CT Extended Reach
Can We Reach Farther?

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How can we reach farther?

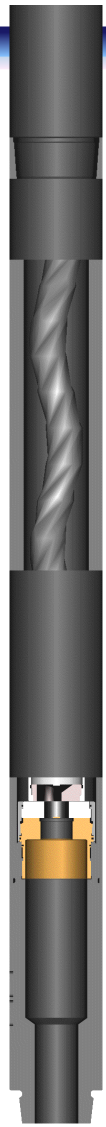
(Force and Friction)

- Apply force to downhole end
  - Tractor
  - Pump down annulus
- Reduce friction
  - Vibration
  - Lubrication
  - Rollers
  - Rotate CT
  - Increase buoyancy (decrease WCF)

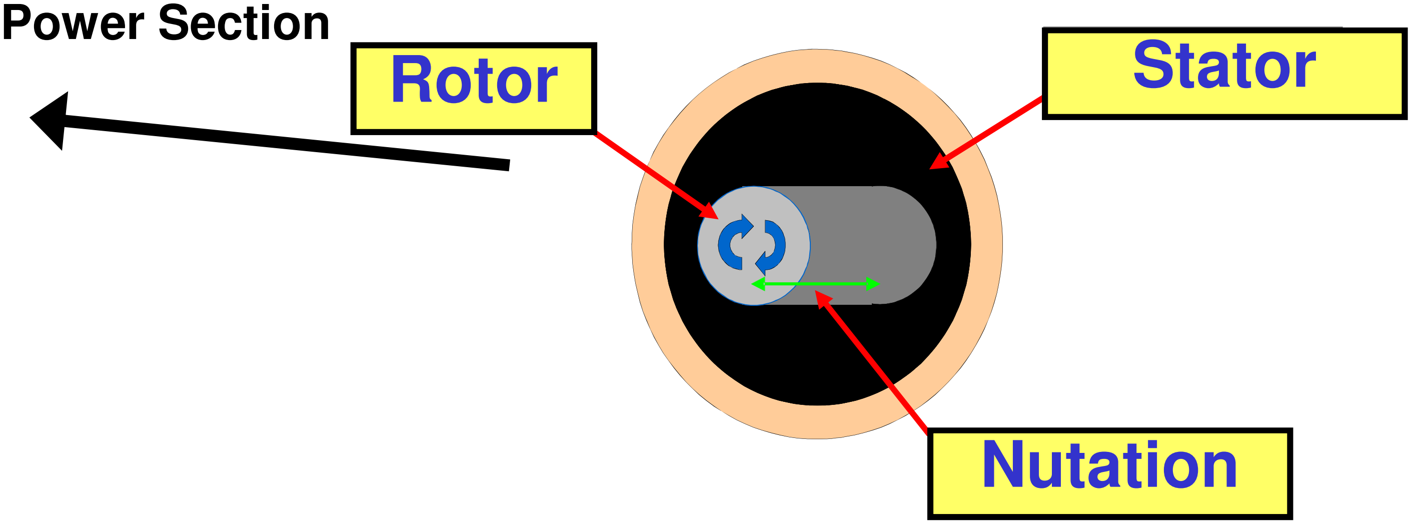
Downhole Pulsation of CT

(Agitator™)

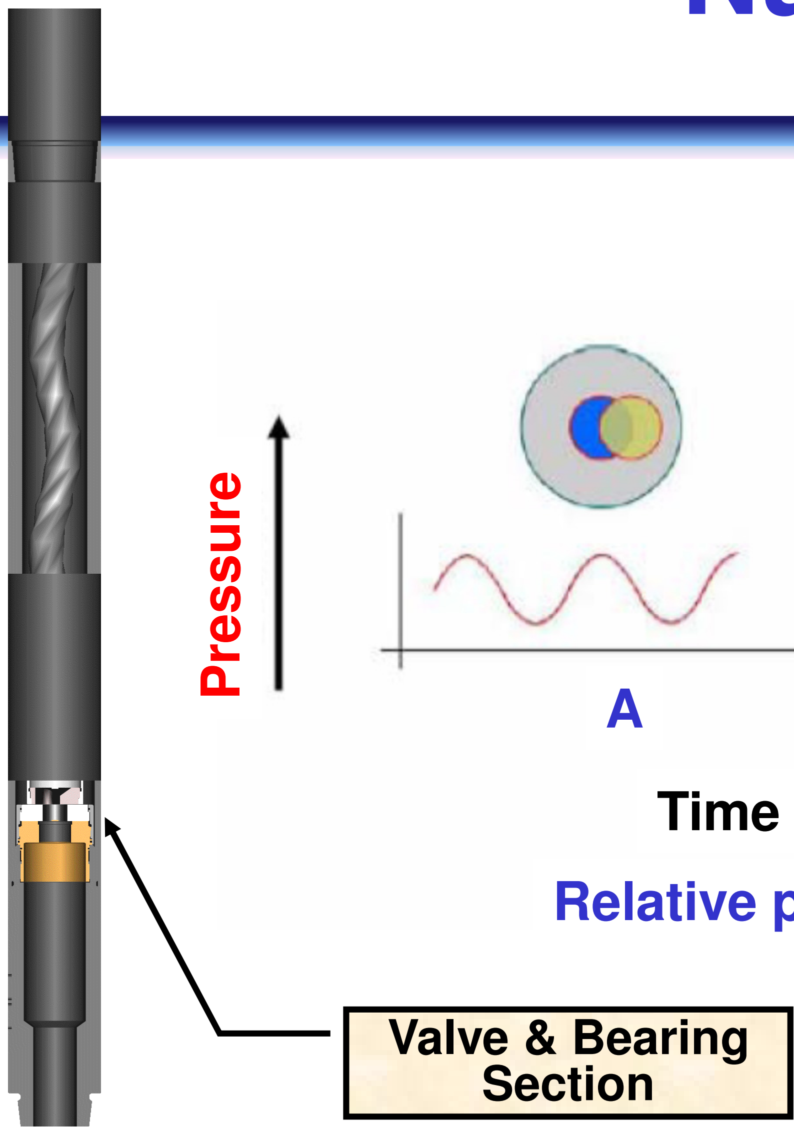
Power Section

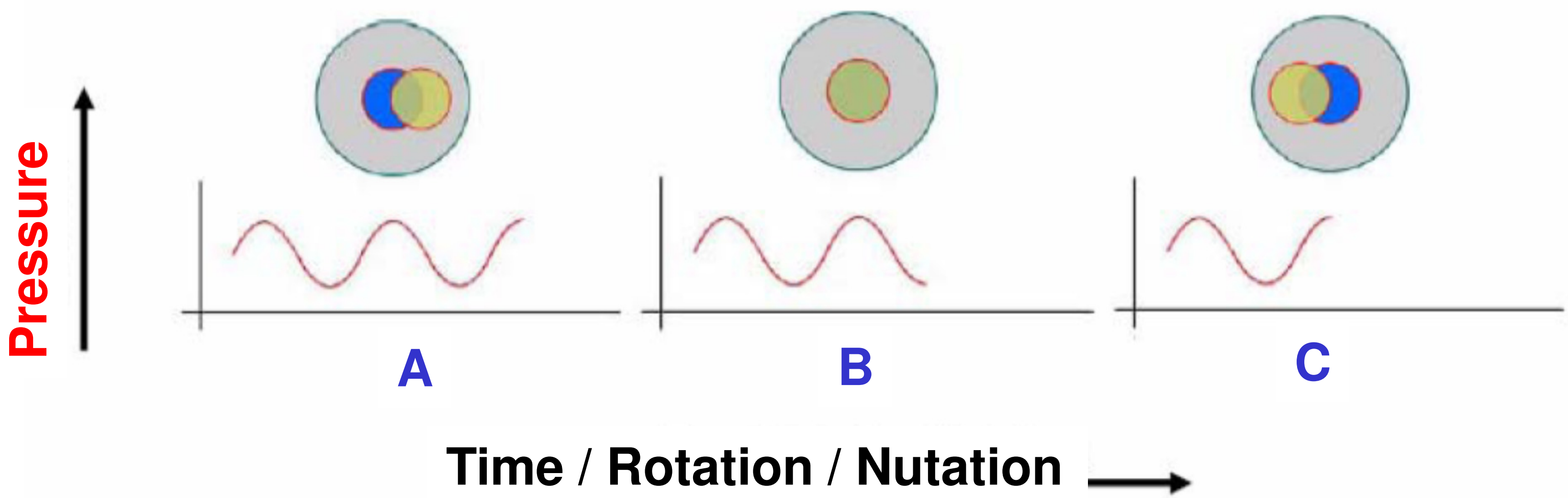


High Speed
Power Section



Nutation



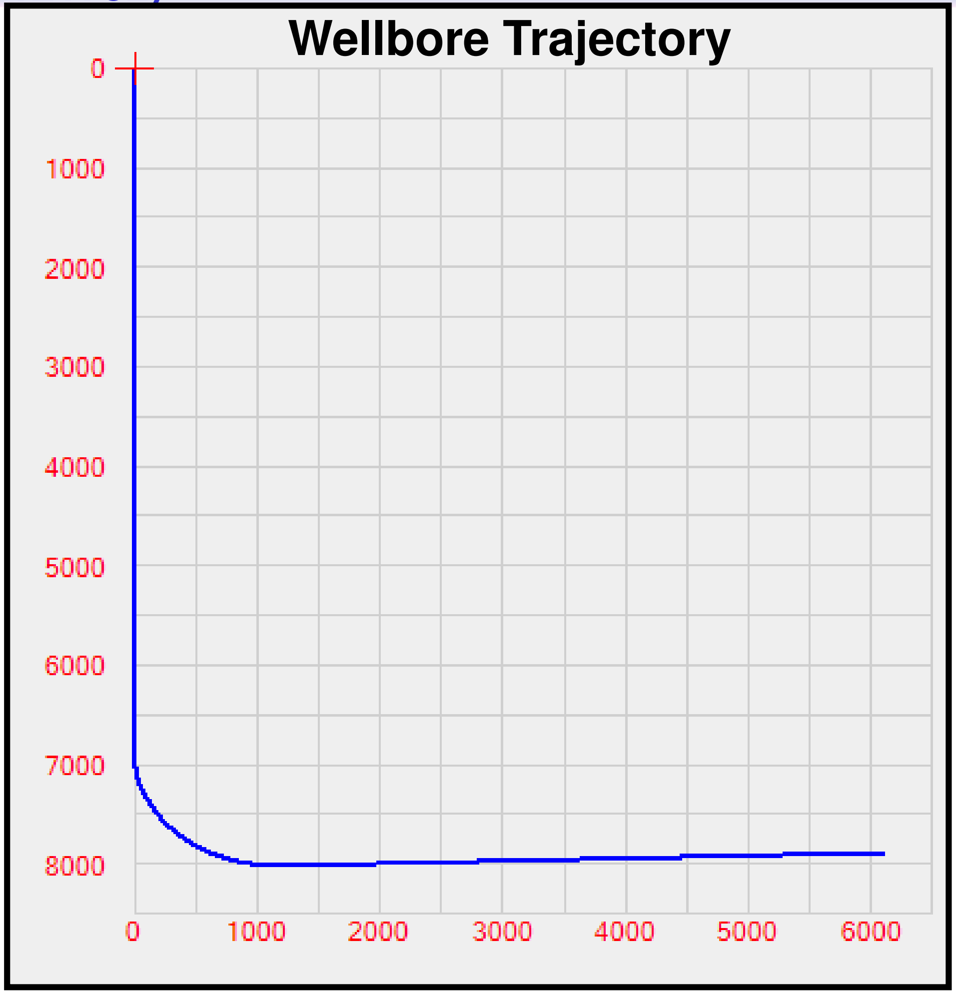


Relative positions of Valve Plates

Field Example: Downhole Pulsation Tool

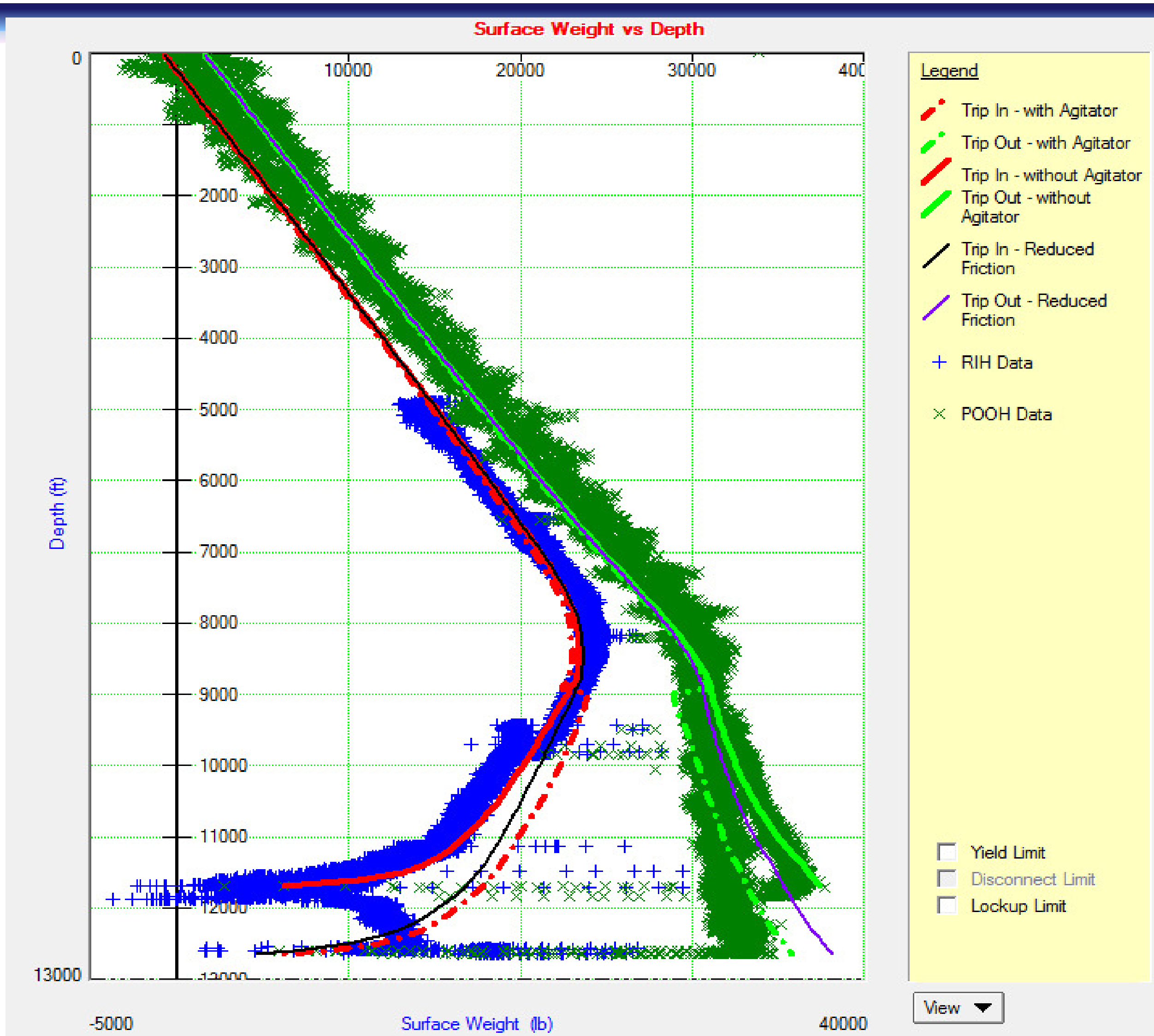
(SPE 121752)

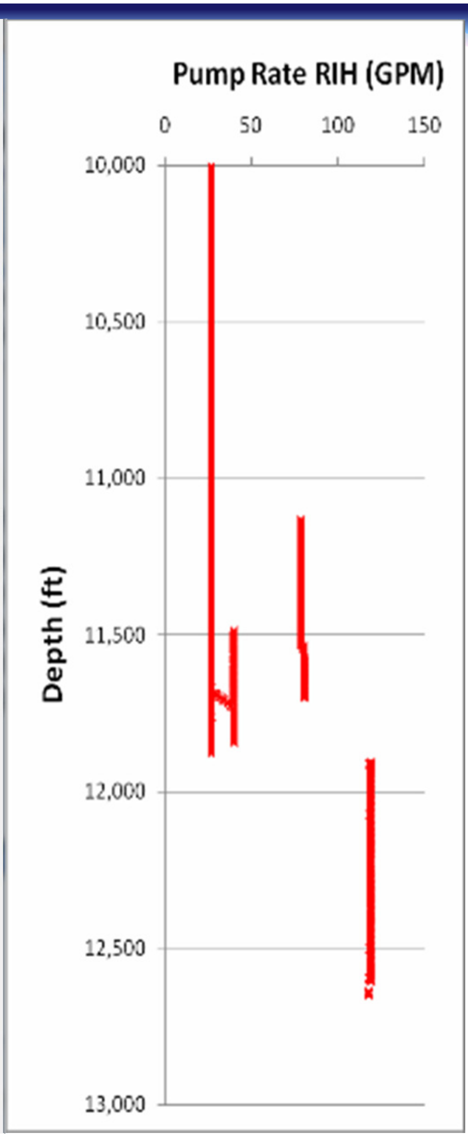
- **5.5" casing to 6,500'**
- **4.5" liner to 14,000'**
- **Purpose of Intervention**
  - **Logging**



Downhole Pulsation Tool

(CT Lockup 11,697' w/o pulsation // 12,652' w/pulsation)





Benefits of Rotating CT

- Reduce friction
  - Increase WOB
  - Extend reach
- BHA orientation
- Reduced risk of sticking
- Improved hole cleaning
- For RIH rotational speed needs to be similar to RIH speed

Rotating CT Unit
(Canister Concept)

Reel Revolution Ltd.

www.reel-revolution.com

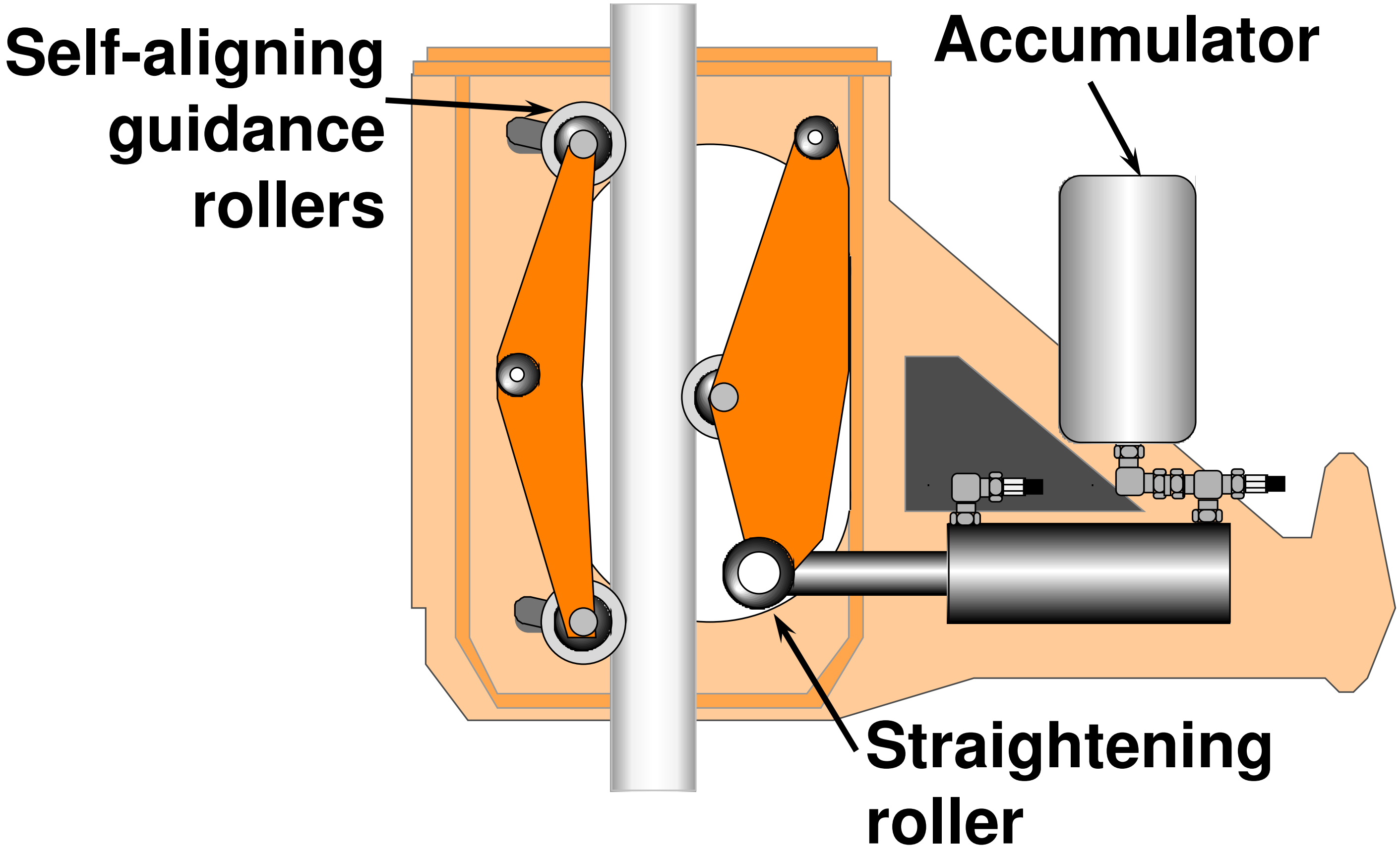
How can we reach farther?

(Reduce Helical WCF)

- Increase CT Stiffness (EI)
  - Increase OD and/or wall thickness
  - Use material with higher modulus of elasticity
- Decrease radial clearance
  - Smaller Hole ID
  - Larger OD CT
- Reduce the residual bend
  - Straightener
- Combined JP/CT string
  - Hybrid CT/JP System

Tubing Straightener

(Mounted on Top of Injector)



Straightener

Tubing Straightener

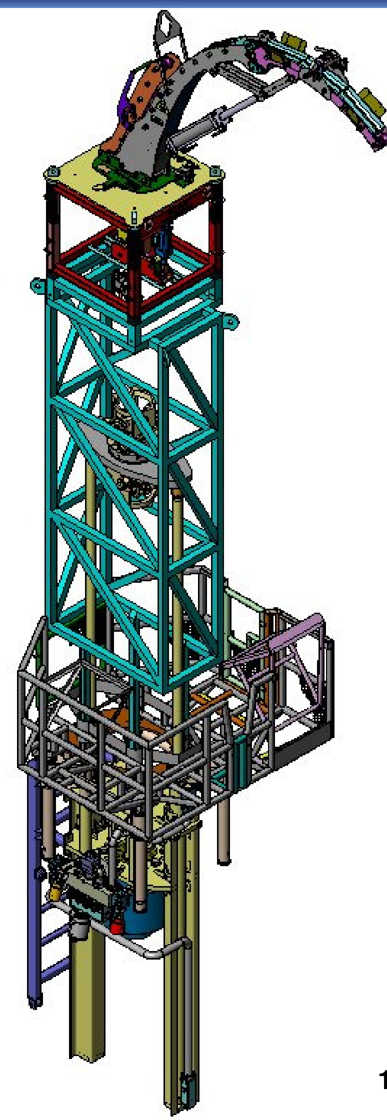
Without With

Hybrid CT/JP System
Key Components

- Gooseneck
- Tower
- HWO Rig Assist Unit
- Reel Trailer

Hybrid CT/JP System
What Does it Do?

- Hydraulic Workover (HWO) unit runs jointed pipe and CT
  - CT injector not used
- Rigless operation
- Well control package – no wireline



Potential Benefits

- Eliminate CT Transportation Weight Constraint Issues
- Use of larger CT sizes
  - Deeper penetration before CT lockup
  - Increased pull/push capacity
  - Enables higher pumping rates

Basic Theory
(buckling)

Sinusoidal

$$SBL = 2\sqrt{\frac{EIW_b \sin\theta}{r_c}}$$

Helical

$$HBL = 2\sqrt{\frac{2EIW_b \sin\theta}{r_c}} = \sqrt{2}SBL$$

- **Straight wellbore with inclination θ**
- **Simplified equations, friction ignored**
- **Straight CT (no residual bending)**

Basic Theory
(post buckling)

$$\beta = \frac{\mu r_c}{4EI}$$

- **Once buckled, friction increases as the square of the effective axial force**

$$F_f = \beta F_e^2 dL$$

- **Force Transfer Factor (FTF) =** $\frac{dF_b}{dF_t}$
- **Lockup defined as 1% FTF**
- **For a horizontal, straight well section:**

$$\frac{dF_b}{dF_t} = \frac{1}{\left(1 - F_t \beta L\right)^2}$$

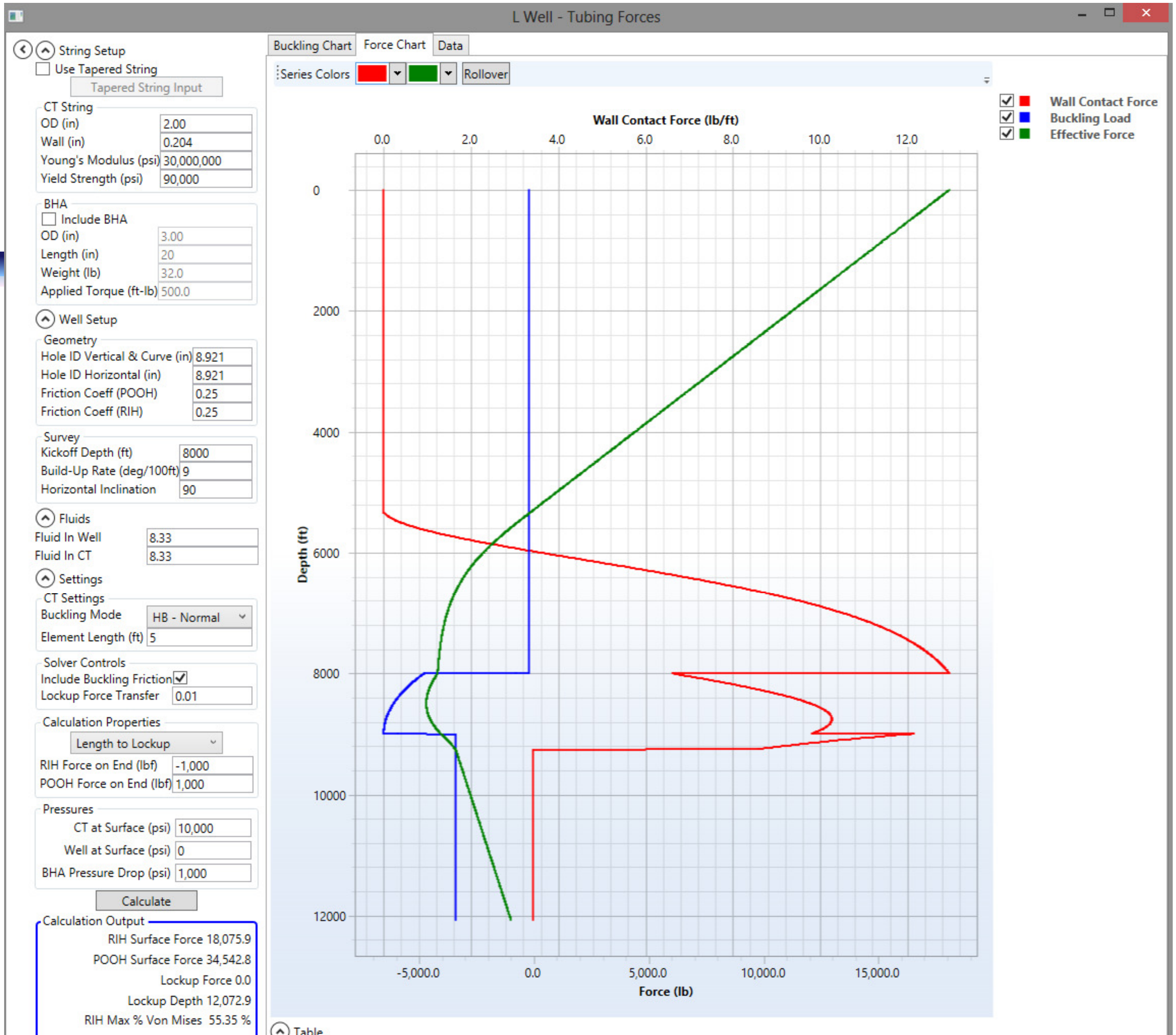
Typical L Shaped Well

- Vertical to 8,000 ft KOP
  - HBL nearly 0 in vertical section
  - Unbuckled CT in upper portion
  - Buckled CT in lower portion
- Build up to 90 deg in 1,000 ft
  - HBL increased in curve – no buckling
  - Buckled CT can be pushed into the curve
- Horizontal
  - Buckled section
  - Unbuckled section

Base Case

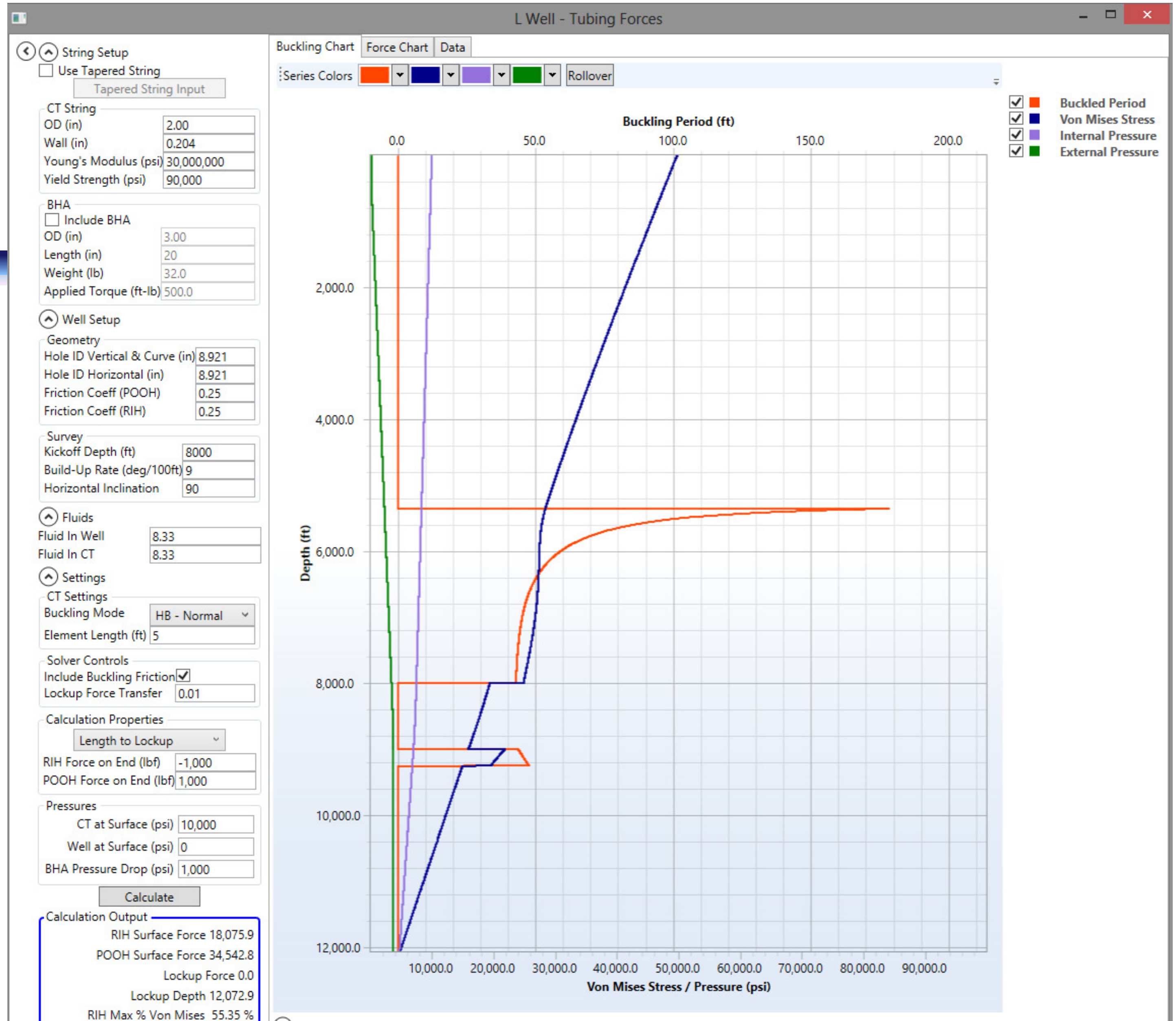
- 2" X 0.204" 90 Grade straight wall CT
- 9 5/8" (8.921") csg entire well
- KOP 8000 ft, BUR 9 deg/100
- Reaches horizontal at 9,000 ft
- Horizontal as long as needed
- Friction coeff 0.25
- Water throughout the CT and the well
- -1,000 lb force on end (WOB)

Base Case



Title	Depth Top (ft)	Depth Btm (ft)	Eff.Force Top (lbf)	Eff.Force Btm (lbf)	WCF Top (lb/ft)	WCF Btm(lb/ft)	VMS Top (psi)	VMS Btm (psi)	Buckled Per. Top (ft)	Buckled Per. Btm (ft)	% Force Transfer
Vertical, unbuckled section	0.0	5,357.9	18,075.9	-226.2	0.0	0.0	49,814.3	28,410.4	0.0	0.0	100.00 %
Vertical, buckled section	5,357.9	7,997.9	-243.3	-4,194.1	0.0	13.0	28,407.1	24,891.0	178.3	42.9	5.33 %
Curve from 0 to 90 deg	7,997.9	9,002.9	-4,195.0	-4,066.5	13.0	12.2	24,879.7	15,960.1	42.9	0.0	66.81 %
Horizontal, buckled section	9,002.9	9,257.9	-4,051.3	-3,414.8	12.1	8.6	21,889.8	19,588.8	43.7	47.6	28.09 %
Horizontal, unbuckled section	9,257.9	12,072.9	-3,406.2	-1,000.0	3.4	3.4	14,943.8	4,806.6	0.0	0.0	100.00 %

Base Case



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Well Parametric Analysis

Change from Base Case	Lockup Depth	Horiz. Length	Force Transfer Factor			Max von Mises	
			Vertical	Curve	Horiz	RIH	POOH
	ft	*ft*	%	%	%	%	%
Base case	12,073	3,073	5.3%	66.8%	28.1%	55.4%	62.2%
Friction coefficients = 0.30	11,415	2,415	3.7%	62.0%	38.3%	55.4%	62.3%
Friction coefficients = 0.35	10,673	1,673	1.8%	57.0%	100.0%	55.2%	62.0%
HBL without curvature	11,817	2,817	4.8%	23.4%	100.0%	55.3%	62.1%
HBL set to 0	11,265	2,265	10.2%	24.1%	40.7%	55.8%	61.7%
3.8" ID tubing to end of curve	12,579	3,579	13.7%	67.3%	10.9%	54.1%	62.6%
6.25" ID casing entire well	13,130	4,130	4.7%	67.3%	32.0%	54.5%	62.9%
Kickoff at 15,000 ft	19,073	3,073	5.3%	66.8%	28.1%	66.4%	77.1%
0 density fluid in well	11,797	2,797	6.5%	64.2%	26.0%	59.0%	69.5%
4.5 deg build from 7,000 ft to 9,000 ft (slower build)	12,033	3,033	74.8%	67.1%	30.0%	56.5%	61.4%

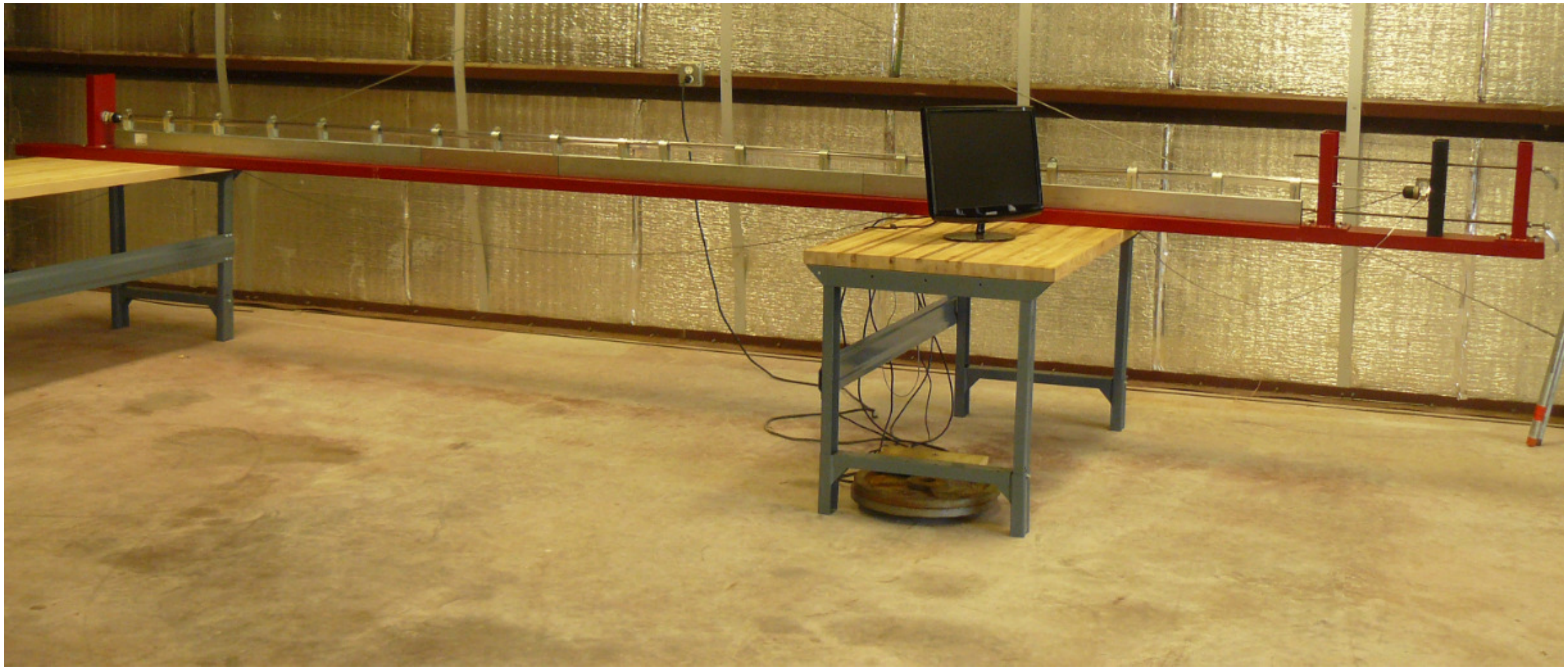
String Parametric Analysis

Change from Base Case	Lockup Depth	Horiz. Length	Force Transfer Factor			Max von Mises	
			Vertical	Curve	Horiz	RIH	POOH
	ft	*ft*	%	%	%	%	%
Base case - 15,000 ft kick-off	19,073	3,073	5.3%	66.8%	28.1%	66.4%	77.1%
HBL = 0	18,265	2,265	10.2%	24.1%	40.7%	67.2%	76.4%
2 3/8" X .204" CT	20,215	4,215	1.9%	67.2%	79.0%	71.0%	81.9%
2 7/8" X .250" CT	21,849	5,849	5.4%	67.1%	27.9%	81.2%	92.5%
2 3/8" X .204" CT - HBL = 0	19,355	3,355	7.6%	34.5%	38.2%	72.8%	83.4%
2 7/8" X .250" CT - HBL = 0	20,820	4,820	5.4%	49.7%	37.1%	70.3%	83.9%
Tapered 2" 125 grade string	20,793	4,793	5.4%	66.8%	27.8%	40.6%	49.6%
Tapered 2" string - HBL = 0	17,964	1,964	21.4%	20.7%	22.6%	51.3%	57.4%
Tapered HBL without curvature	20,522	4,522	4.5%	22.4%	100.0%	54.0%	67.0%

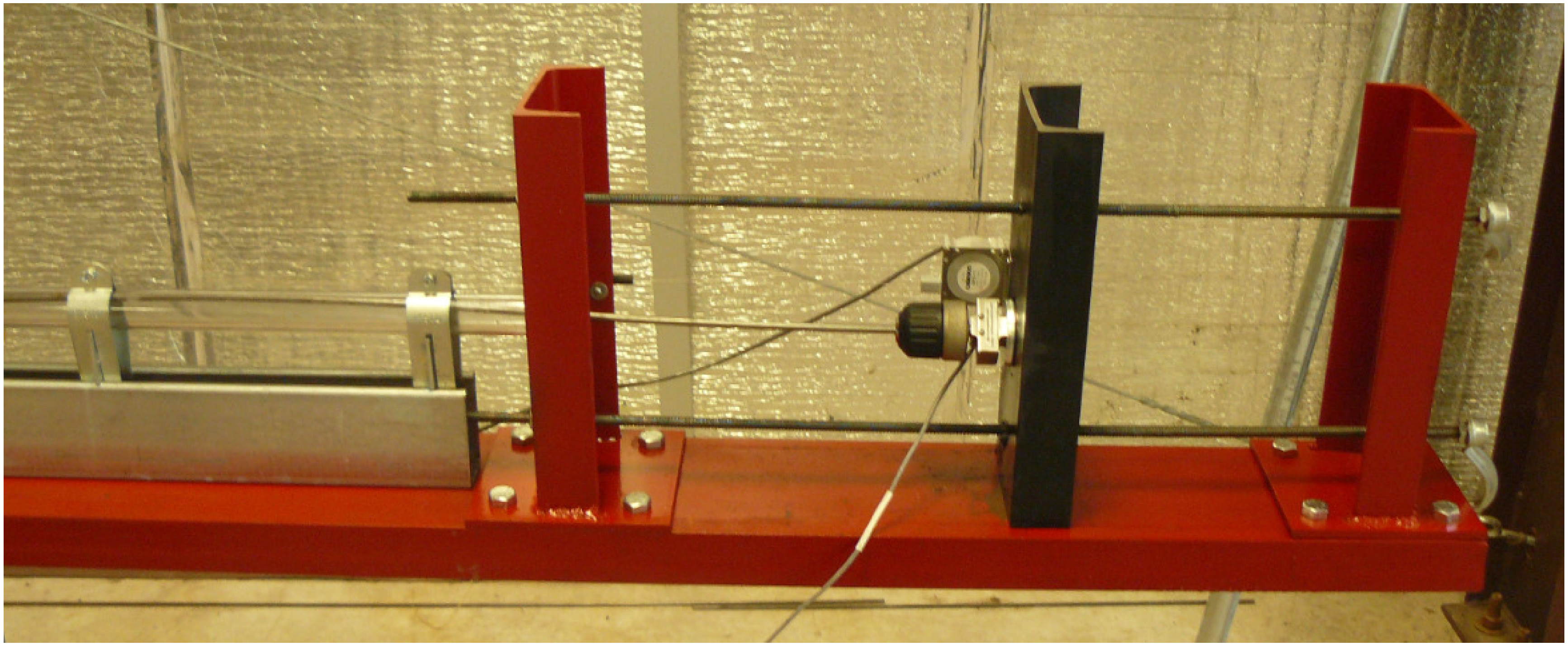
Modeling Conclusions

- Whether or not residual bend exacerbates the onset of helical buckling is a major issue that needs to be understood
- If the HBL is understood, a tapered string may be designed which significantly extends the reach
- Picking up and setting down may remove buckling in the curve, allowing further reach
- Increasing the yield strength increases the residual bending

Tubing Forces Lab



Tubing Forces Lab

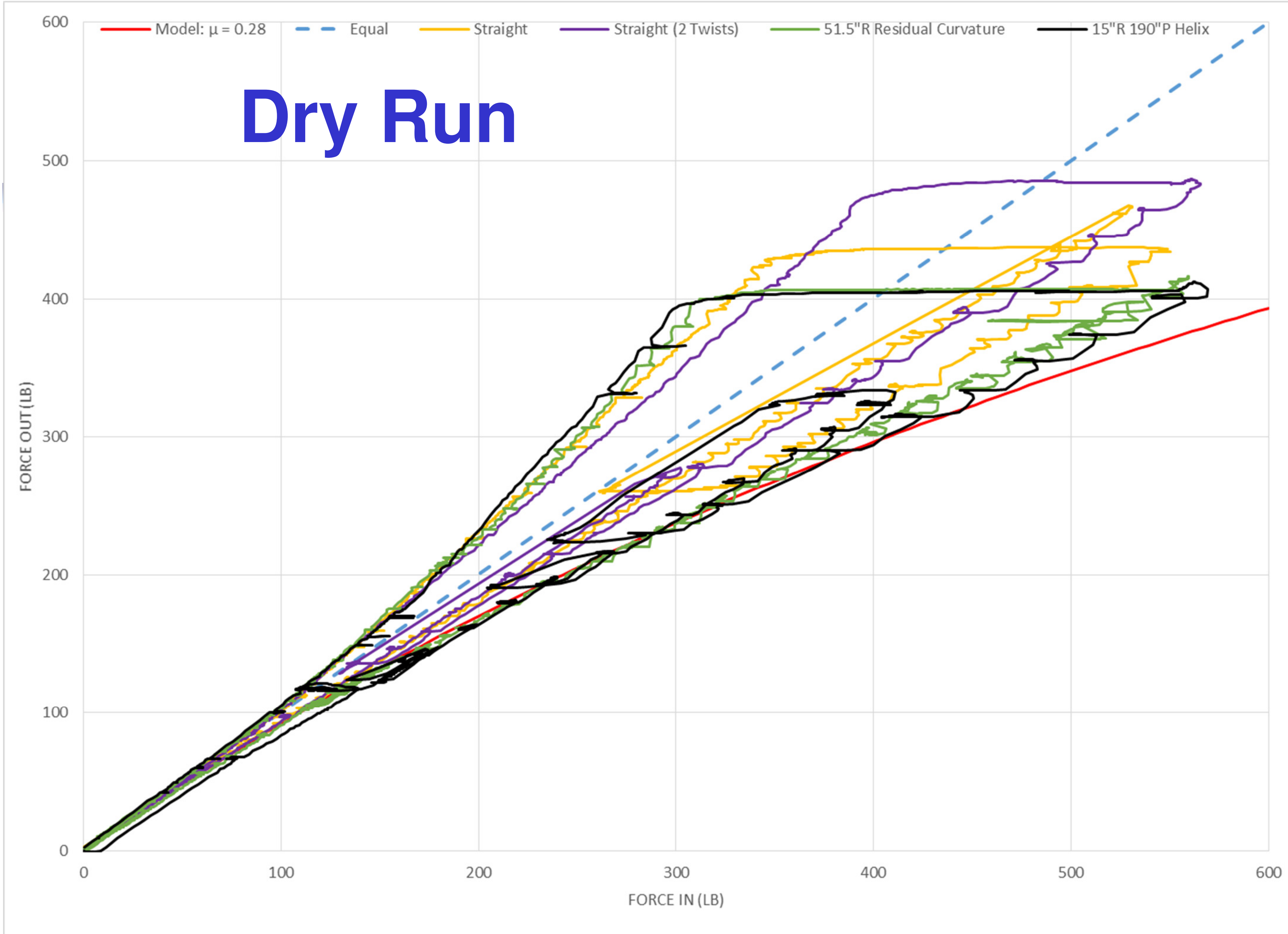


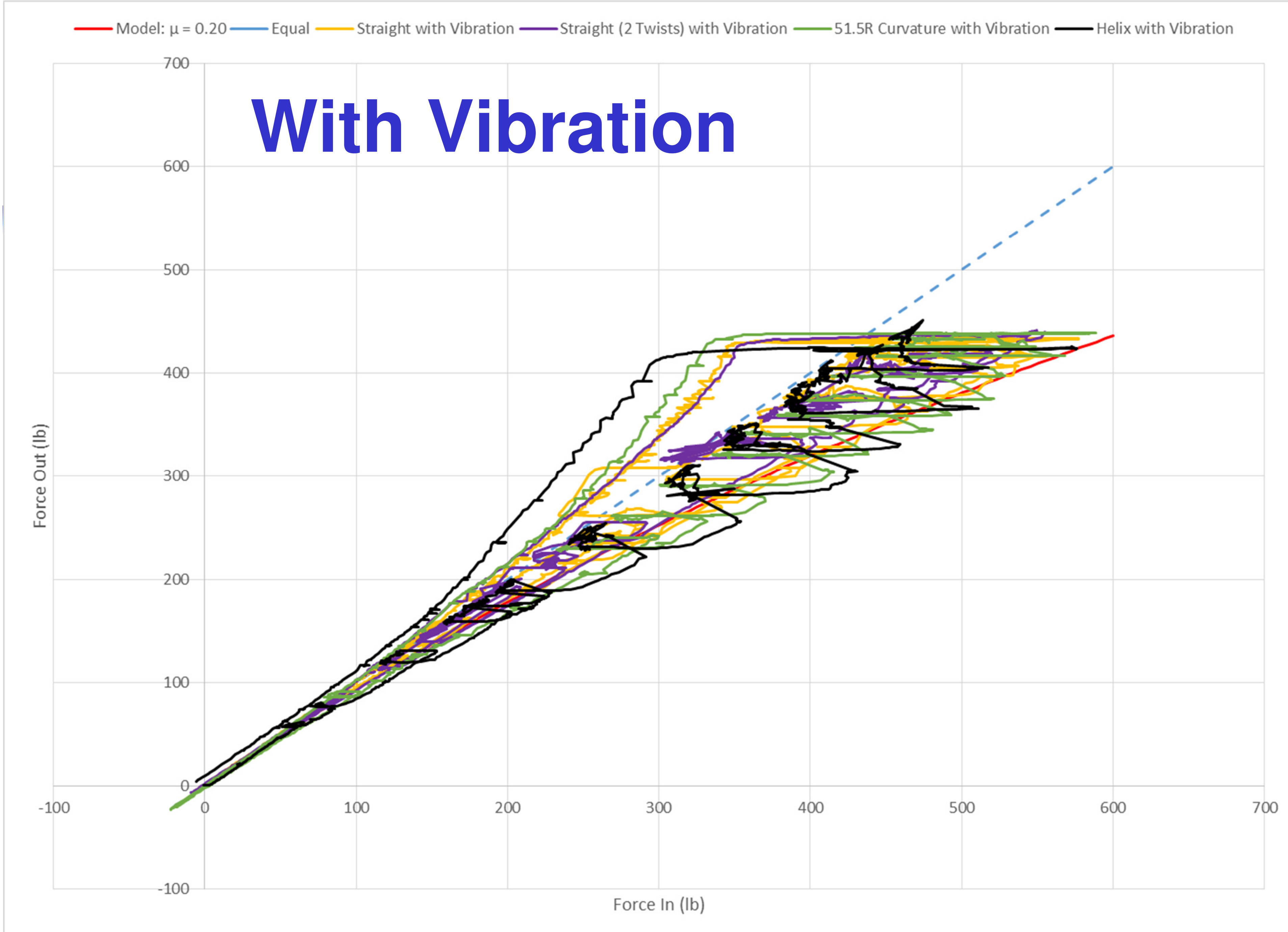
Tubing Forces Lab

- 1” ID, 16 ft L clear ‘Casing’
- ¼” OD, 17 ft L ‘Test Samples’
- Dual screw tailstock
- Force input and output load cells
- Depth string potentiometer

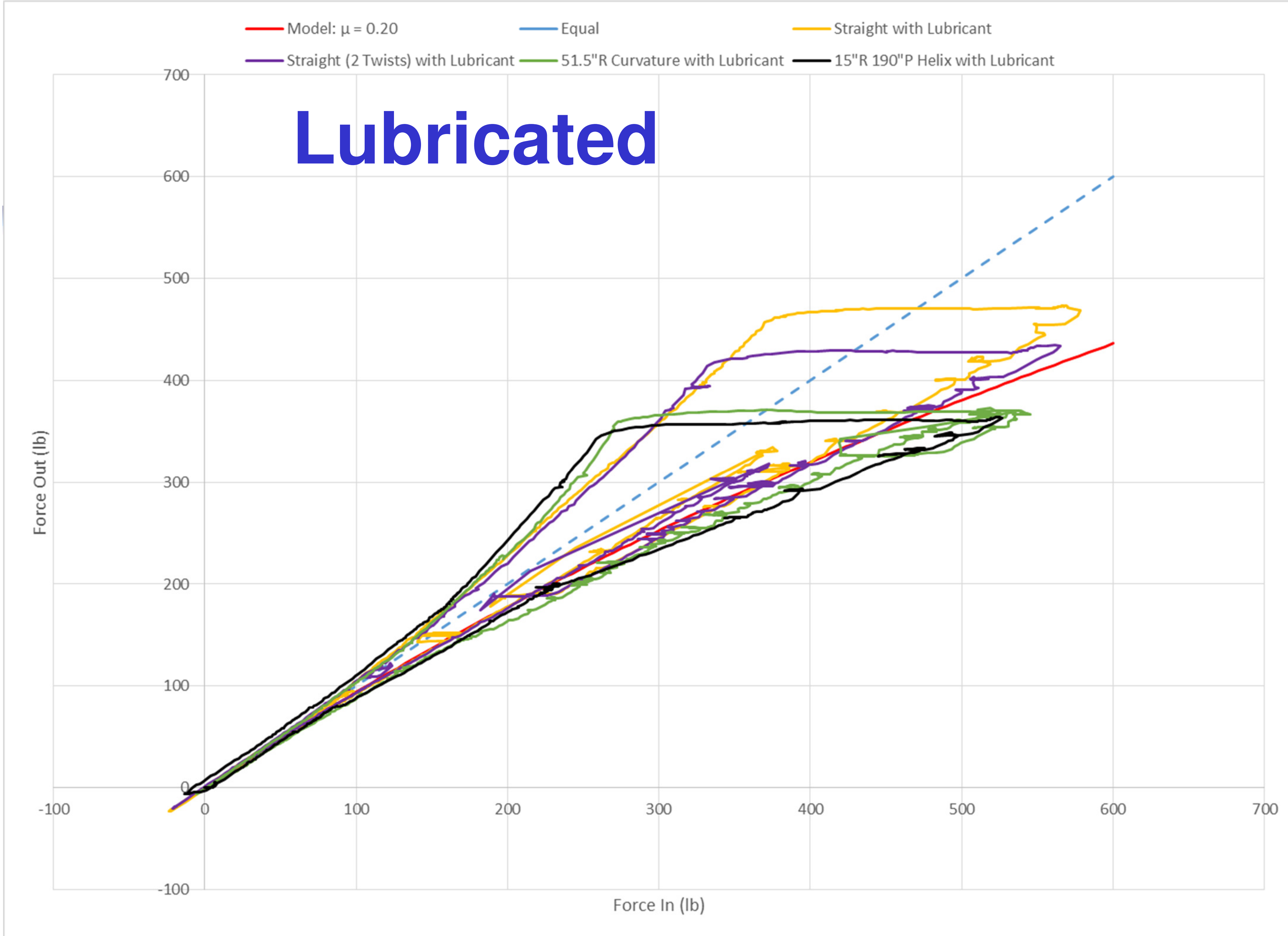
Test Samples

Buckled Specimen


Model: μ = 0.28
Equal
Straight
Straight (2 Twists)
51.5"R Residual Curvature
15"R 190"P Helix
Dry Run
FORCE OUT (LB)
FORCE IN (LB)
0
100
200
300
400
500
600

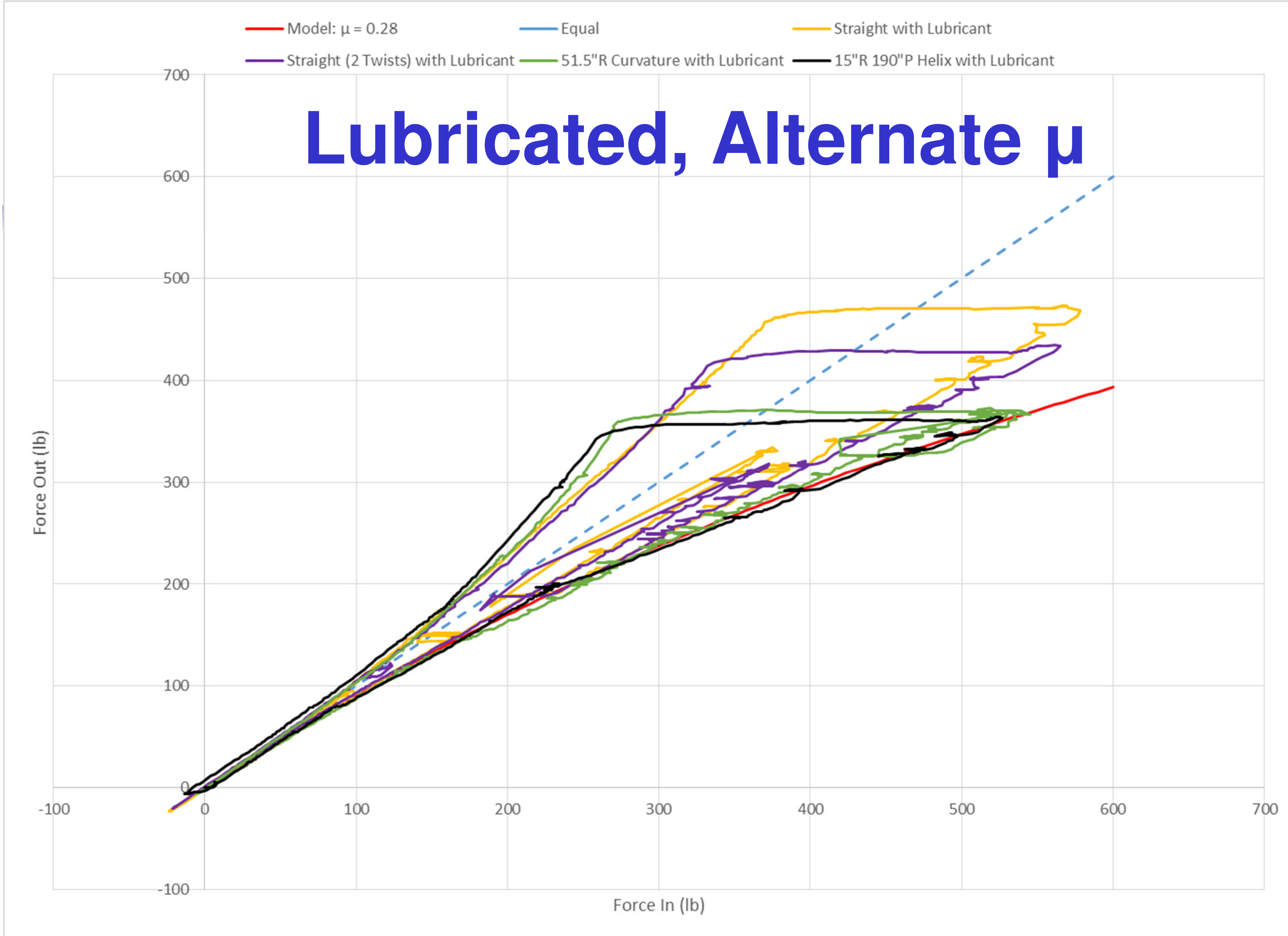


Model: μ = 0.20
Equal
Straight with Vibration
Straight (2 Twists) with Vibration
51.5R Curvature with Vibration
Helix with Vibration
With Vibration
700
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600
700
Force Out (lb)
Force In (lb)



Model: μ = 0.20
Equal
Straight with Lubricant
Straight (2 Twists) with Lubricant
51.5"R Curvature with Lubricant
15"R 190"P Helix with Lubricant
Lubricated
Force Out (lb)
Force In (lb)
700
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600
700

Lubricated, Alternate μ



Initial Conclusions from Testing

- Residual curvature causes premature buckling and increased wall contact forces
- Residual curvature and residual torsion is even worse
- Residual torsion alone has little effect