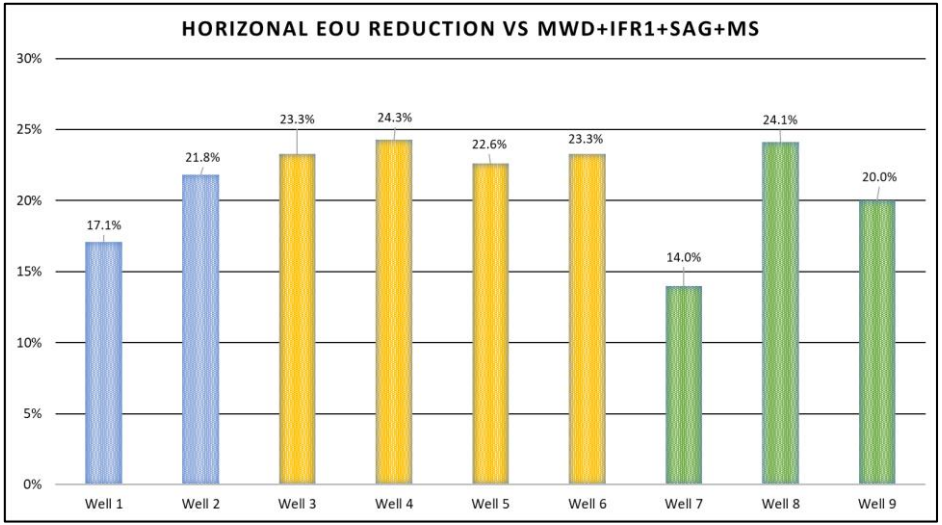
- 9 Wells (3 Drilling Pads)
- U.S. Land Applications
  - Various oil & gas fields as well as target formations
  - Varying well plan configurations
- Target Expectations Based on Lab Testing
  - 20% EOU reduction in the horizontal (semi-major) plane over MWD+IFR1+SAG+MS
  - 45% EOU reduction in the vertical (semi-minor) plane over MWD+IFR1+SAG+MS

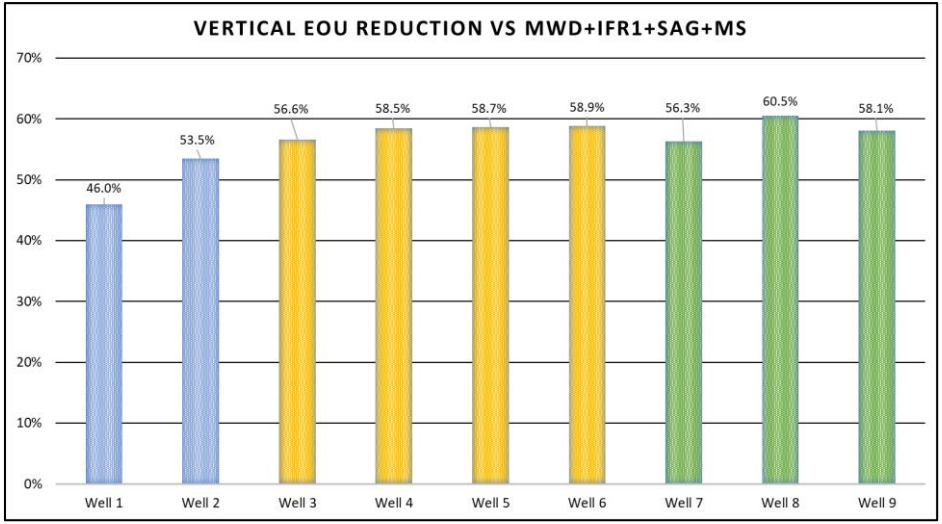


Horizontal EOU Reduction vs MWD+IFR1+SAG+MS	Vertical EOU Reduction vs MWD+IFR1+SAG+MS
24.1%	60.5%

*Including Global Declination Uncertainty
**3-Sigma Values

Field Trial Description & Results





Pad	Vertical Section Direction	Avg. Horizontal EOU Reduction vs MWD+IFR1+SAG+MS	Avg. Vertical EOU Reduction vs MWD+IFR1+SAG+MS
Pad 1	0°	19.5%	49.8%
Pad 2	165°	23.4%	58.2%
Pad 3	0°	19.4%	58.3%

*Comparison shots between runs omitted on Well 1 & Well 7 which would have likely improved the EOU reduction metrics

Conclusions

- Accurate positioning is paramount to maximizing ROI over the life of the well
  - Economic realities have prevented significant advances in this field in recent decades
- The challenges to reducing positional uncertainty are numerous
  - Tools are now available to overcome these challenges at minimal cost
- Dual-Sensor MWD packages when paired with a High-Fidelity Modeling Algorithm will more accurately represent the wellbore trajectory
- Field trial results indicate substantial positional uncertainty improvement:
  - 21.1% average EOU reduction in the horizontal (semi-major) plane over MWD+IFR1+SAG+MS
  - 56.3% average EOU reduction in the vertical (semi-minor) plane over MWD+IFR1+SAG+MS

THANK YOU / QUESTIONS