Ask Echometer 19 Online Seminar – September 23, 2020

Addressing Plunger Tracking, Fall Velocity, and Troubleshooting

# Conventional and Bypass Plunger Performance

TOTAL ASSET MONITOR (TAM)

http://www.echometer.com/Software/Total-Asset-Monitor

Session 3 - "Introduction to Plunger Lift", Rowlan, https://www.echometer.com/Support/AskEchometer

"Two-Piece Plunger Fall Velocities and Practical Application in the Field", Busygin,Rowlan ALRDC Gas Well Deliquification, 02-2017

"Plunger Lift Analysis, Troubleshooting, and Optimization", Rowlan, McCoy, Podio, Canadian Petroleum Society 2007-159

"Modified Foss and Gaul Model Accurately Predicts Plunger Rise Velocity", Rowlan, Lea, McCoy, SPE120636, 2009

"Measured Plunger Fall Velocity Used to Calibrate New Fall Velocity Model", Rowlan, McCoy, Lea, Nadkrynechny, Cepuch SPE164495

Presenters: O. Lynn Rowlan

Q & A: Gustavo Fernandez and Echometer Engineering and Support

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Download the Session 19 PDF Bundle and TAM Example Data from

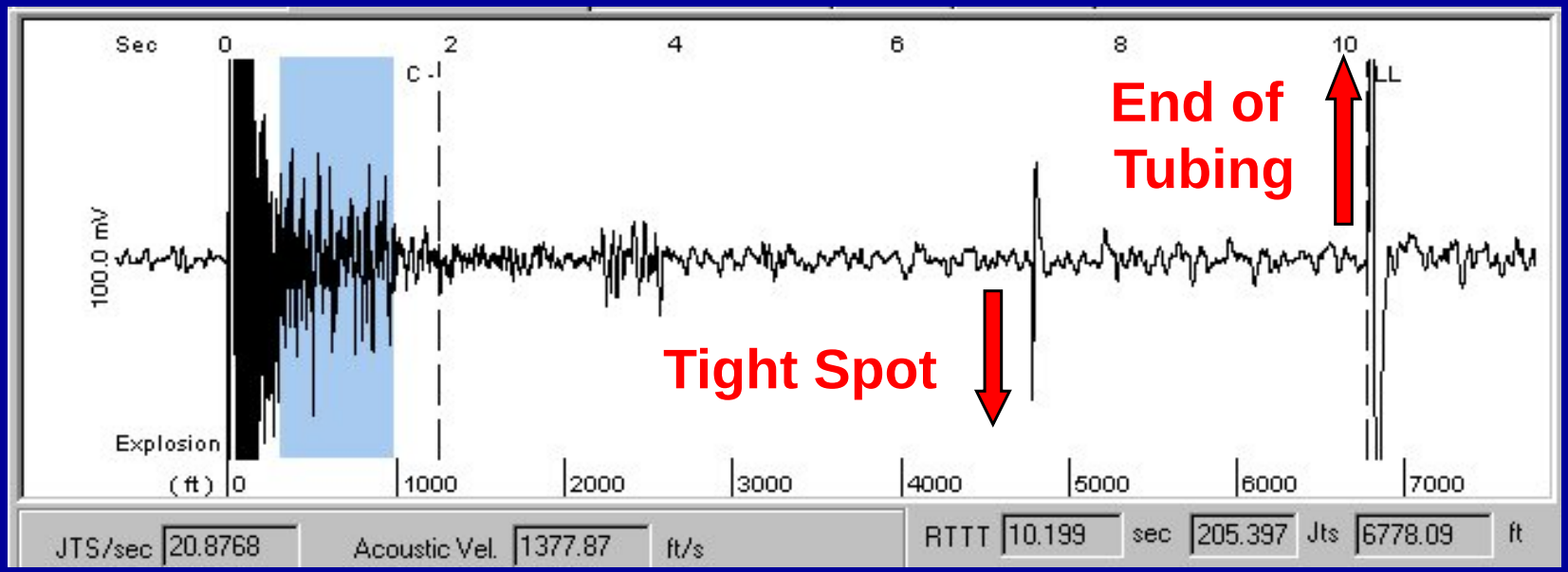
**https://echometer.com/Support/AskEchometer**

# PLUNGER LIFT SURVEY ANSWERS THE FOLLOWING WELL PERFORMANCE QUESTIONS:

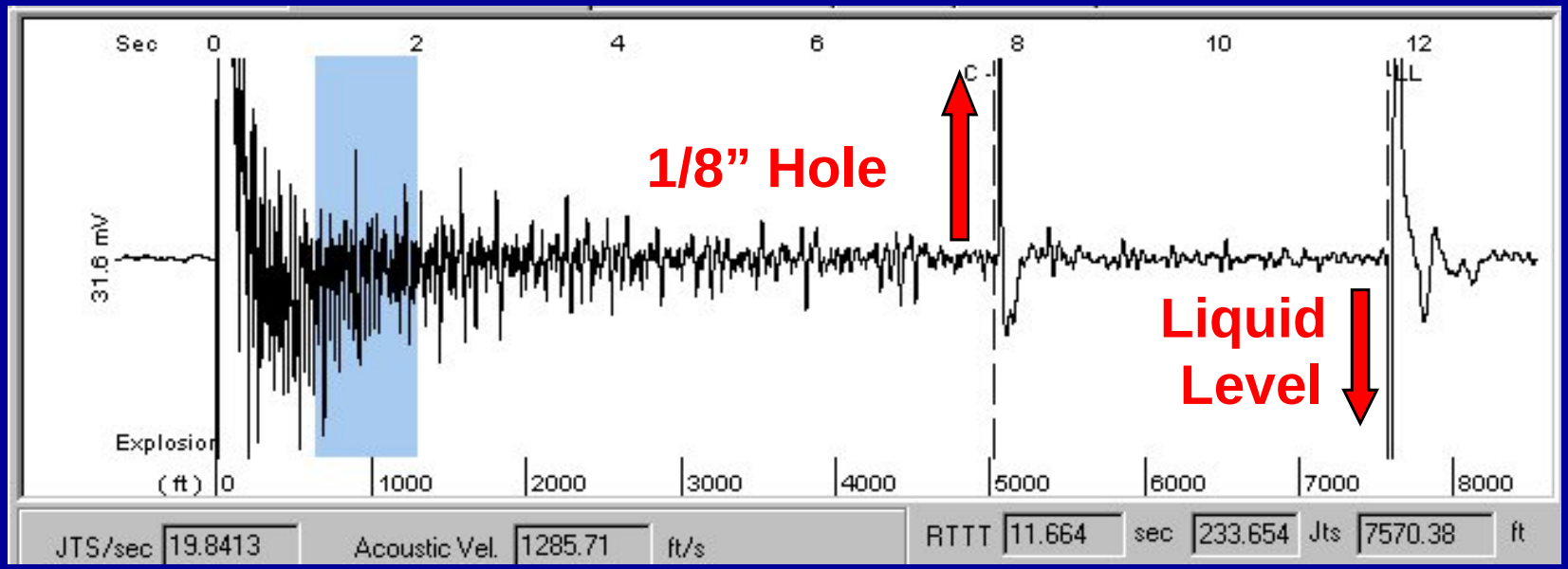
- Where is the plunger? Surface? In or above the liquid? On Bottom?
- What is the depth to the top of the liquid in the Tubing?
- What is the producing and Static BHP?
- Is liquid in the casing annulus above the tubing intake?
- What are the casing and tubing pressures during the operational cycle?
- Does tubing gas/liquid pressure push liquid out of tubing?
- What is the maximum production rate available from the well?
- What is the gas flow rate? From Formation? Annulus? Flowline?
- What is the gas gravity?
- Are there restrictions to plunger fall in the tubing?

# 1st Step is to Shoot Fluid Levels to Alert You to What is Downhole

@ 4750'
Tight Spot
in Tubing

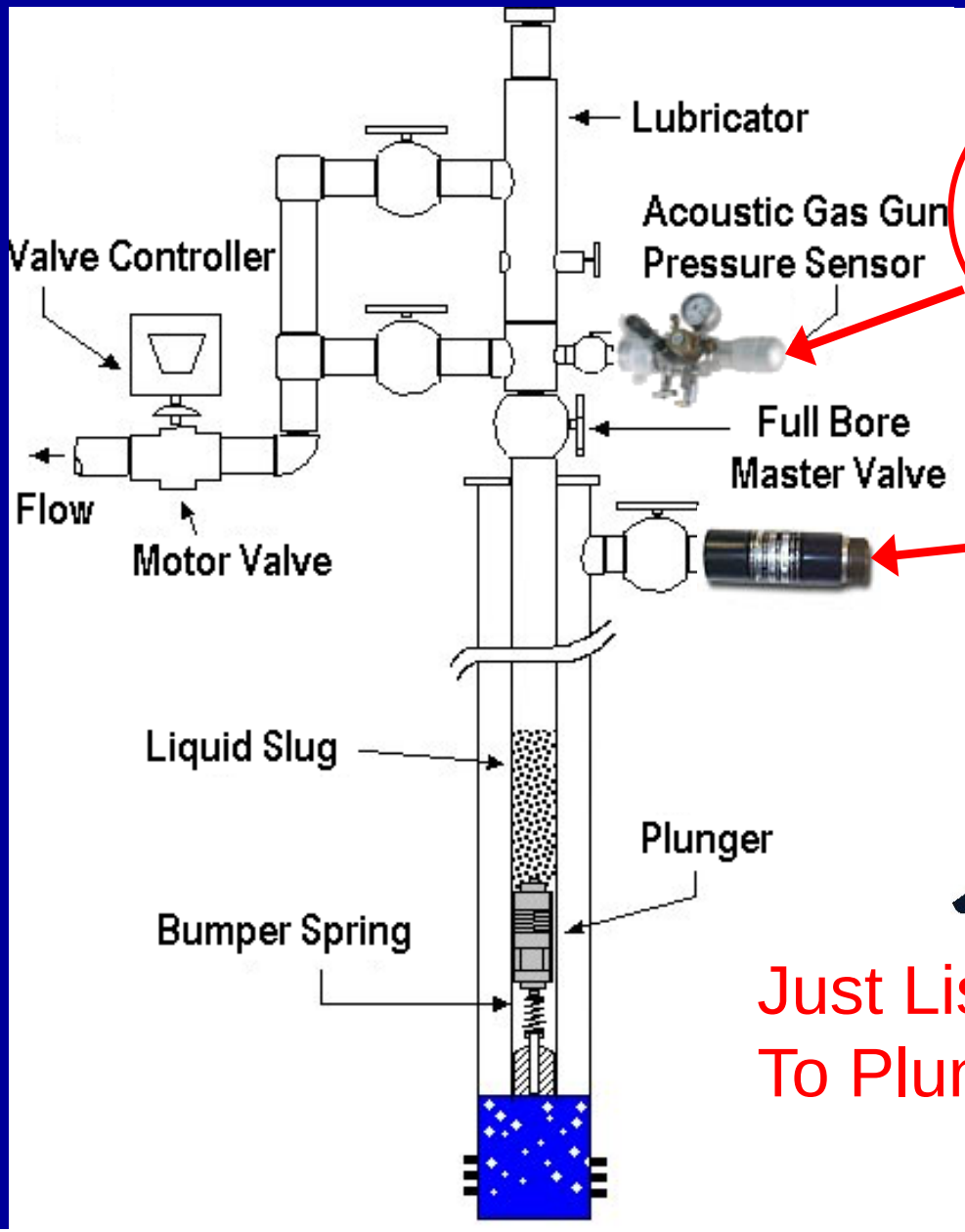



@ 5050'
1/8" Hole
in Tubing



# *How:* Listen to Plunger Signals During Shut-in

1) 3 Channel High Frequency (30Hz or greater) Data Acquisition
2) Tubing
   a) Pressure
   b) Acoustic signal
3) Casing pressure




Pressure sensor & microphone

Pressure sensor

Just Listen To Plunger

# Wired Technology for Analyzing Plunger Lift

Good Line-of-sight

Good Line-of-sight

# Track a Plunger

Wireless Gas Gun OR
Pressure Sensor on Casing

# Conventional Plunger Cycle

**Plunger lift operation cycle can be divided into three parts:**

1) **<u>Shut-in</u>:** Surface valve closed, flow shut-in, plunger falls down the tubing. Goal of the operator or controller is to try to achieve Shut-in of the well for the shortest amount of time possible, But long enough for plunger to reach bottom. And long enough for the pressure to build high enough to bring the plunger back to surface.

   *How long does it take plunger to get to bottom during shut-in?*

2) **<u>Unloading</u>:** Surface valve open and pressure stored in the casing lifts the accumulated liquid and plunger to the surface

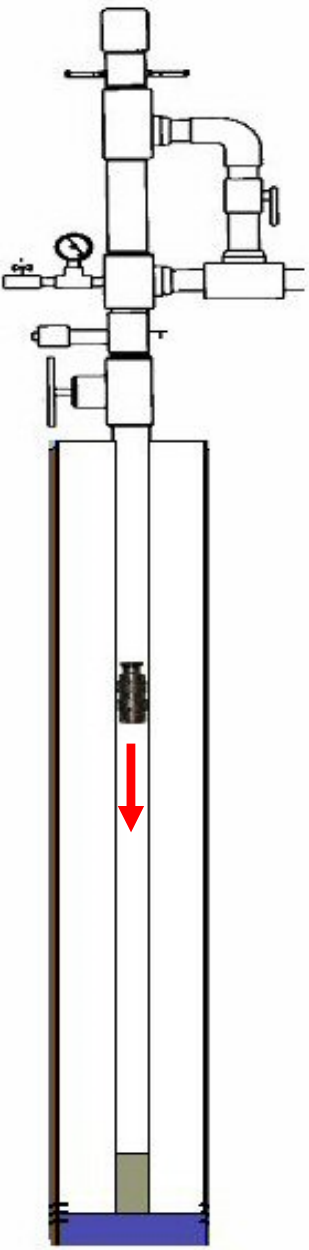
   *How much Casing Pressure is Required?*

3) **<u>After-flow</u>:** Surface valve open and well continues to flow after plunger reaches the surface. Plunger held at surface by differential pressure from flow of gas up the tubing. Well is producing gas. Most liquid produced from the formation tends to fall back, accumulating at the bottom of the tubing. The goal of the operator or controller is to Flow the well only until the well begins to load with liquids.

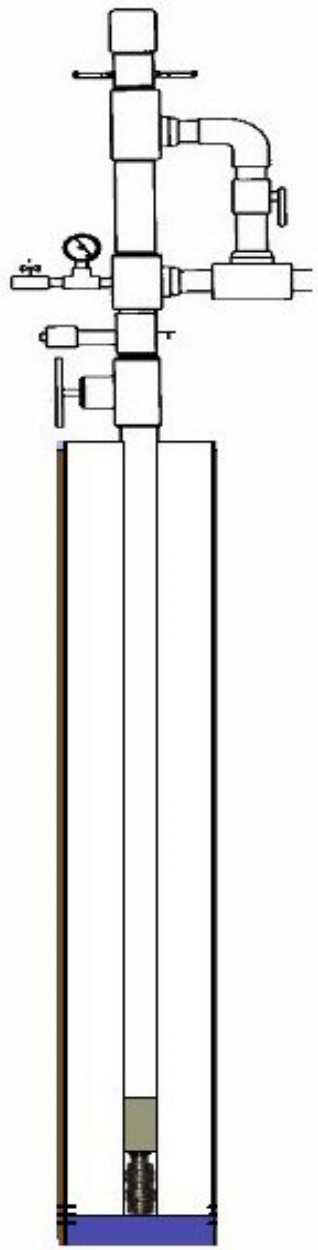
**Thanks: Dan Phillips and Scott Listiak**

# How Does Conventional Plunger Lift Work

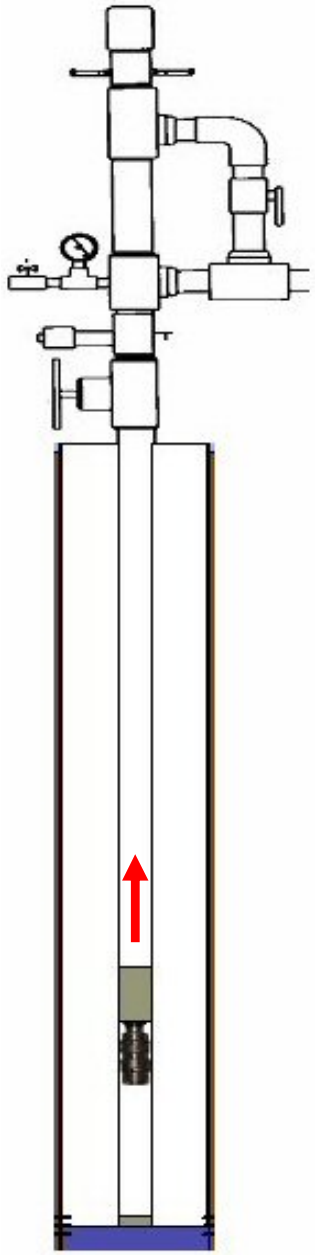
**[A] Valve Closes, Shut-in Begins and Pressure Starts Increasing**



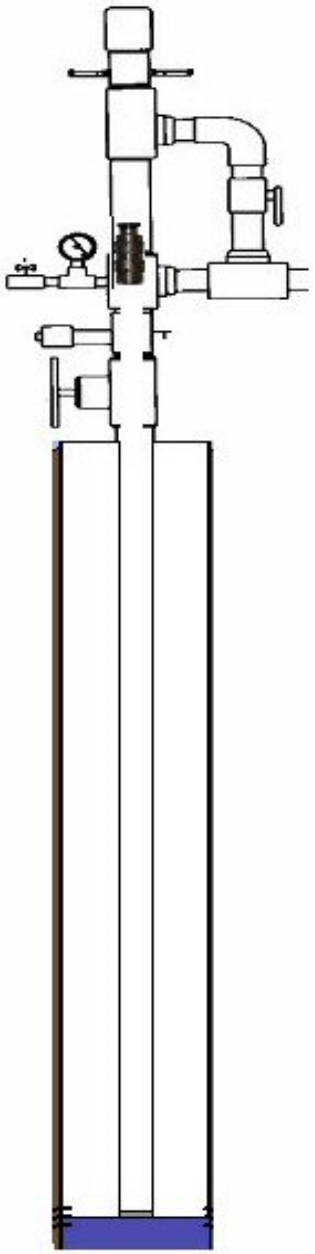
**[2] Shut-in Valve Closed, w/ Pressure Increasing**



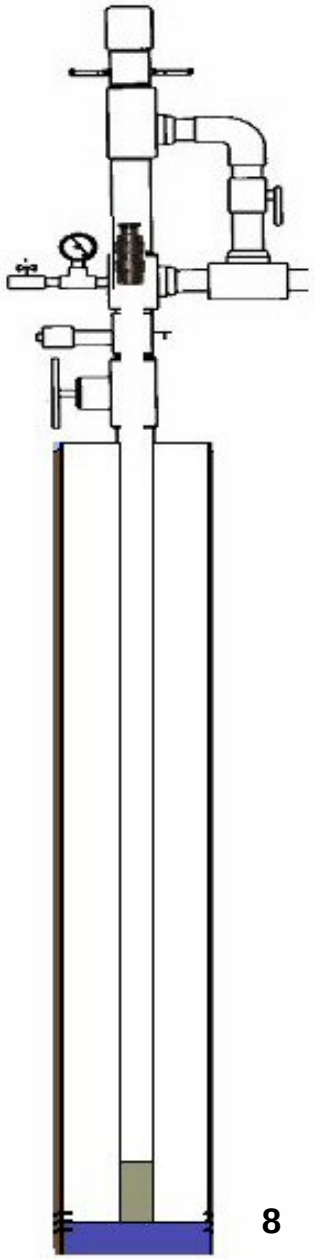
**[B] Valve Opens, Unloading Begins**



**[4] Plunger Arrives, Tubing Pressure Spike Maximum, After-flow begins**



**[C] Valve Closes, Cycle Repeats**



# ycle 90 Min.

| Plunger Cycle Events | Elapsed Time Minutes | Tubing Pressure psi (g) | Casing Pressure psi (g) |
|---|---|---|---|
| [A] Valve Closes (Shut In Begins) | 2.267 | 137.0 | 192.7 |
| [1] Plunger Hits Liquid | 47.467 | 235.5 | 273.1 |
| [2] Plunger On Bottom | 59.283 | 235.5 | 290.7 |
| [B] Valve Opens (Unloading Begins) | 69.267 | 272.8 | 306.0 |
| [3] Liquid Arrives | 79.550 | 126.3 | 235.1 |
| [4] Plunger Arrives | 80.717 | 206.2 | 231.5 |
| [C] Valve Closes (Shut In Begins) | 91.333 | 126.2 | 171.4 |

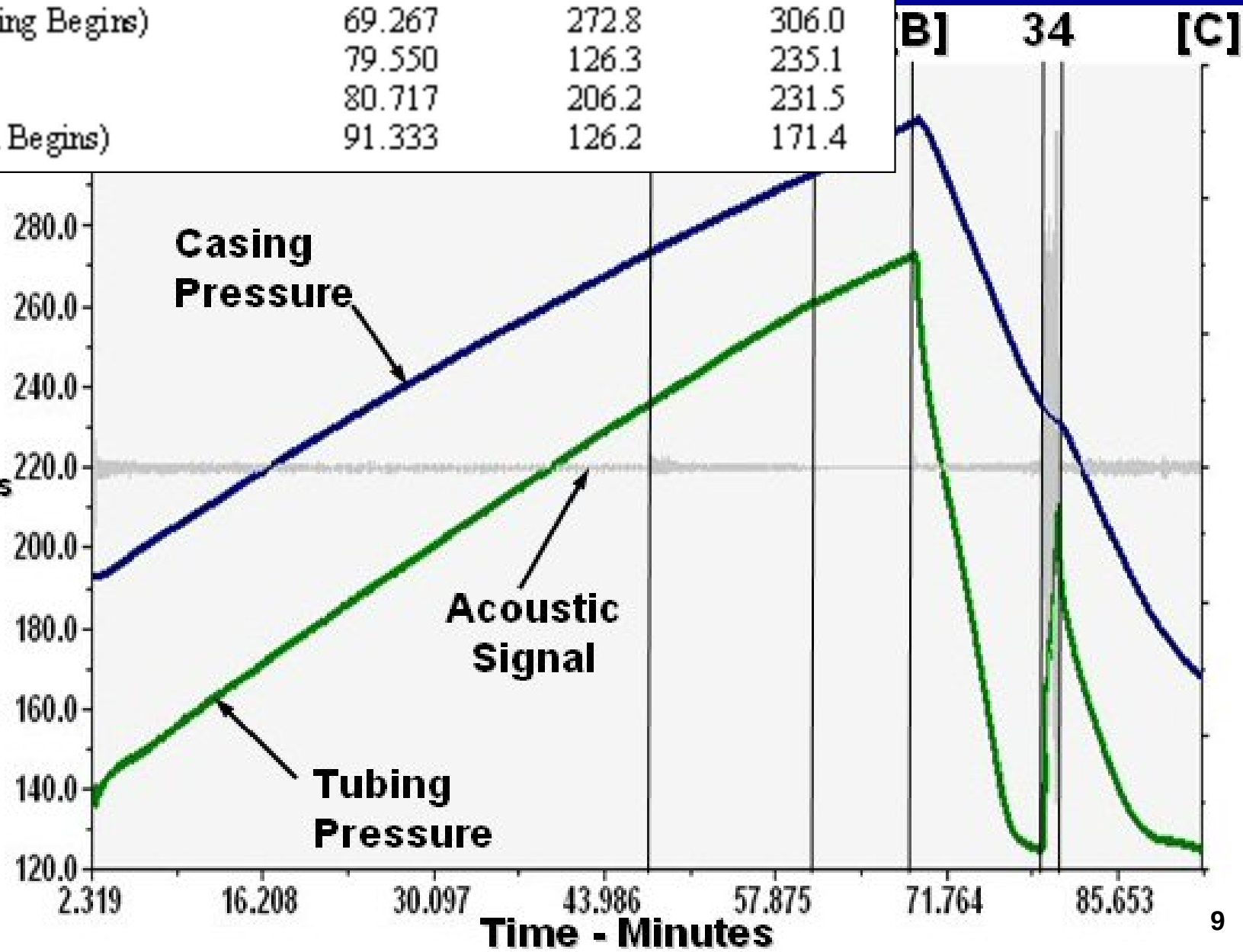
Increasing

1. Plunger hits Liquid
2. Plunger on Bottom

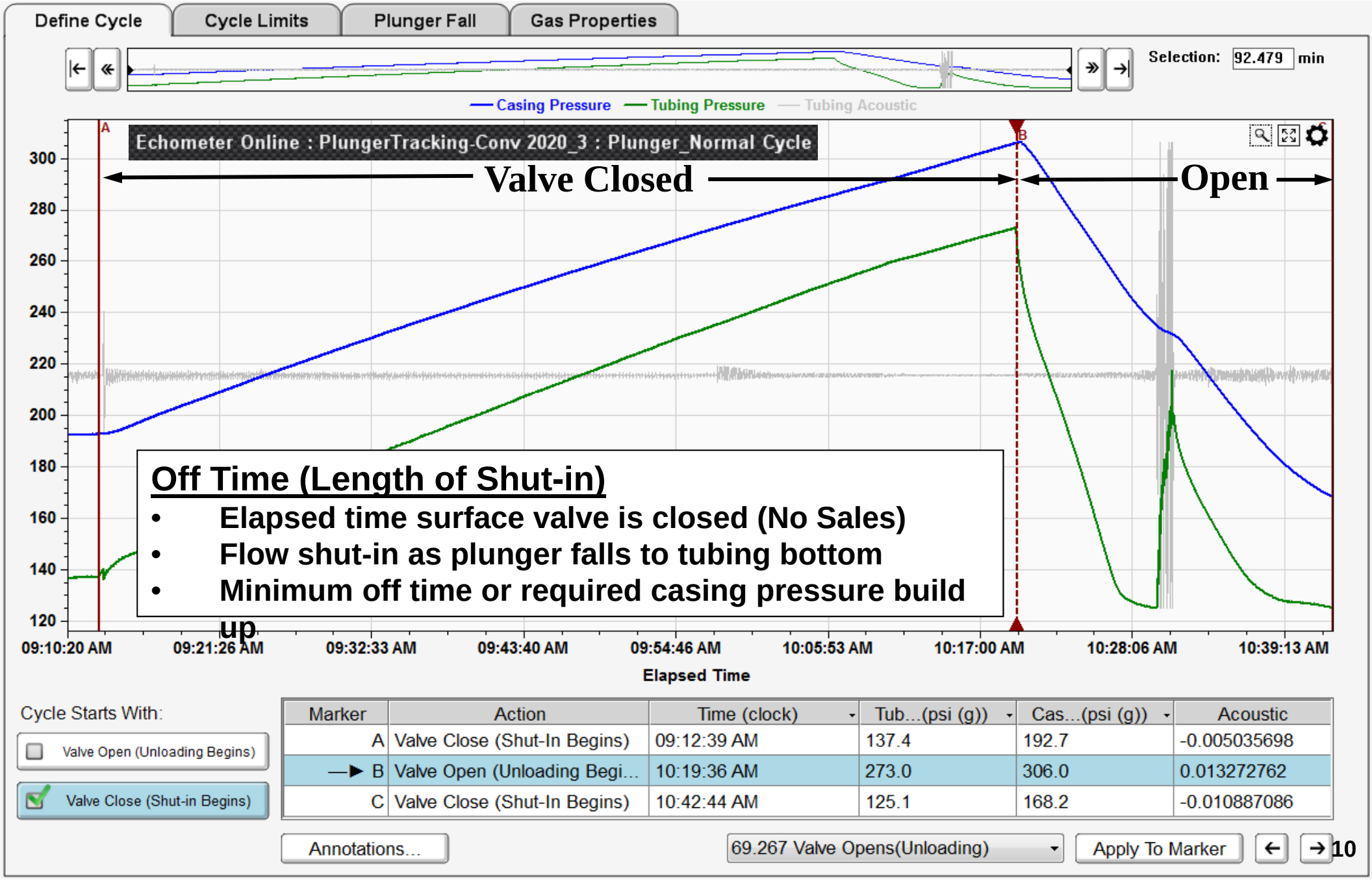
[B] Valve Opens, Unloading Begins

3. Liquid Arrives, Tubing Pressure at Minimum
4. Plunger Arrives, After-flow begins Tubing Pressure Maximum Spike

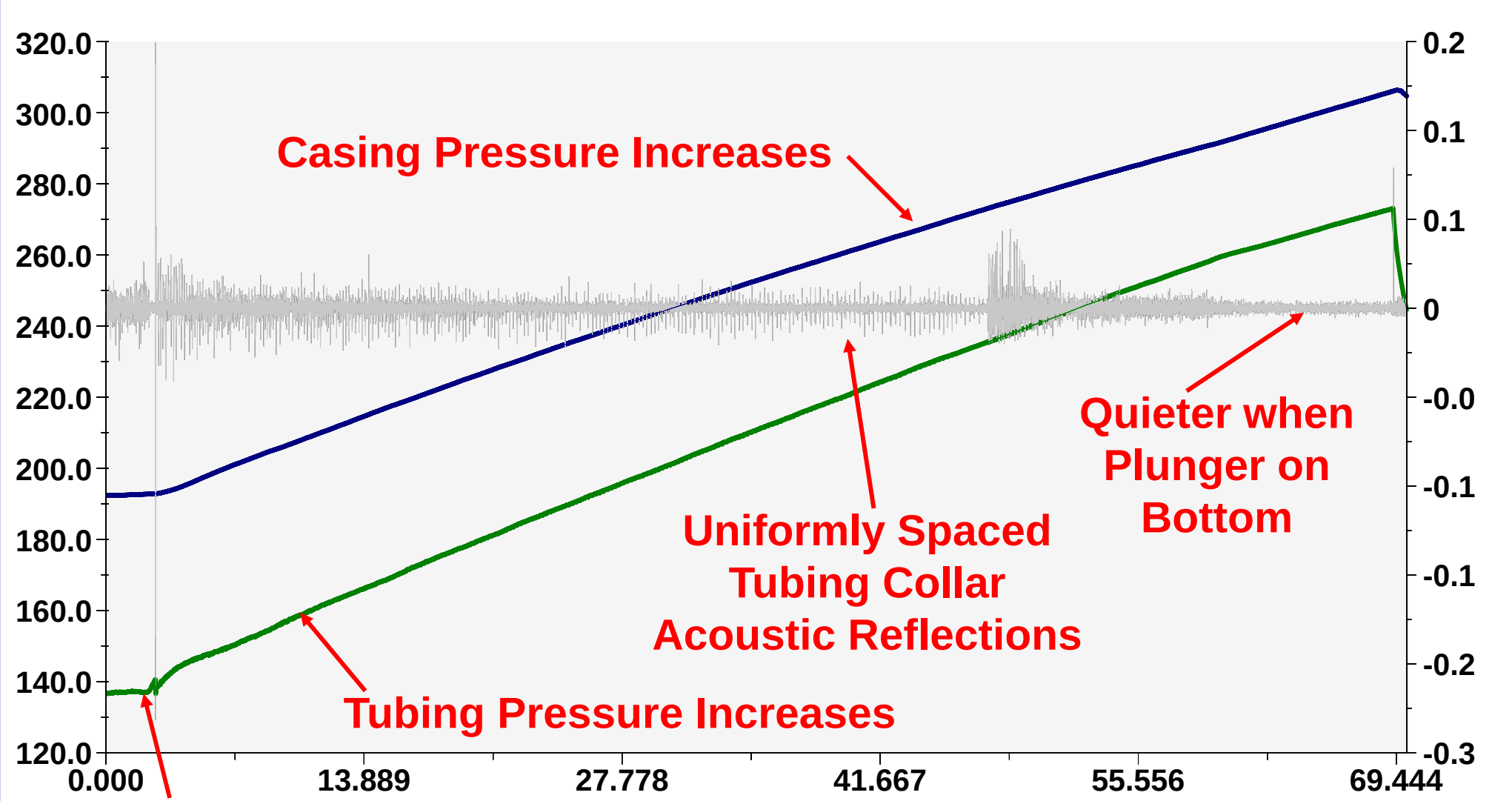
[C] Valve Closes, Cycle Repeats



# Plunger Controller acts as an on/off switch to Control Motor Valve.



# When the Flow Line Motor Valve Closes Shut-in Begins (Flow down flow line stops)



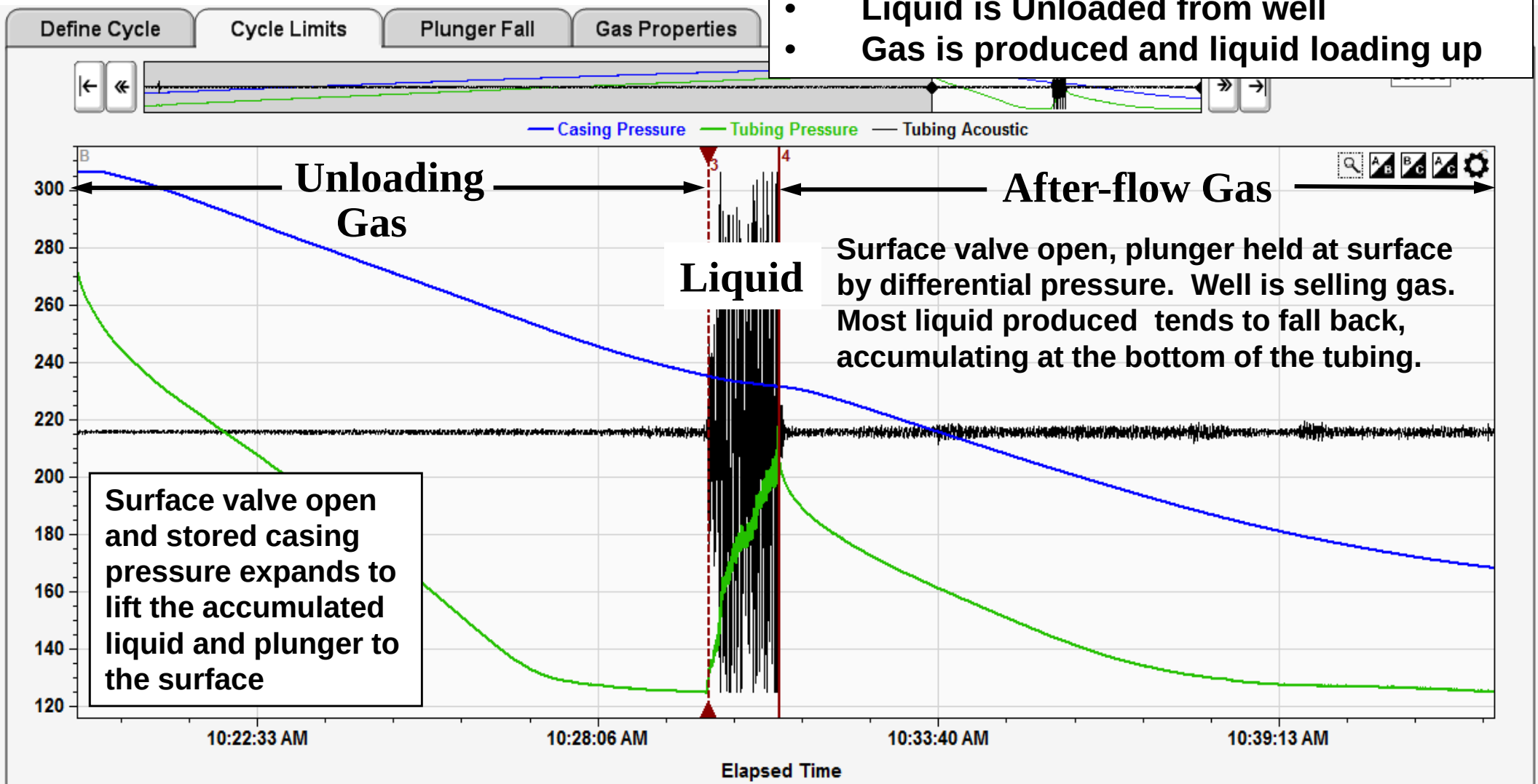

**Identify Shut-in Begins When Tubing Pressure Just Starts to Increase**

**Zoom in X-axis Range to see Details**

# Unloading and After-flow

**On Time (Length of Flow)**

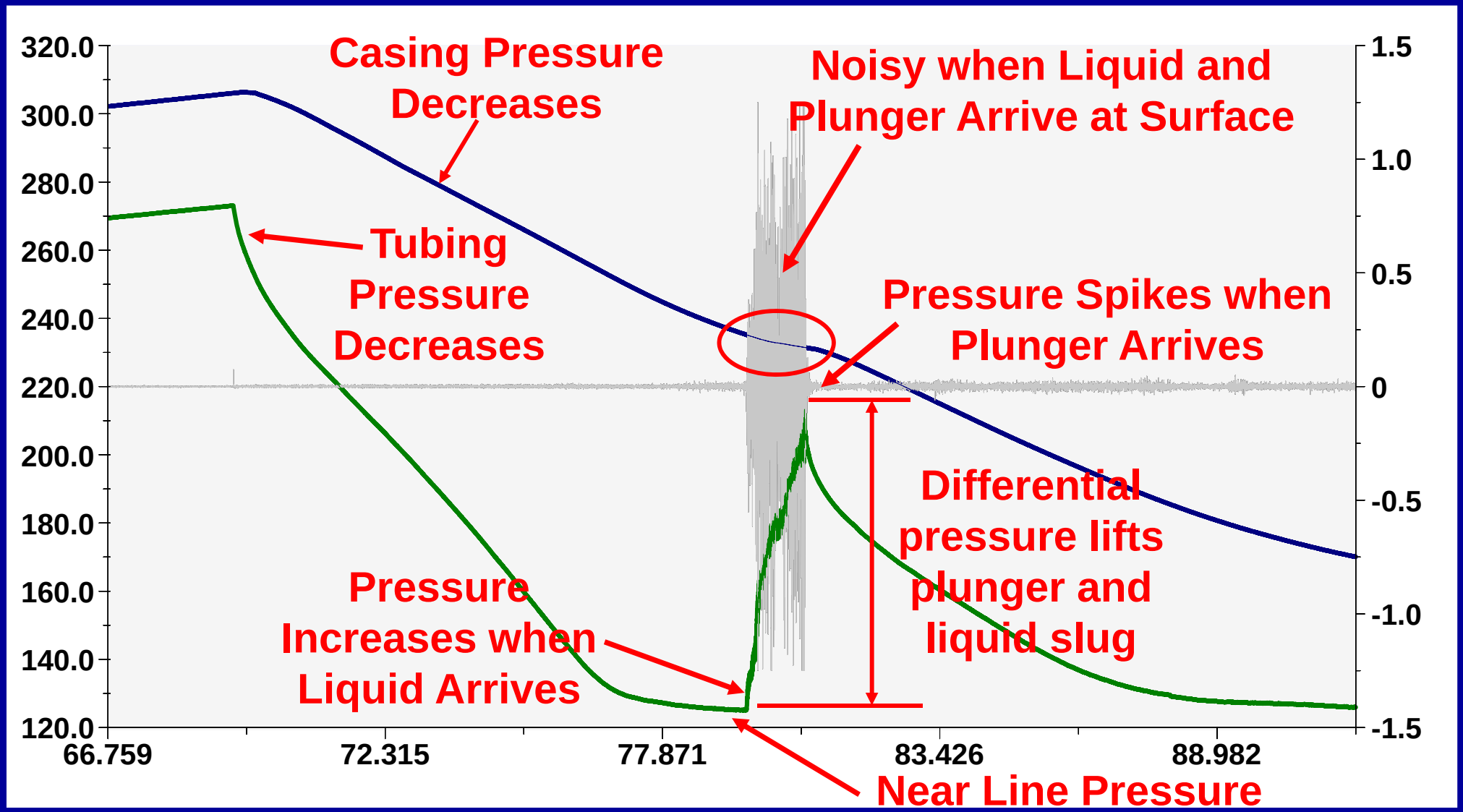
- Elapsed time valve is open (Gas sold)
- Liquid is Unloaded from well
- Gas is produced and liquid loading up




| | Marker | Action | Time (clock) | Tub...(psi (g)) | Cas...(psi (g)) | Acoustic |
|---|---|---|---|---|---|---|
| Shut-In Time Period | 1 | Plunger Hits Liquid | 09:57:50 AM | 235.7 | 273.2 | 0.001957268 |
| | 2 | Plunger On Bottom | 10:09:36 AM | 258.1 | 290.6 | 0.003727674 |
| Unloading Afterflow Time-Period | 3 | Liquid Arrives | 10:29:53 AM | 126.3 | 235.1 | 0.025217682 |
| | 4 | Plunger Arrives | 10:31:04 AM | 204.4 | 231.4 | -0.006651878 |

Annotations... | 79.550 Liquid Arrives | Apply To Marker

# Unloading begins when Controller opens motor valve between tubing and flow line.



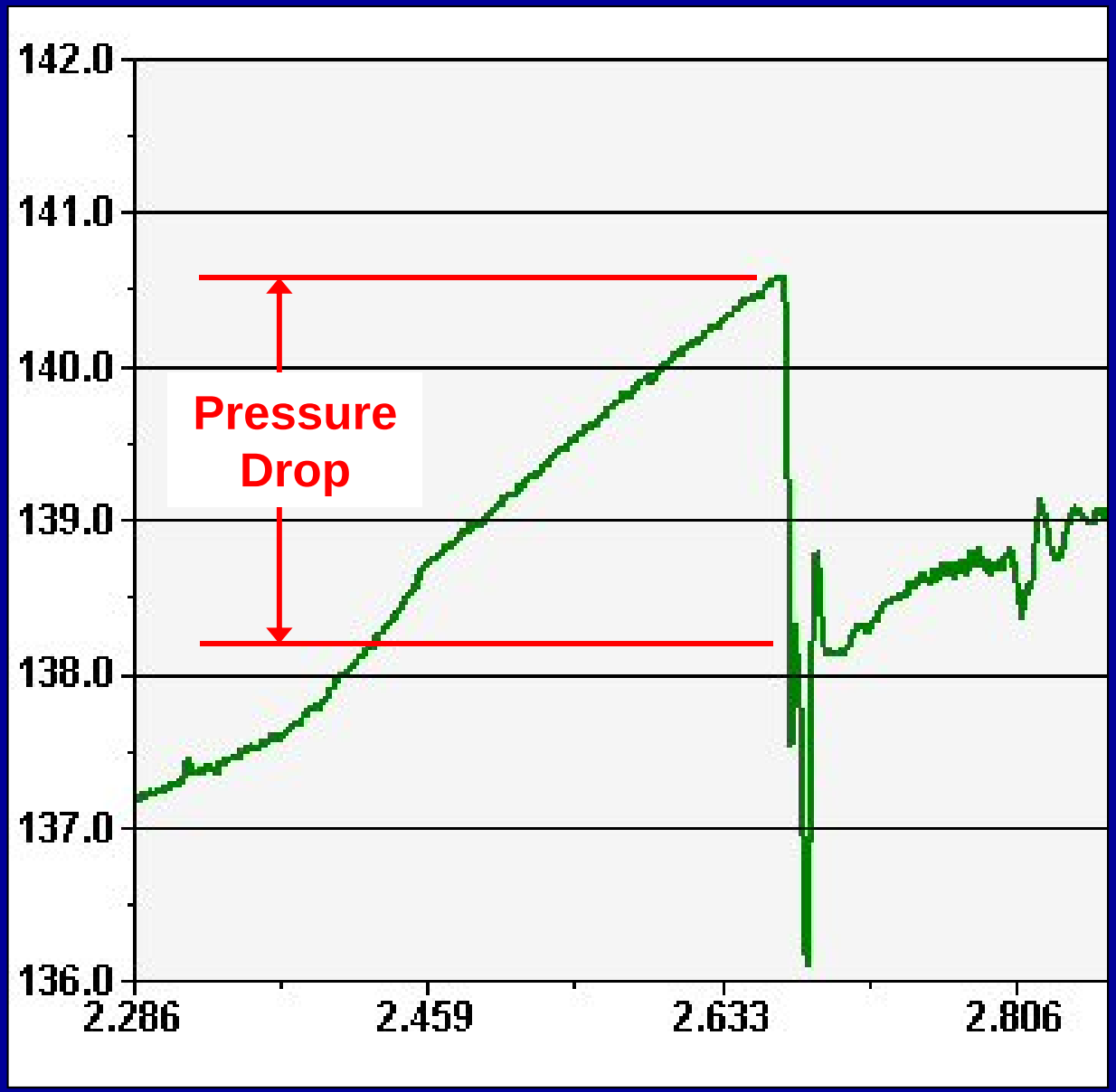

Plunger_Normal Cycle

# When Shut-in Begins the Tubing Pressure Drops as Plunger Starts to Fall

**Pressure Drop = Weight / Area**

**Pressure Drop =**

**2.4 psi**



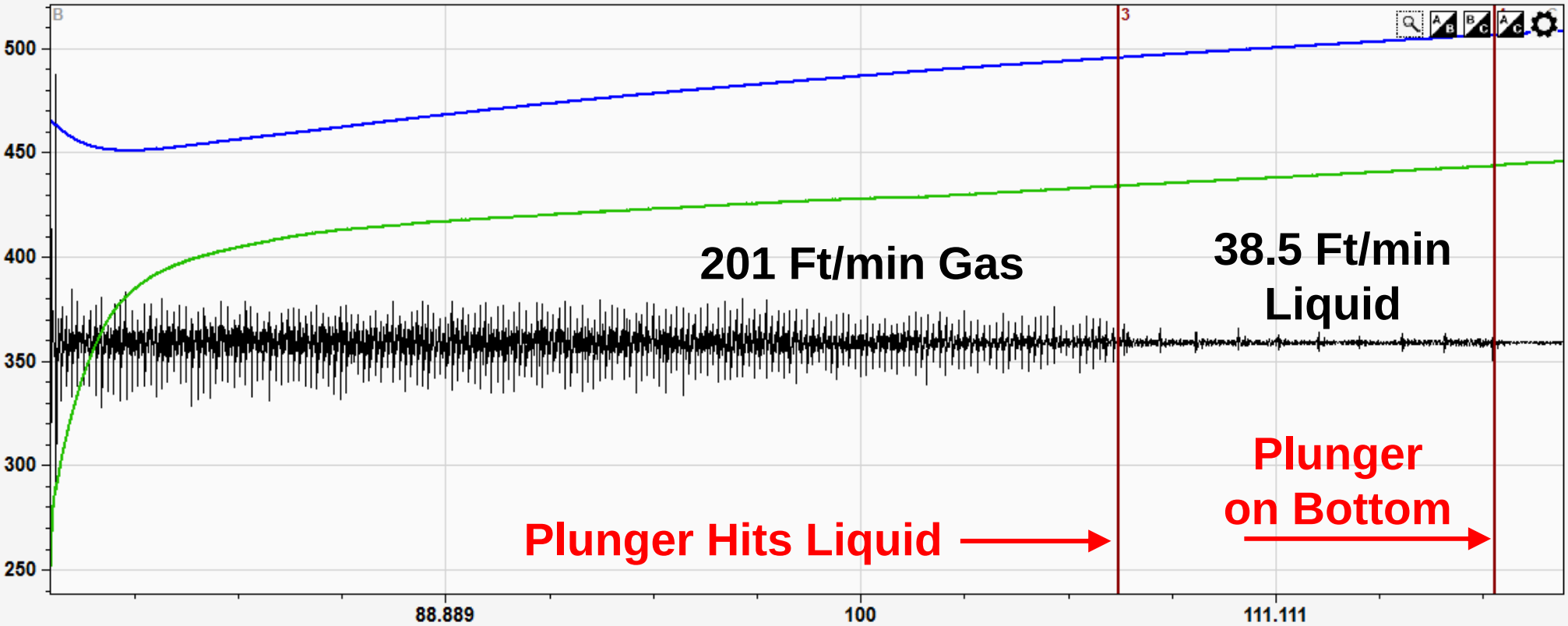

Plunger weight (8 lbs) / Area of 2-3/8”

# Take Guess Work Out of Setting Shut-in Time

Define Cycle | Cycle Limits | Plunger Fall | Gas Properties

Selection: 40.554 min

Casing Pressure — Tubing Pressure — Tubing Acoustic



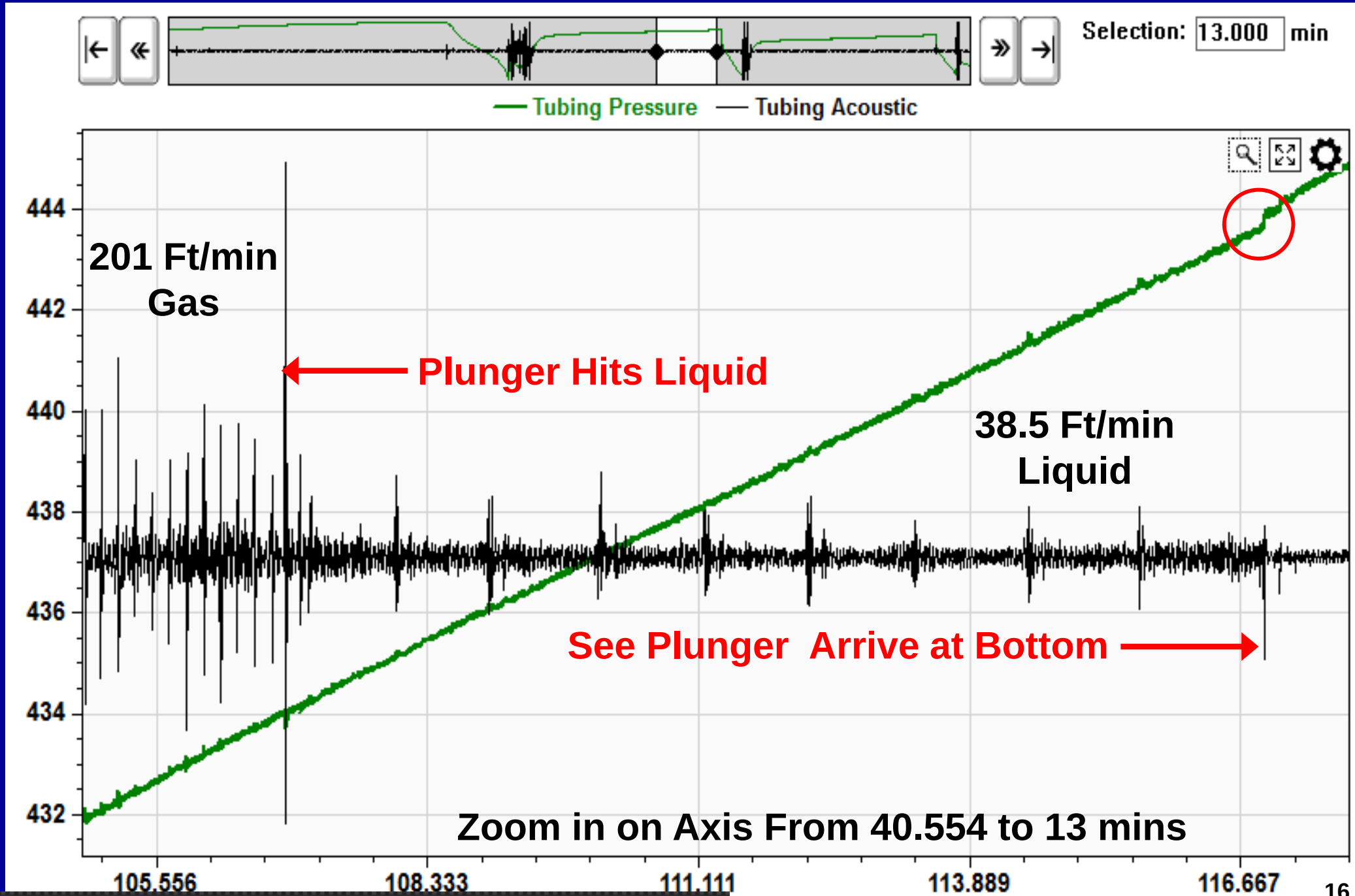

**Only Shut-in Time Period Shown**

| | Marker | Action | Time (min) | Tub...(psi (g)) | Cas...(psi (g)) | Acoustic |
|---|---|---|---|---|---|---|
| Unloading Afterflow Time-Period | 1 | Liquid Arrives | 73.047 | 74.1 | 528.2 | -0.044774562 |
| | 2 | Plunger Arrives | 77.868 | 293.0 | 471.5 | 0.431897640 |
| Shut-In Time Period | 3 | Plunger Hits Liquid | 106.914 | 434.1 | 495.7 | 0.002819300 |
| | 4 | Plunger On Bottom | 116.977 | 443.9 | 506.6 | 0.000317395 |

Annotations... | Apply To Marker

Echometer Online : PlungerTracking-Conv 2020_3 : Plunger_3CyclesFromStatic

# See Plunger Fall in Gas and Liquid

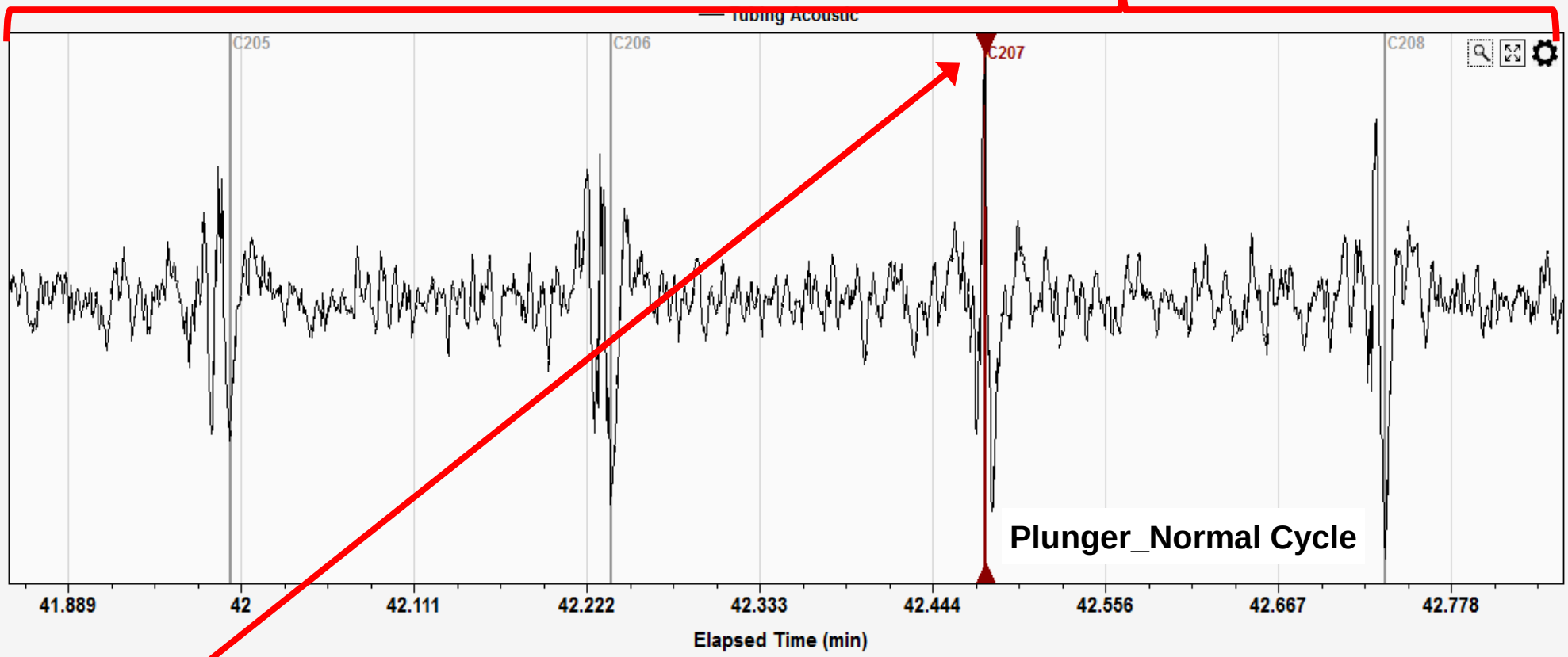



Echometer Online : PlungerTracking-Conv 2020_3 : Plunger_3CyclesFromStatic

# Count Collars for Fall Velocity & Depth

Define Cycle | Cycle Limits | Plunger Fall | Gas Properties

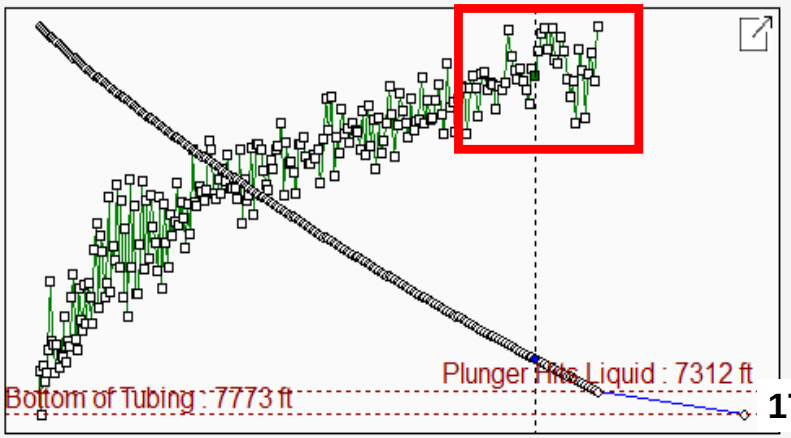
Selection: 1.000 min




Collar #207 42 min

Remove | Done | Remove All

| # | Time (min) | Velocity (ft/min) | Depth (ft) |
|---|---|---|---|
| C206 | 42.238 | -131.43 | 6633.20 |
| C207 | 42.478 | -133.86 | 6665.40 |
| C208 | 42.736 | -125.18 | 6697.60 |
| C209 | 43.006 | -119.01 | 6729.80 |




Average Plunger Vel. (gas): **-168.19 ft/min** Average Jts/min (gas): **5.223**

Average Plunger Vel. (Liq.): **-39.18 ft/min** Average Jts/min (Liq.): **1.217**

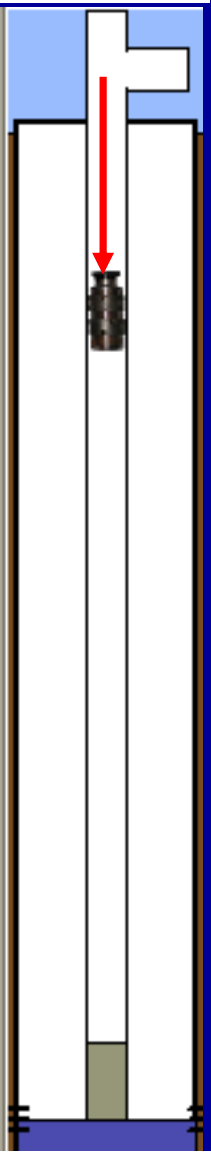
# *Velocity:* Plunger Fall Speed Between Two Consecutive Counted Collars

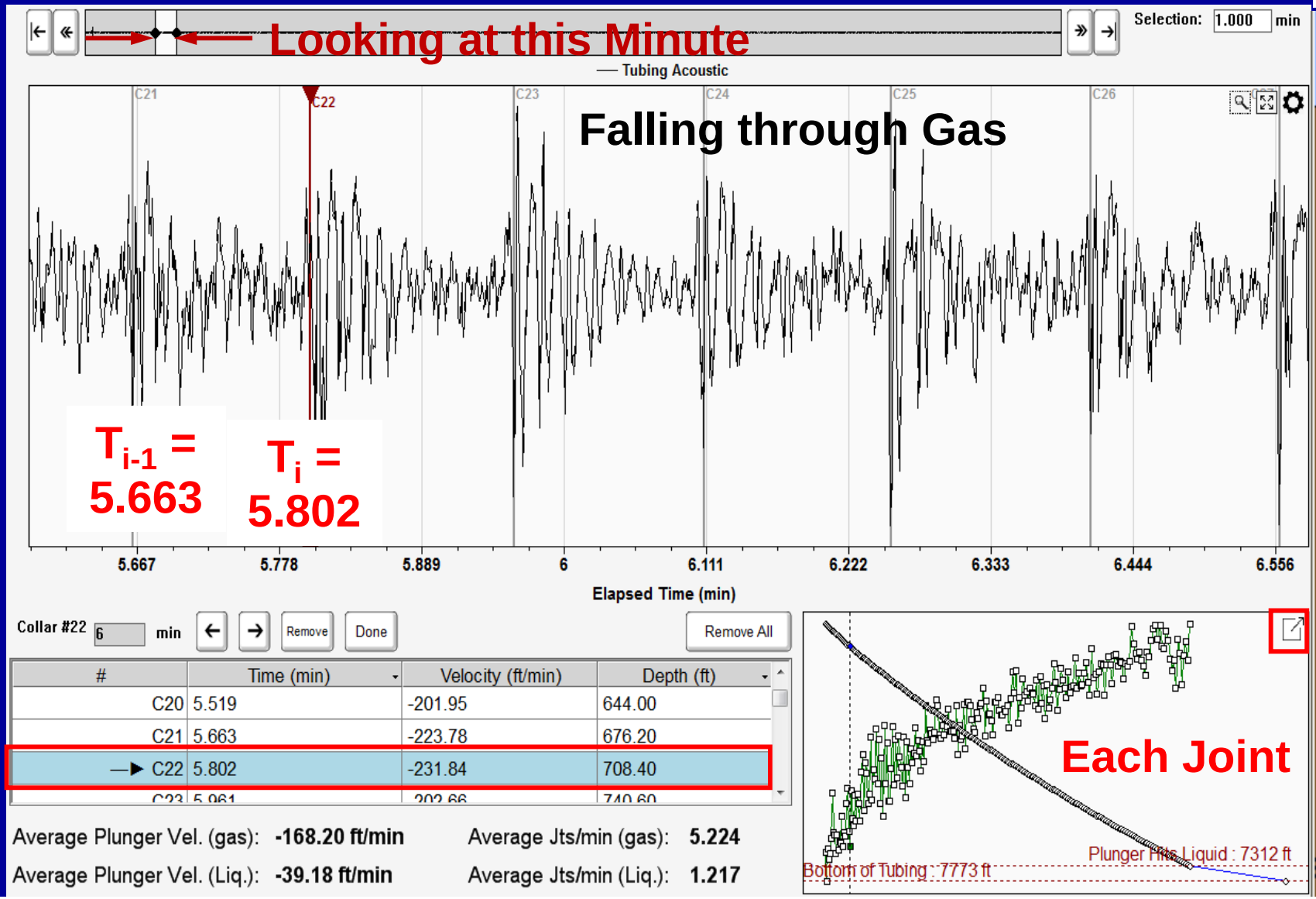
**Plunger Velocity @ Joint 22 equals the change in depth divided by the change in elapsed time.**

**Velocity = $(D_i - D_{i-1}) / (T_i - T_{i-1})$ = -231.8 ft/min**

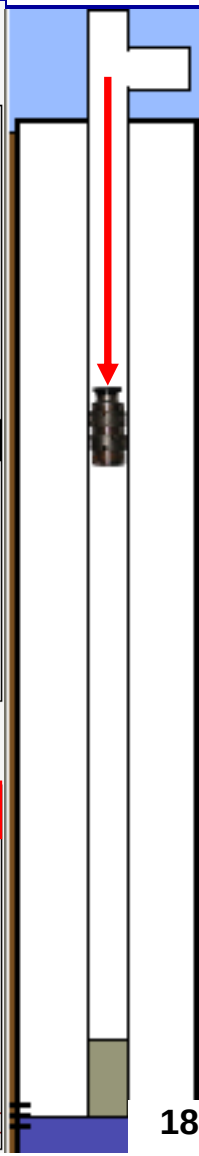
$D_{i-1}$ = 676.2

$D_i$ = 708.4

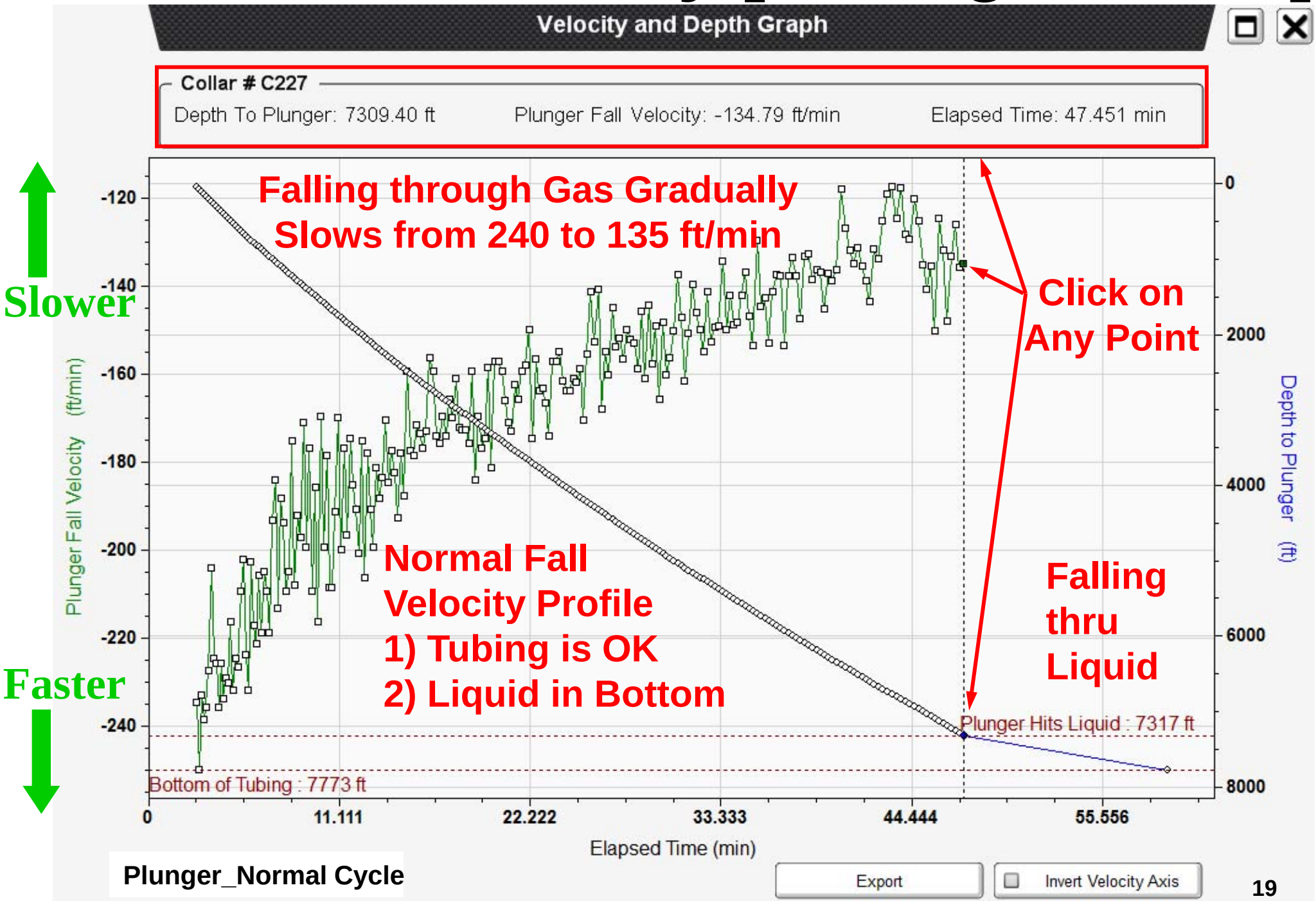





| # | Time (min) | Velocity (ft/min) | Depth (ft) |
|---|---|---|---|
| C20 | 5.519 | -201.95 | 644.00 |
| C21 | 5.663 | -223.78 | 676.20 |
| C22 | 5.802 | -231.84 | 708.40 |
| C23 | 5.961 | 202.66 | 740.60 |

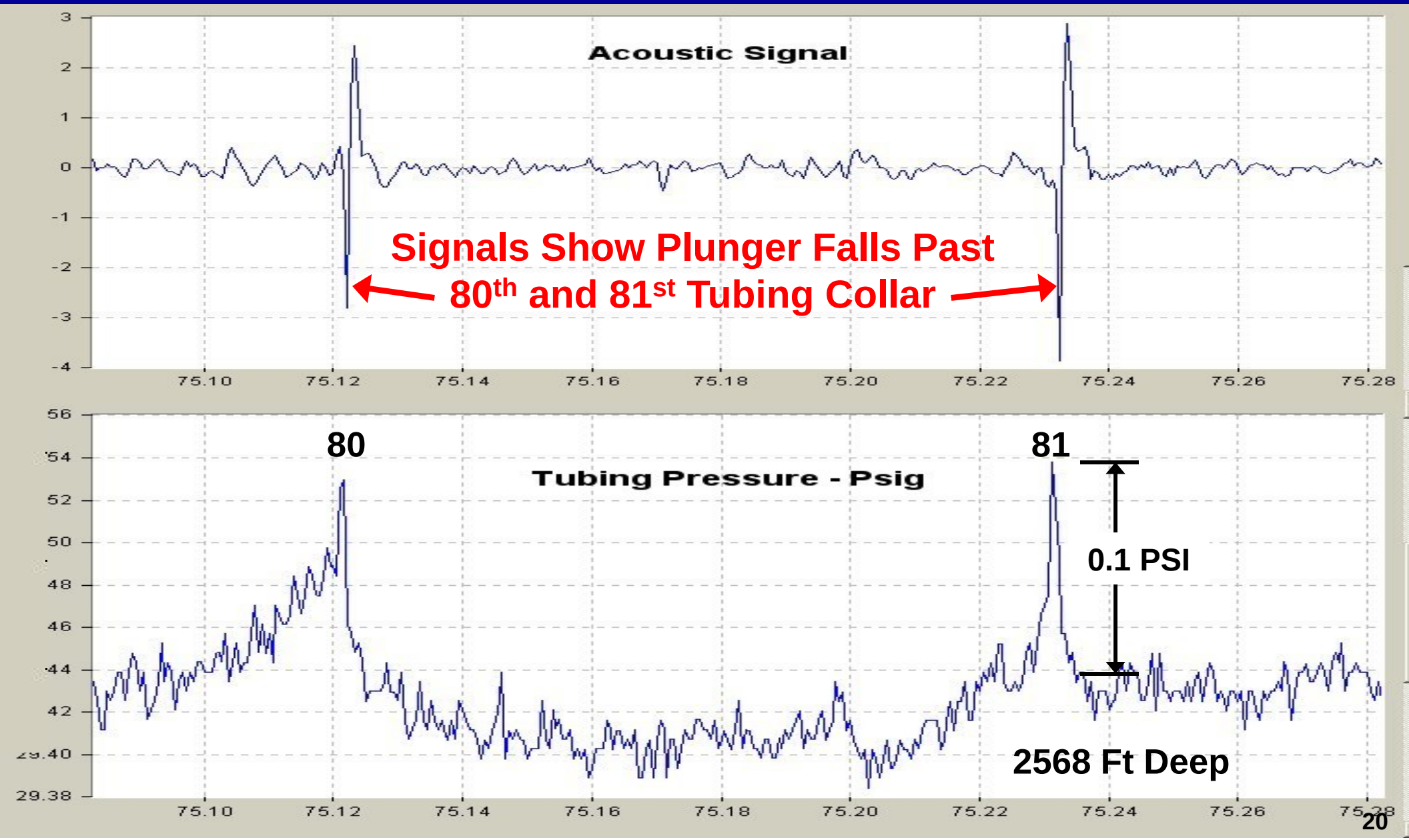


# Normal Fall Velocity [During Shut-in]




Plunger_Normal Cycle

# Passive Monitoring Requires High Resolution Pressure & Acoustic Data



# Gas Properties Determined by Fall

Define Cycle | Cycle Limits | Plunger Fall | Gas Properties

Determine Gas Specific Gravity by Selecting Echo Repeats

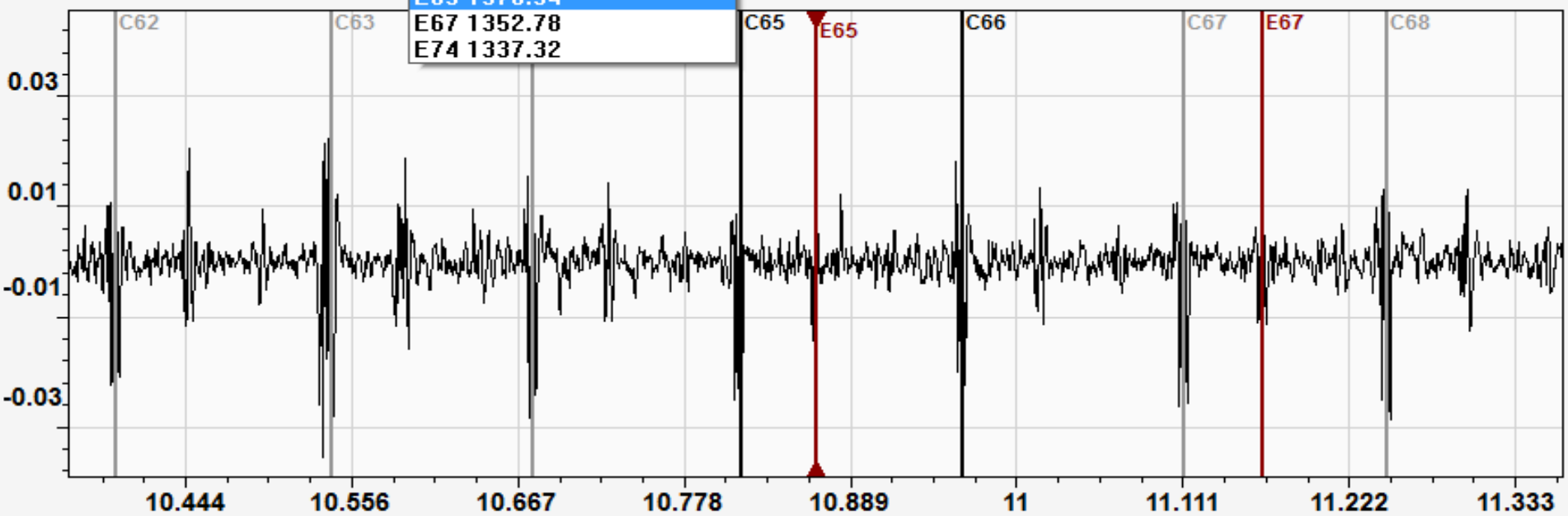
Acoustic Velocity: 1364.53 ft/sec

E65 1370.34

E57 1352.14
E65 1370.34
E67 1352.78
E74 1337.32

Remove | Done

Tubing Acoustic




Enter Gas Specific Gravity, Composition Analysis, or Acoustic Velocity

Acoustic Velocity: 1369.58 ft/sec

Retrieve Gas Gravity from Previous Acoustic Test

Acoustic Velocity: 757.14 ft/sec

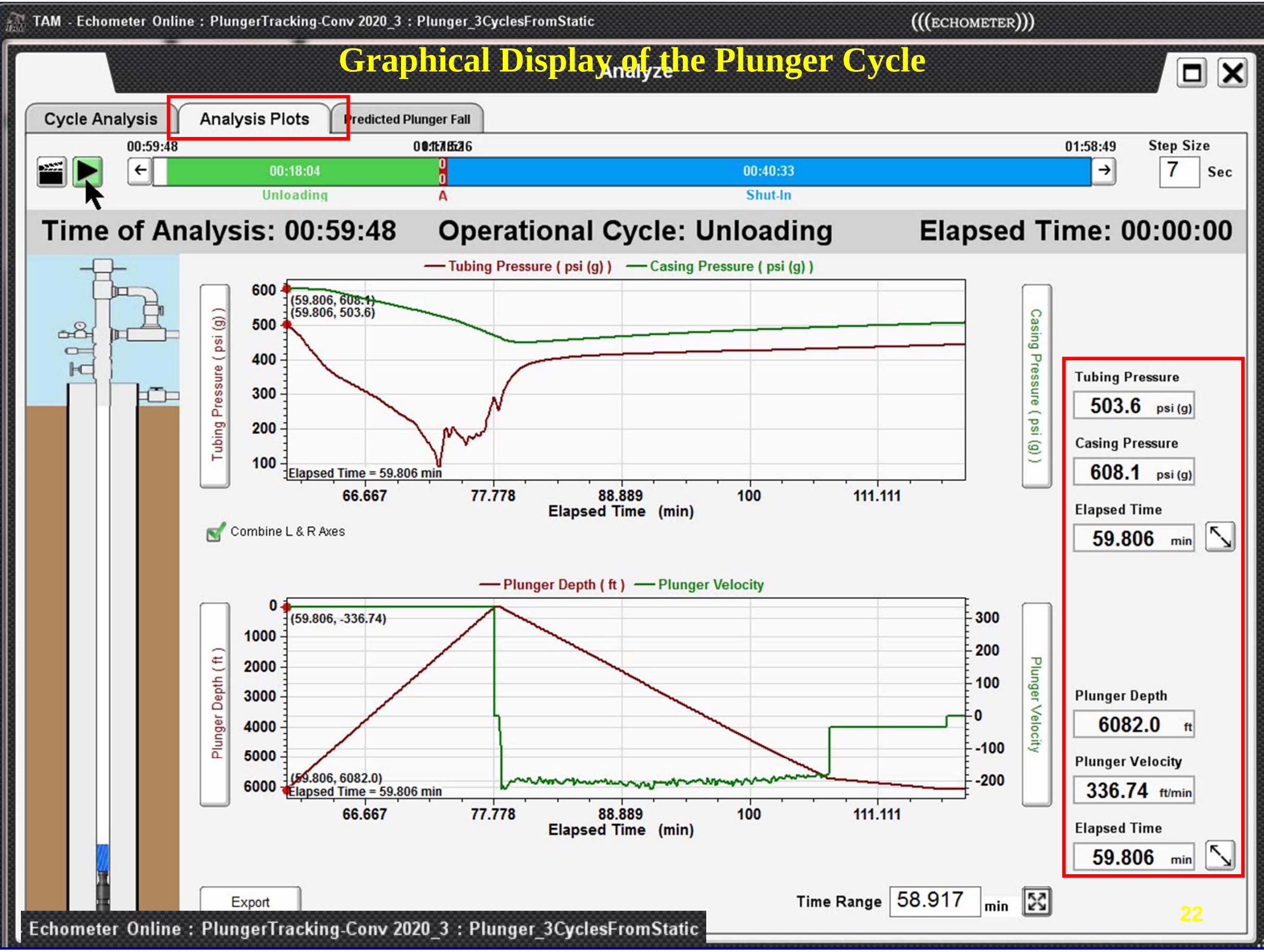
The liquid level test used for analysis:
10/15/2004 05:08:10AM

Plunger_Hole in Tbg Deep

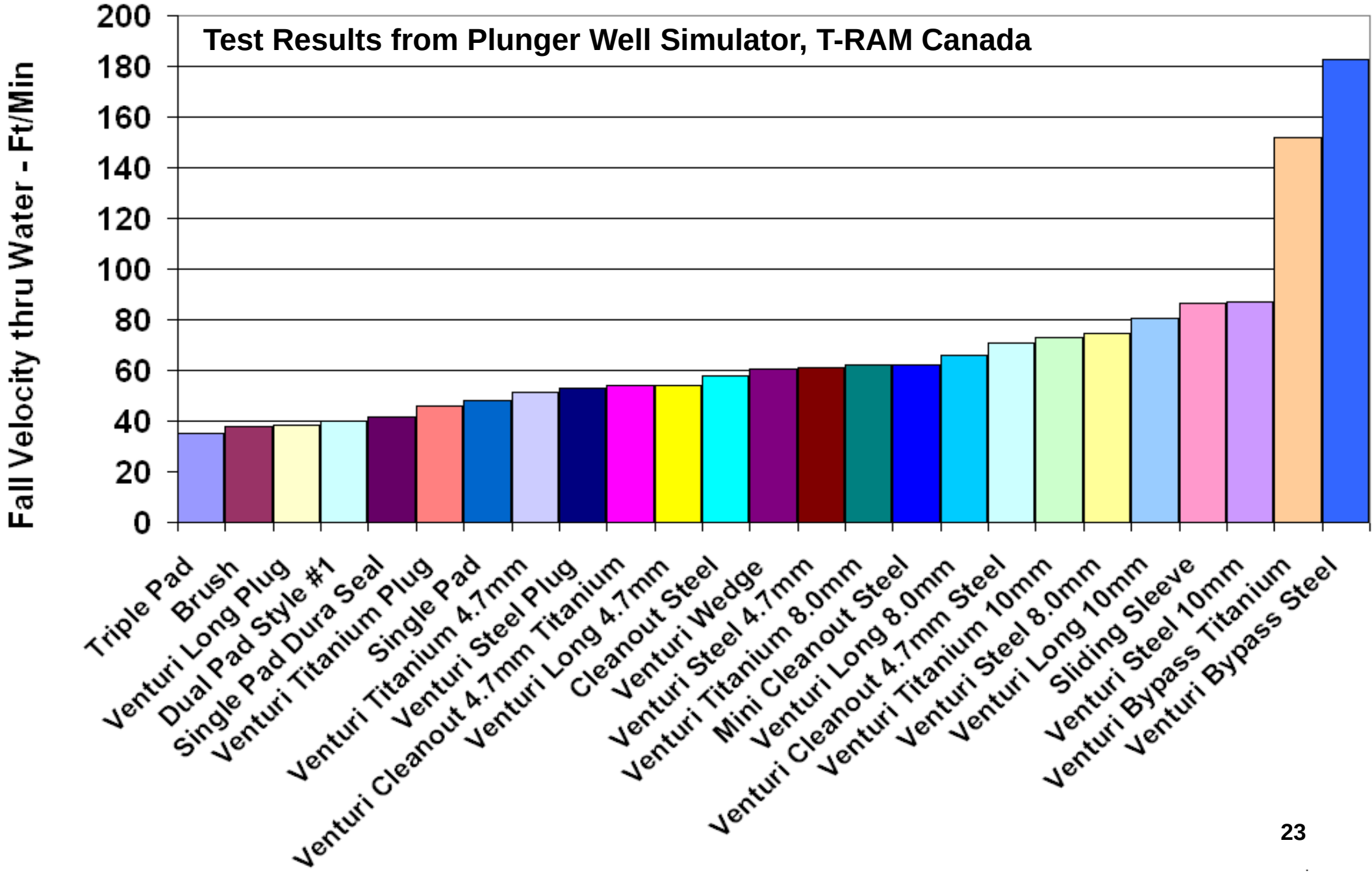
Acoustic Velocity 1364.53

Gas Specific Gravity 0.65400 (Air = 1)

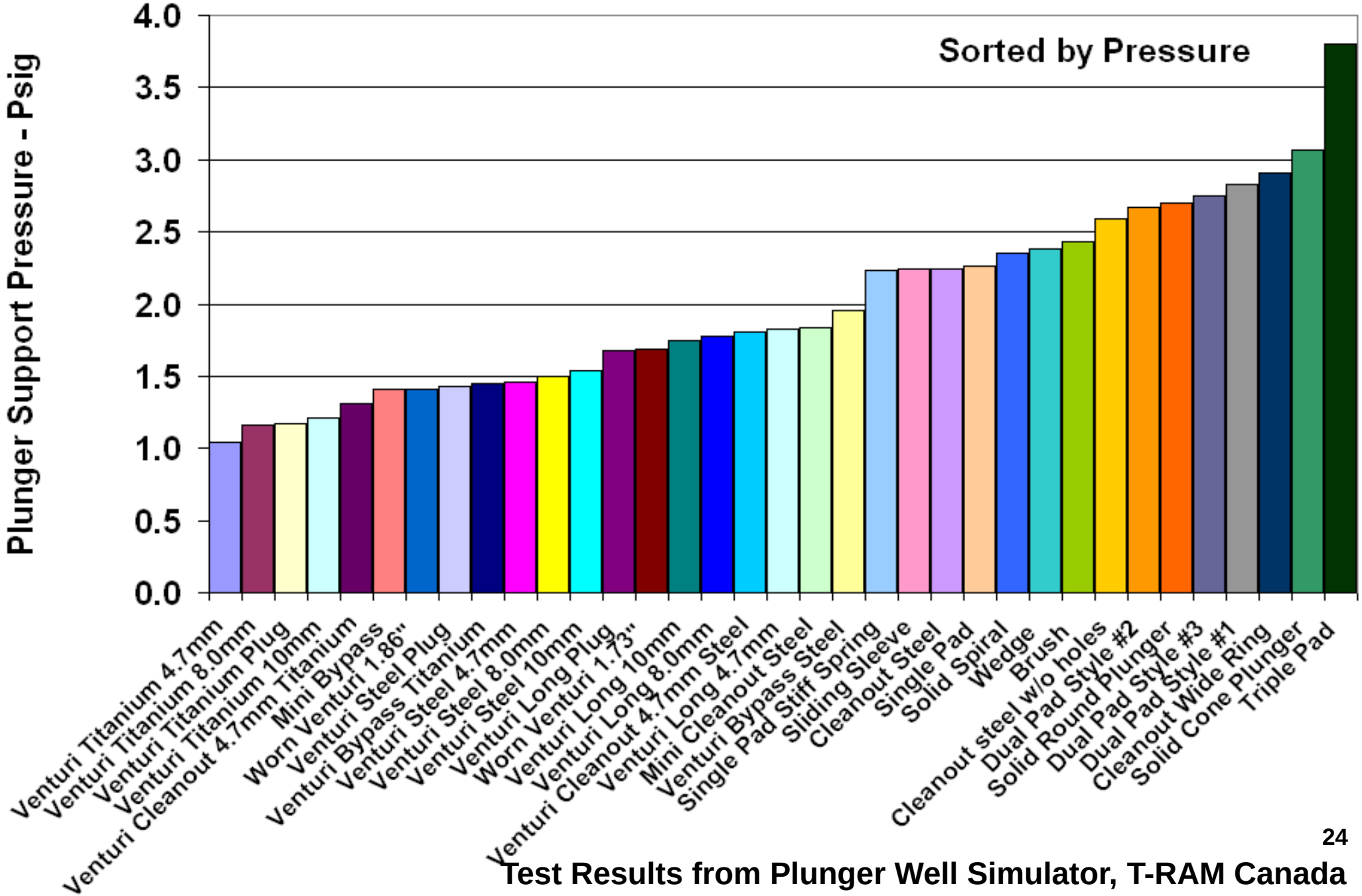
# Graphical Display of the Plunger Cycle



# Plunger Fall Velocity Through Gas Free Water



# Dry Gas Pressure Required to Float Plunger at Constant Height at Low Pressure Constant Flow






Test Results from Plunger Well Simulator, T-RAM Canada

# Conventional Brush Plungers

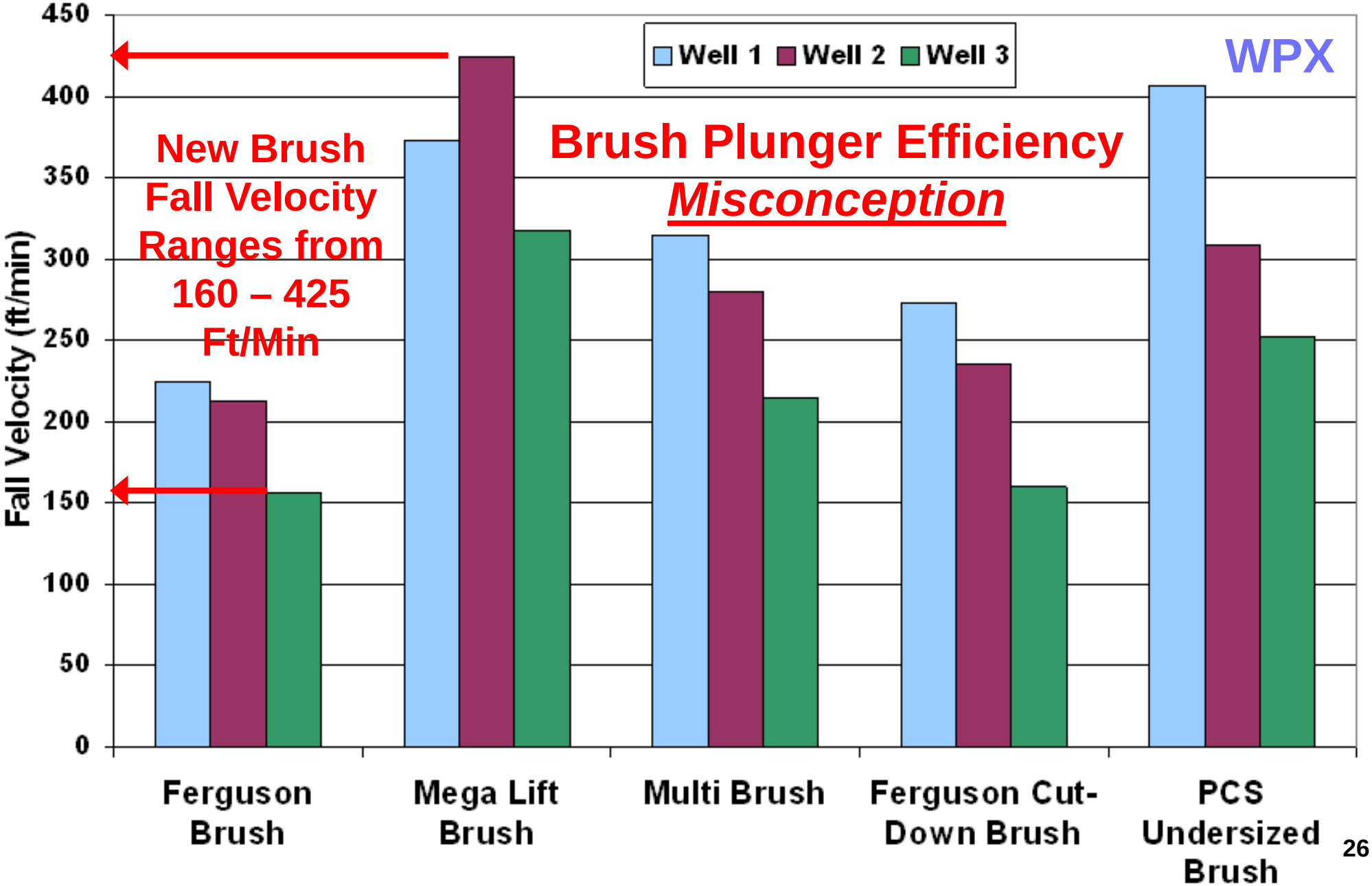
**Strengths**

1. **Initial Efficiency very high** if brush bristles fill tubing (most available in conventional)
2. Ability to move sand, fibers allow for sand to be in fibers without sticking plungers

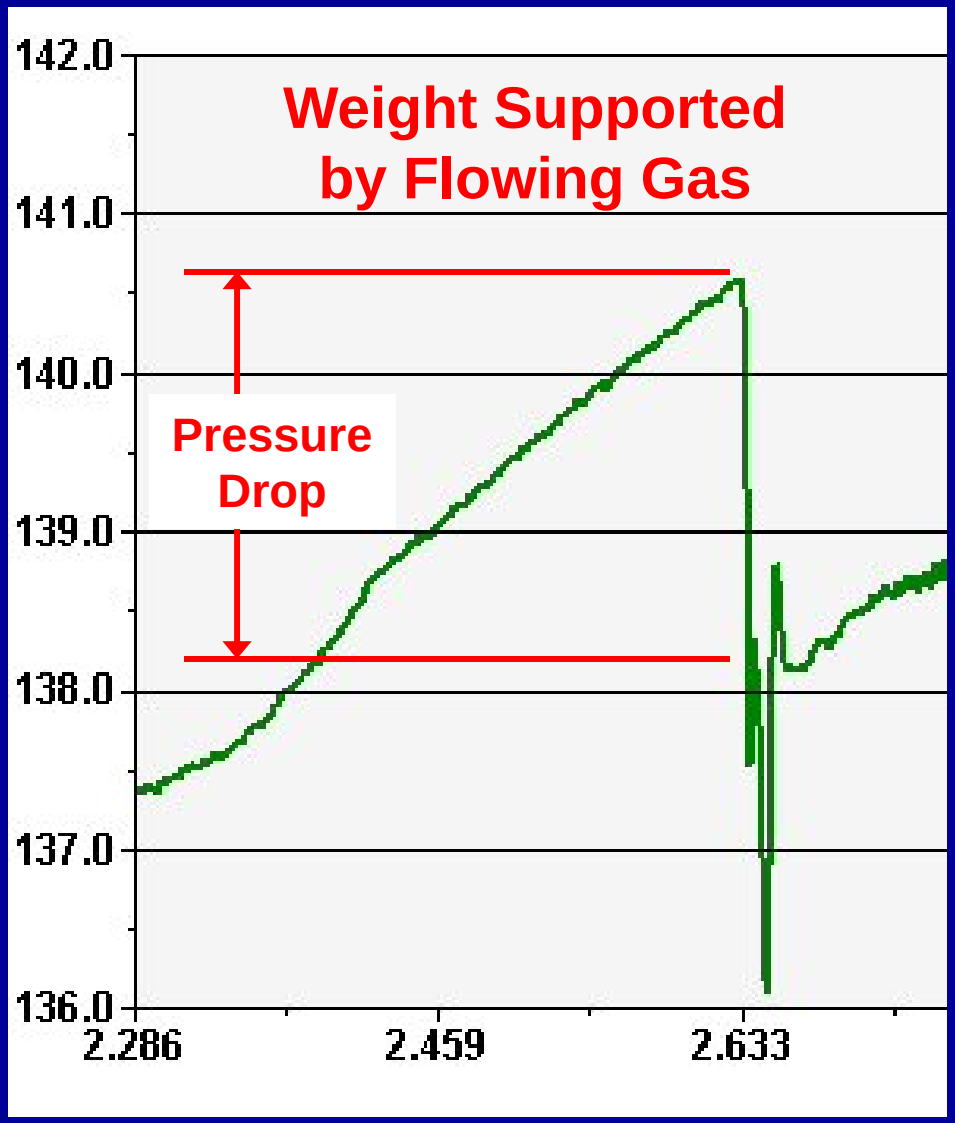
**Weaknesses**

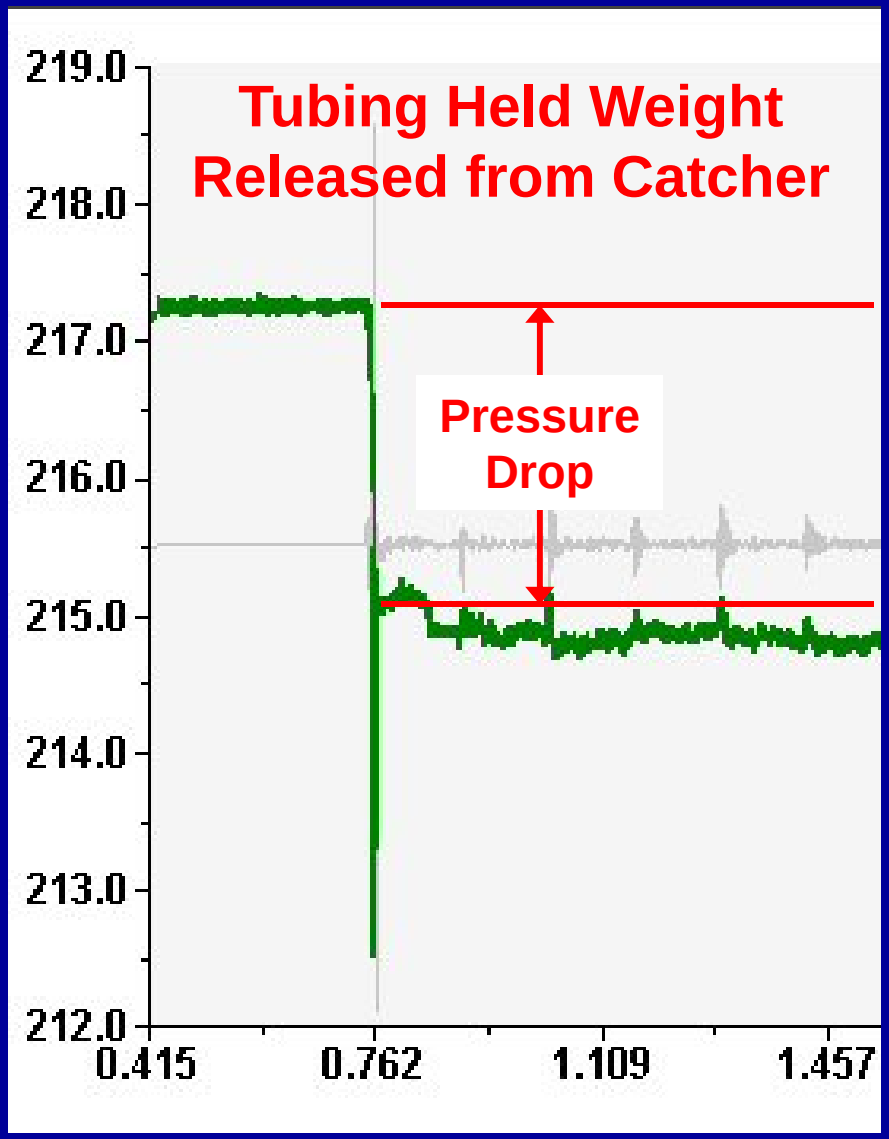
1. Wears out quickly, both speed and efficiency change
2. Loss in efficiency make control more difficult.
3. Expensive and difficult to re-wrap.

# Manufacturer Designed Brush Stiffness and Seal Impact Fall Velocity



# When Shut-in Begins the Tubing Pressure Instantly Drops when Plunger Starts to Fall



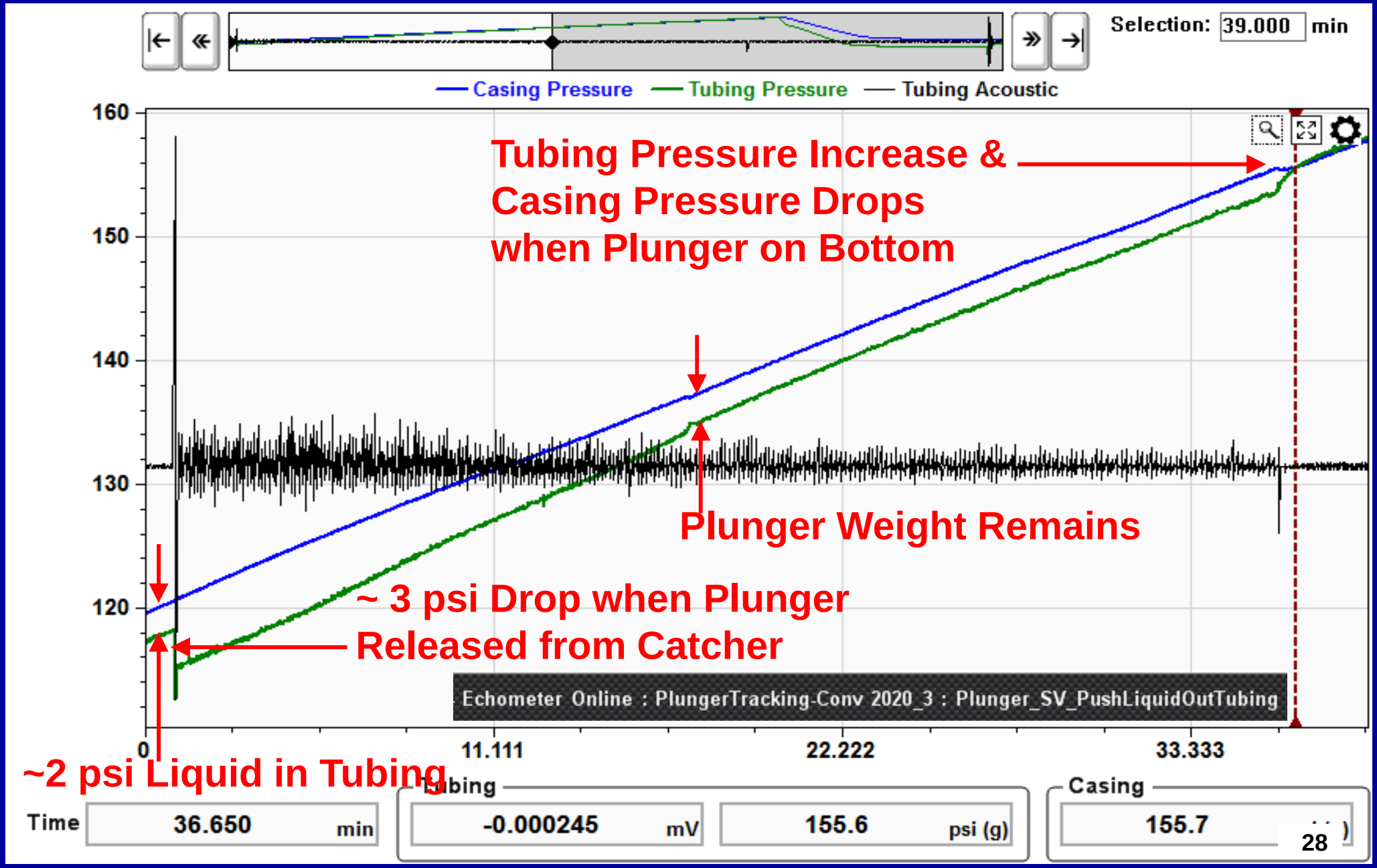




**Pressure Drop = Weight / Area**

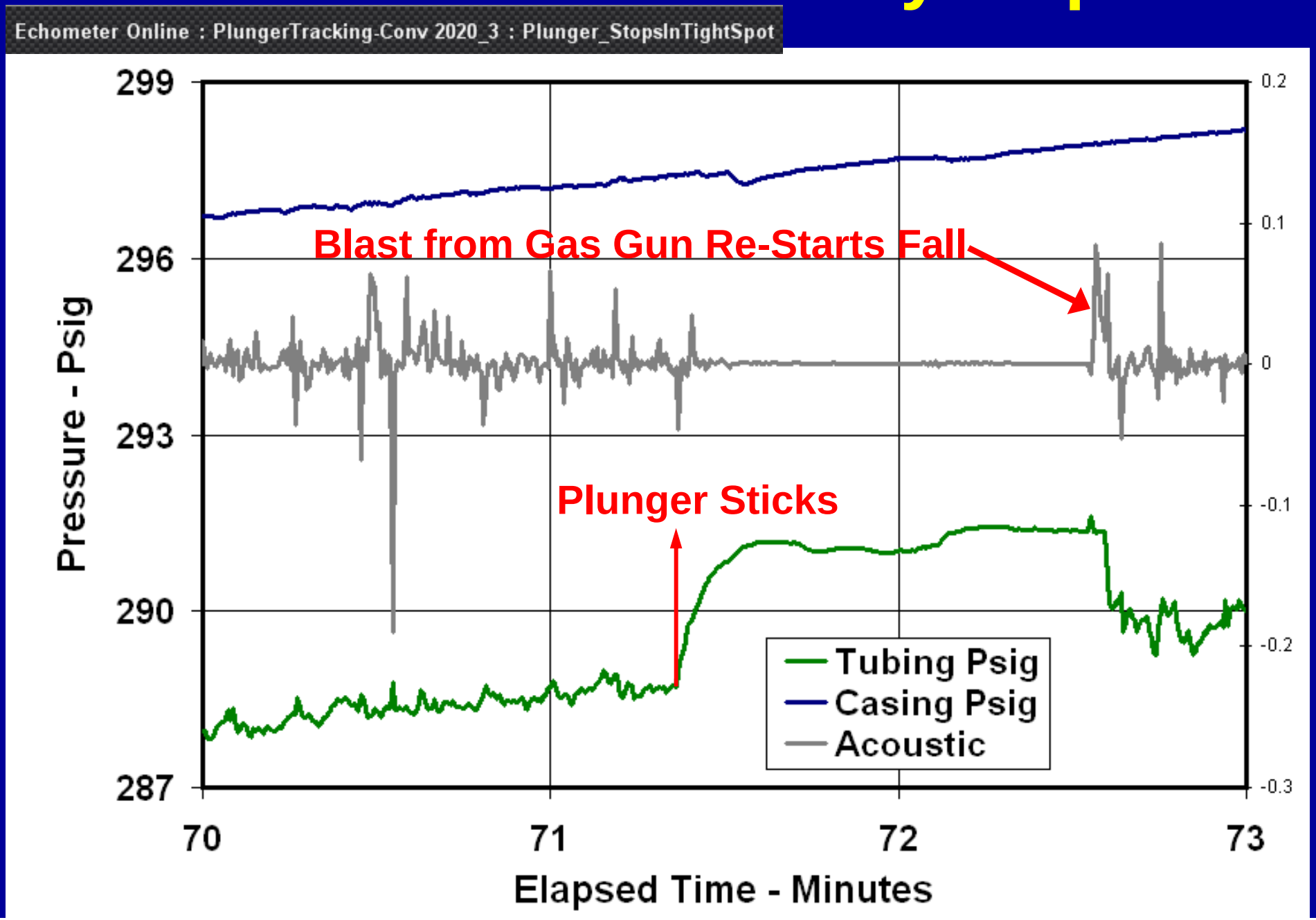
Plunger weight (8 lbs) / Area of 2-3/8”

# Tubing & Casing Pressure

## React to Plunger Falling in Well

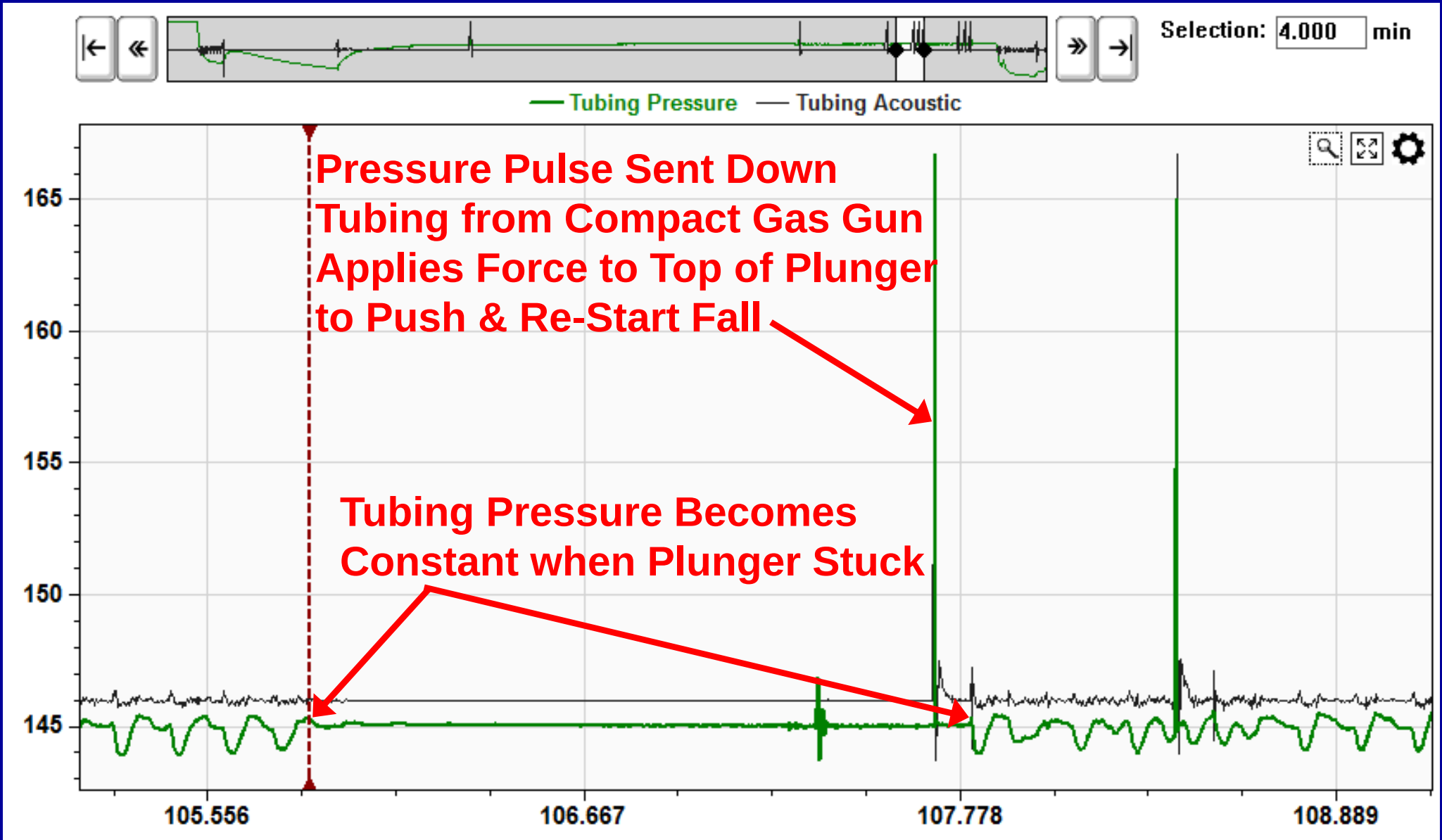


# Identify When Plunger Becomes Stuck Pressure Increases By ~3 psi



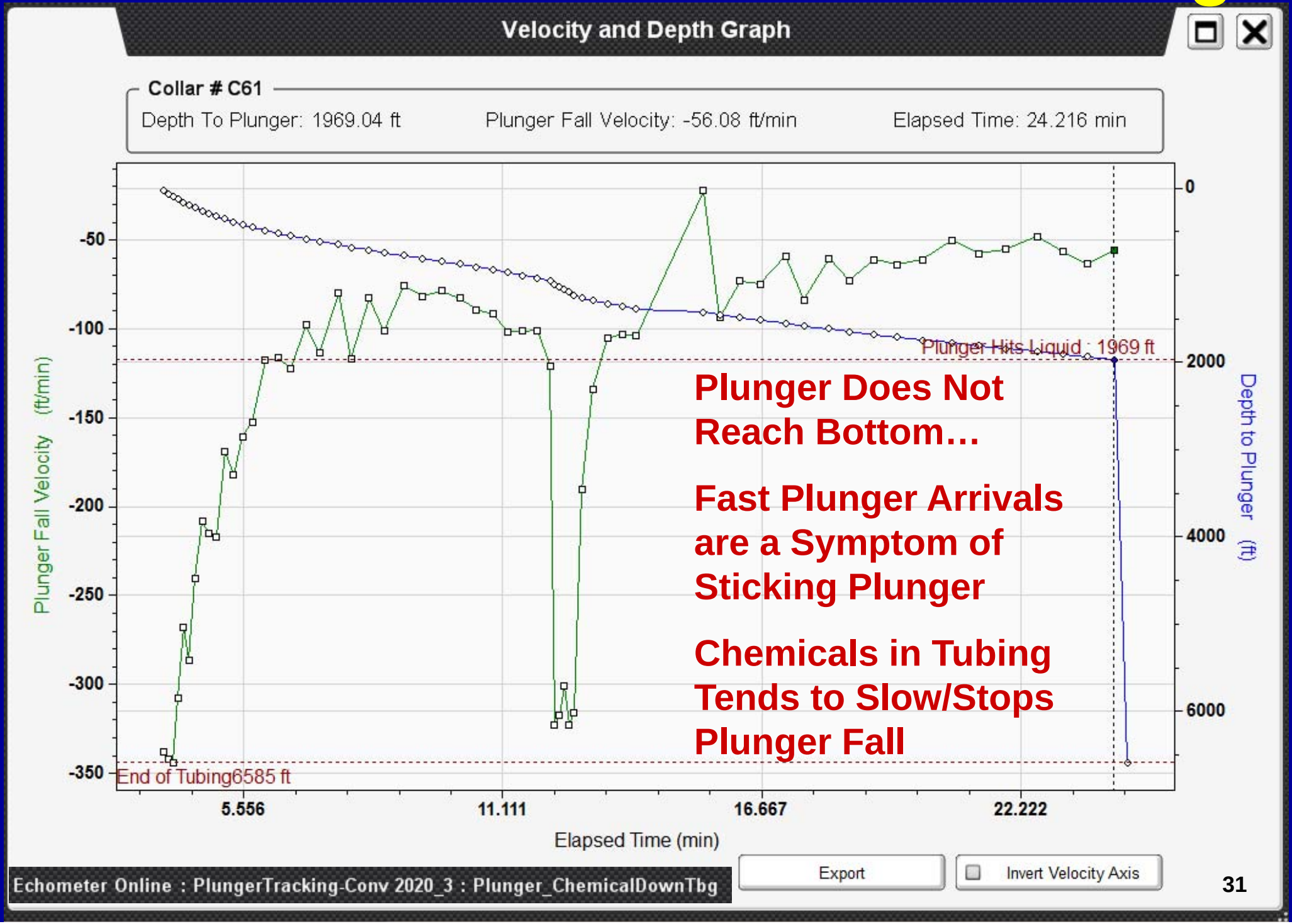
# Paraffin Stops Plunger Fall

## 9 Shots Used to Push Plunger to Bottom

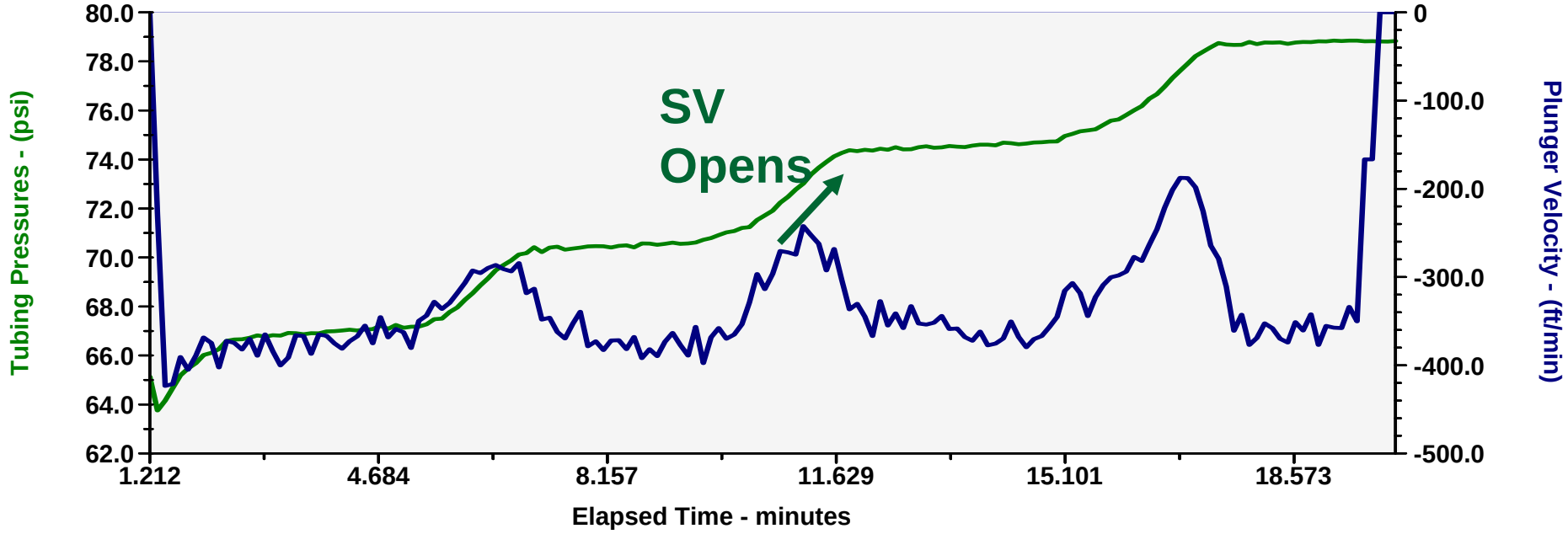


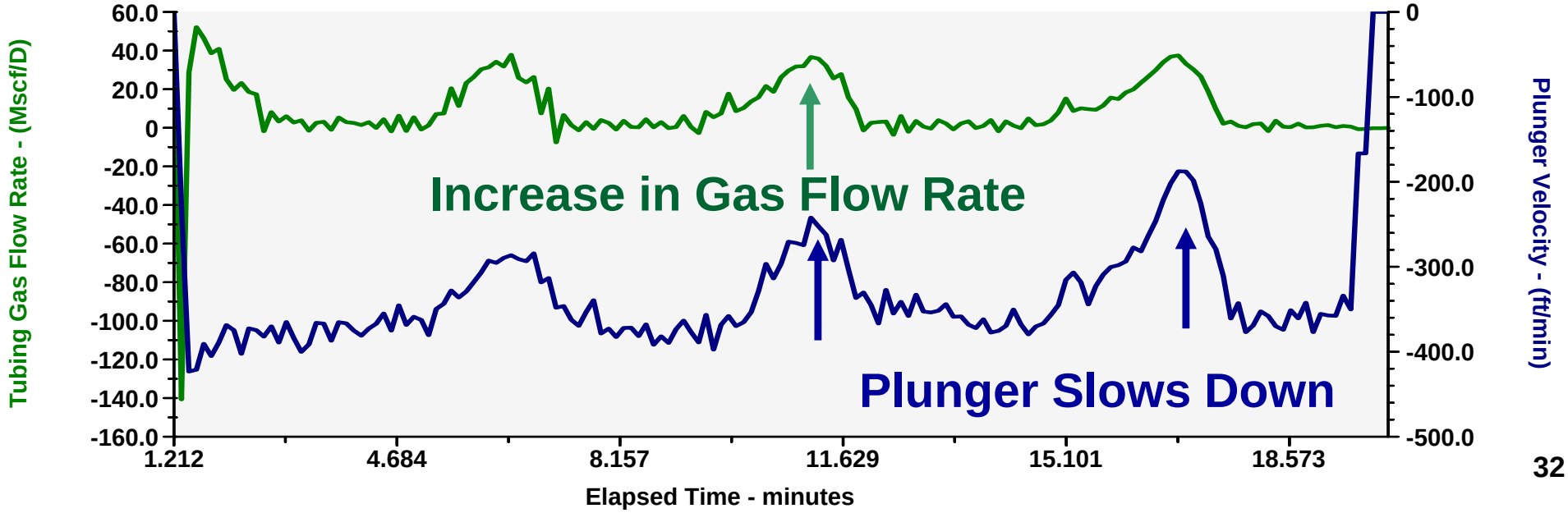

Plunger Lift Seminar : Plunger_StickingParaffin_MovewGG

# Chemical Treatment Down Tubing

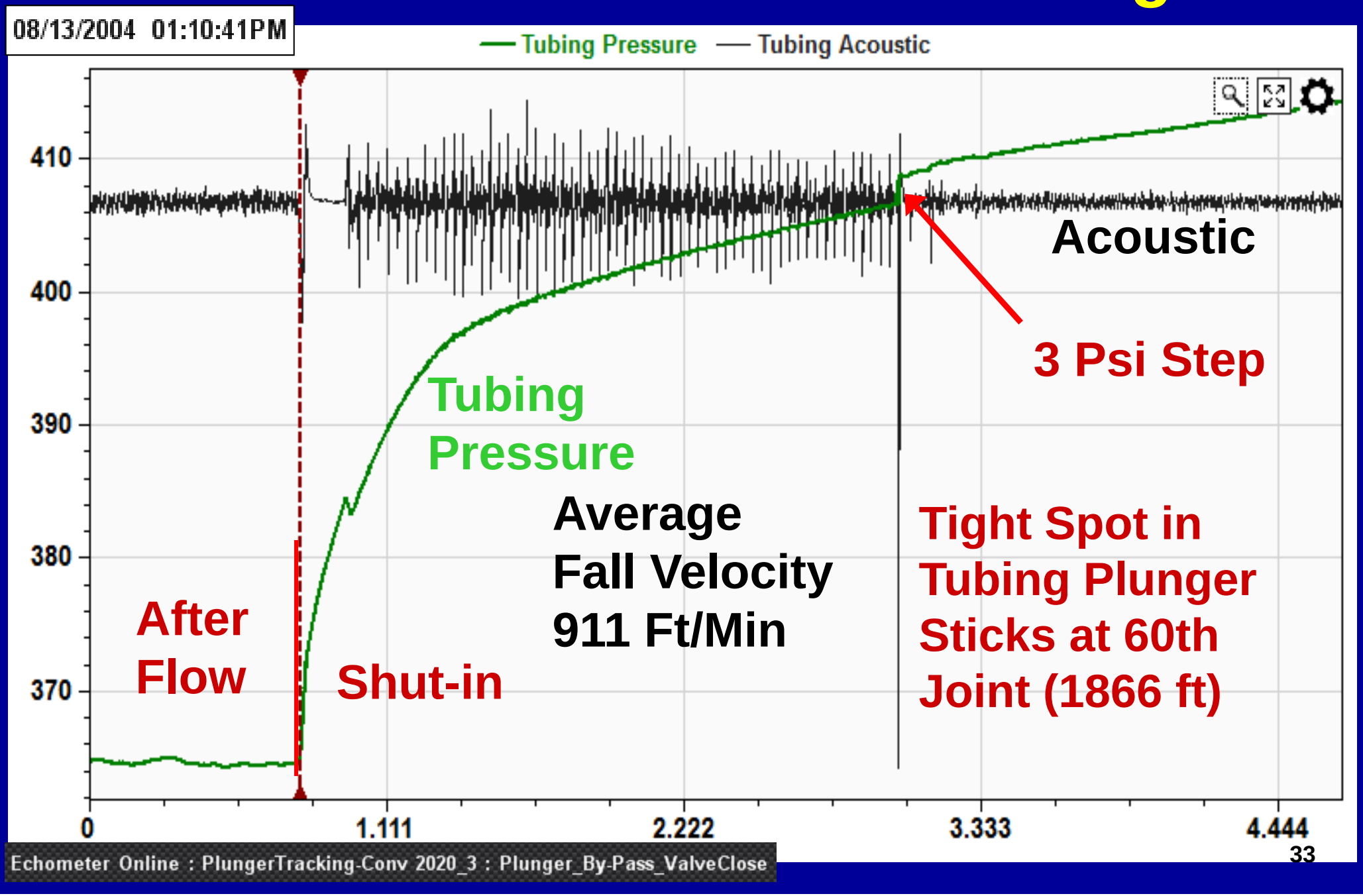


# Increase in Gas Flow Rate Past Plunger Results in Plunger Slowing Down…

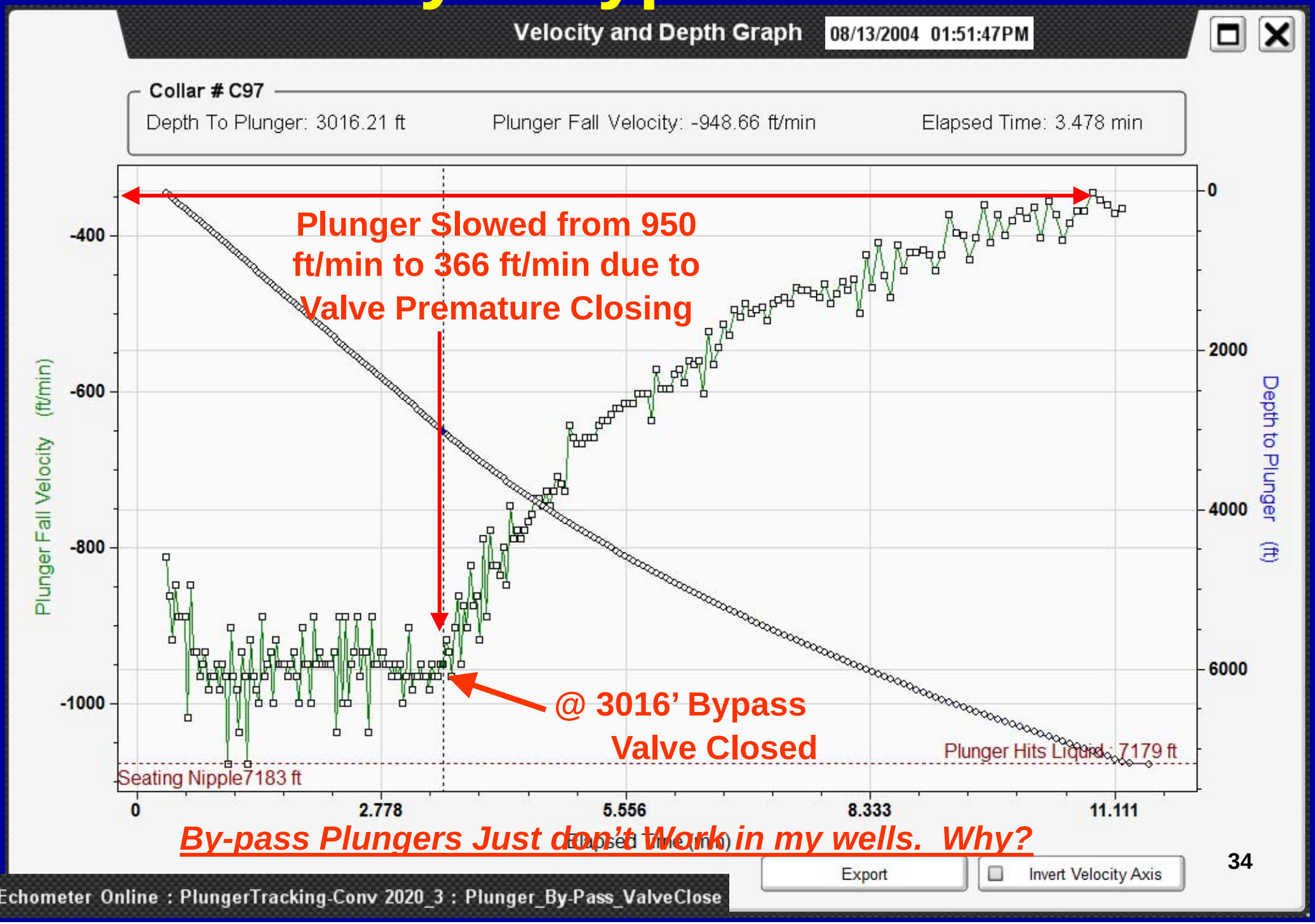


# 2 3/8” By-Pass Shut-in Period
# Notice Pressure and Acoustic Signals

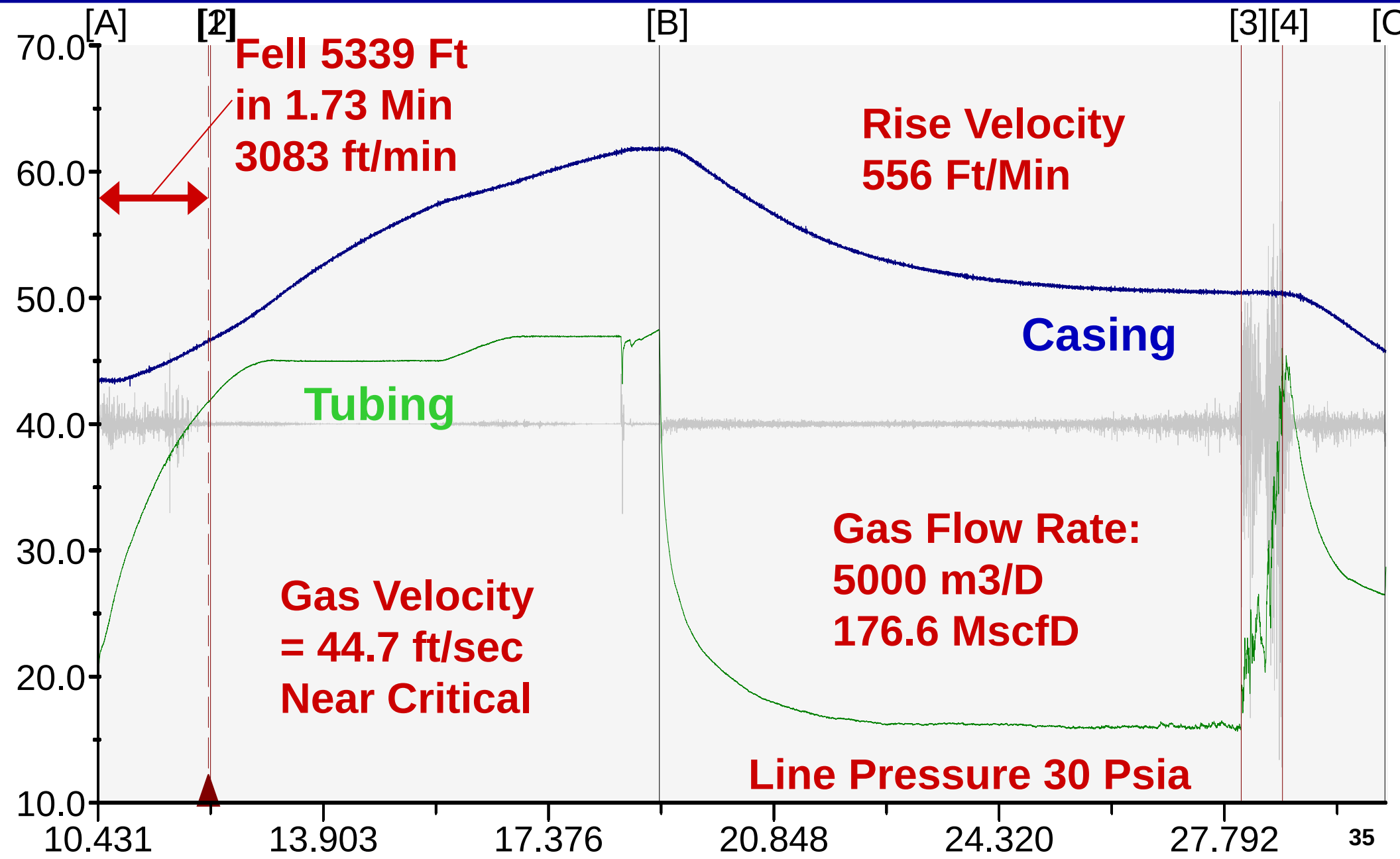


# Fall Velocity – Bypass Valve Closes

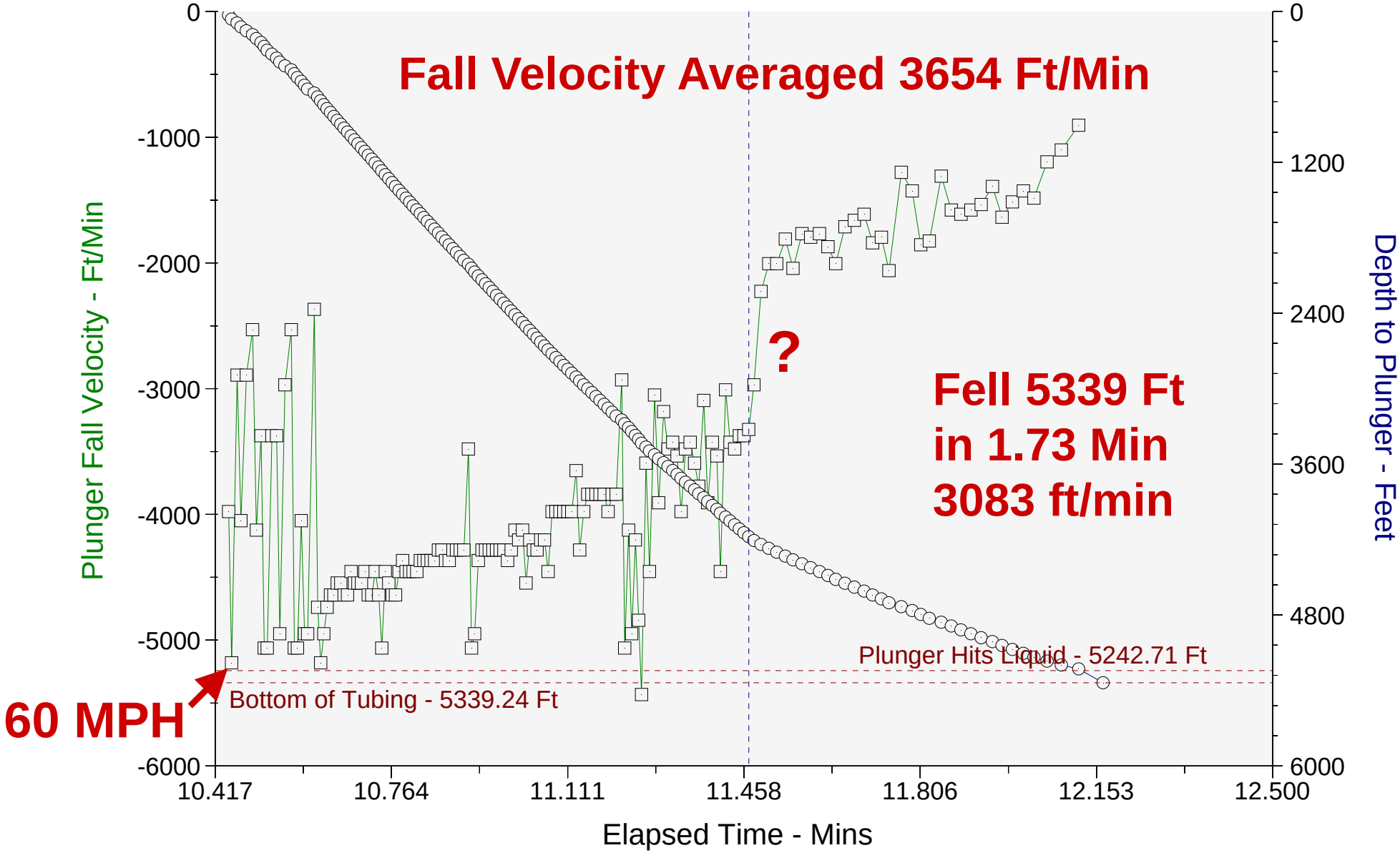



***By-pass Plungers Just don't Work in my wells. Why?***

# 2 7/8 inch Bypass Plunger w/ Standing Valve Hits at Bottom *Very* Hard ~ almost 60 Mile/Hr

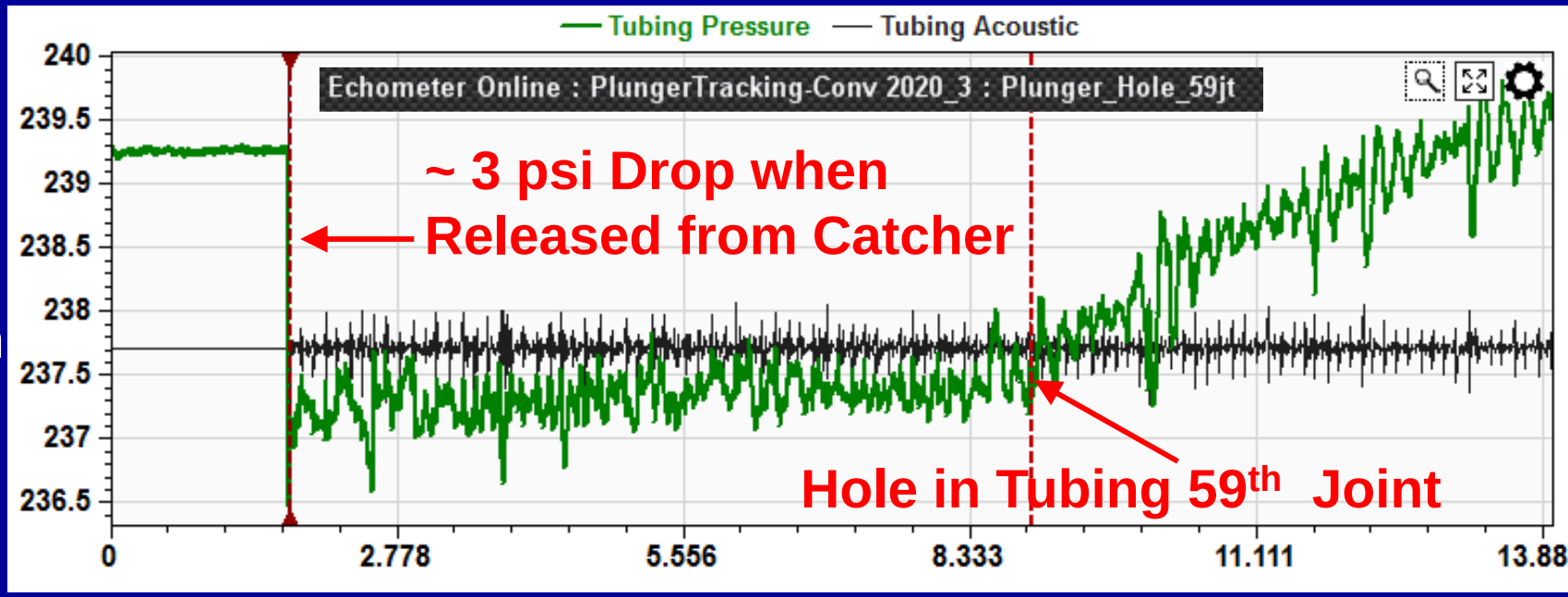


# 2 7/8 inch Bypass Plunger
# Fall Velocity Range 5000-1000 ft/min

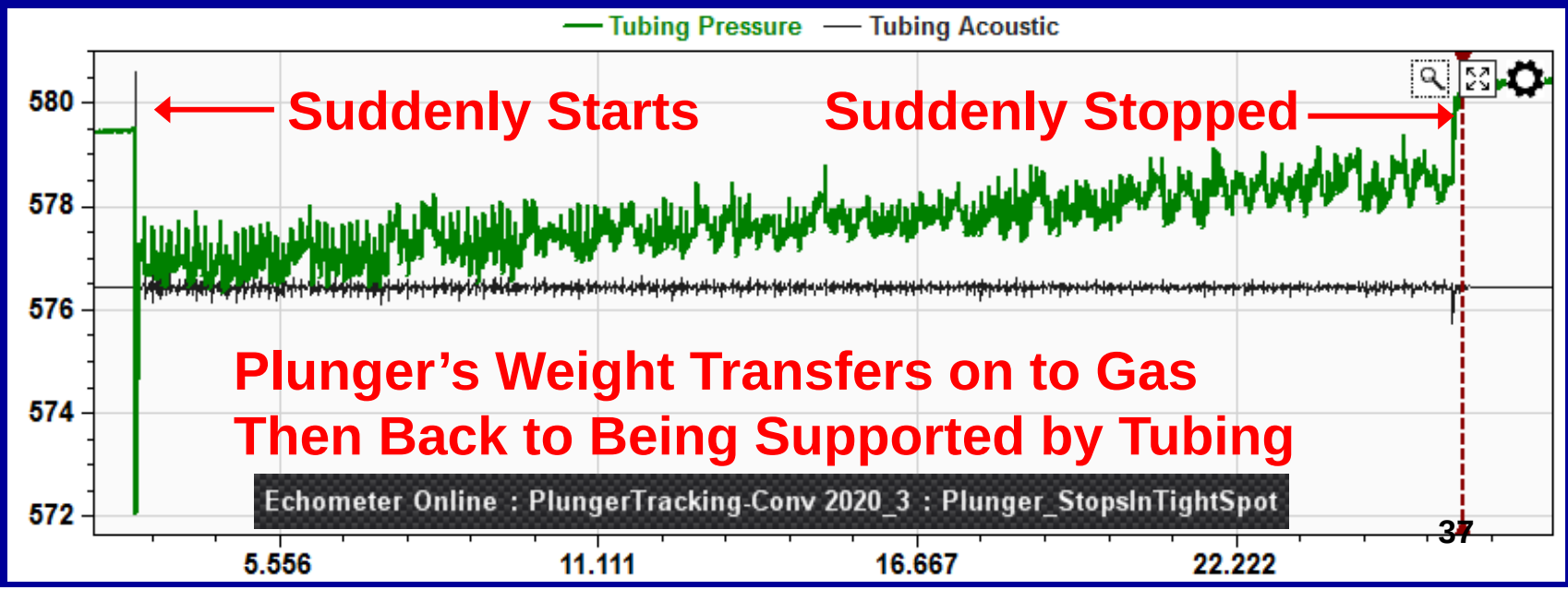


# Tubing Pressure Helps to Identify Downhole Problems

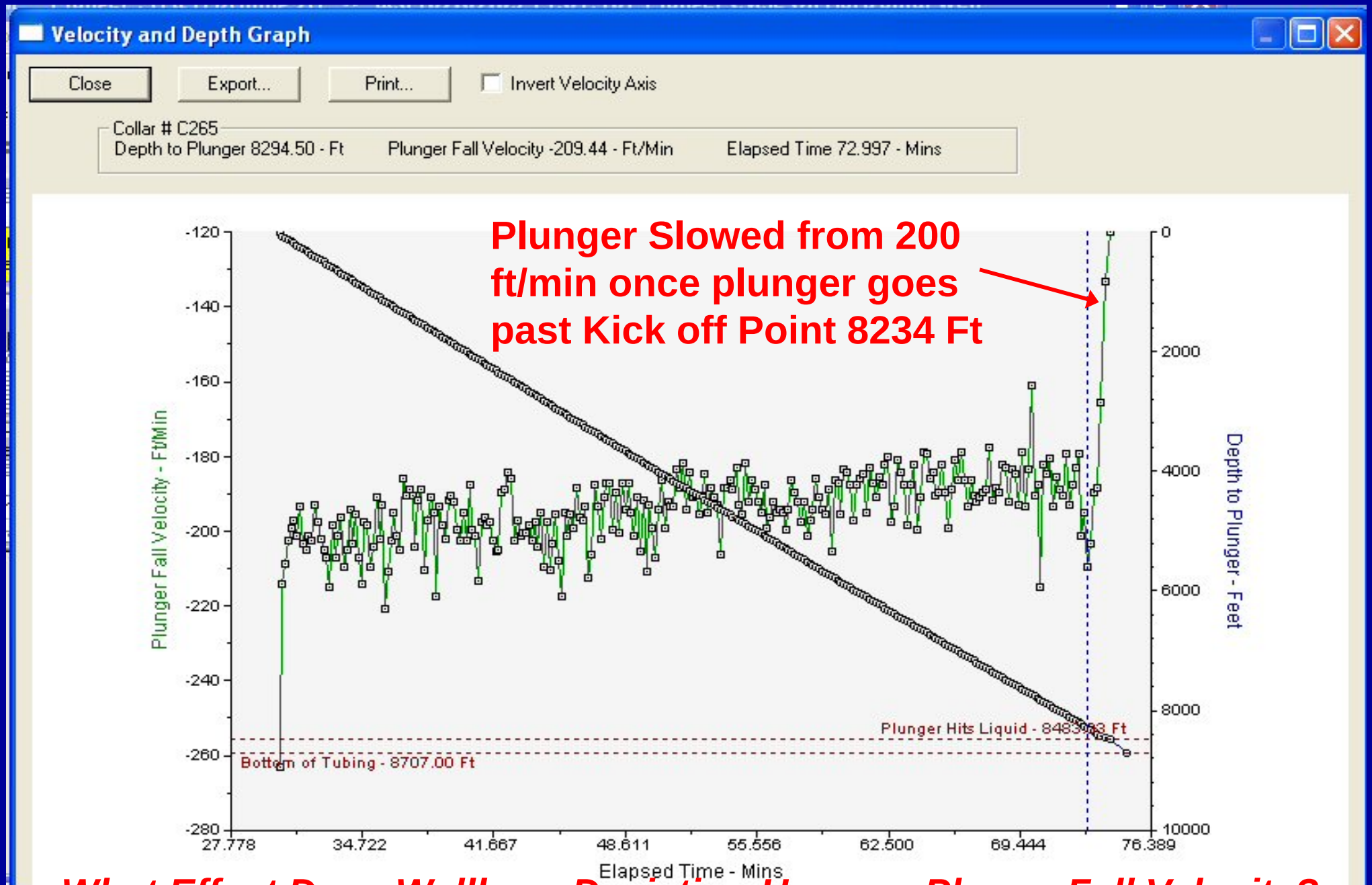
Plunger falls Past Hole at 1872 feet and Pressure from Casing Flows Into Tubing




Rapid Tubing Pressure Increase if Plunger has Sudden Stop



# Fall Velocity Slows in Deviated Well




***What Effect Does Wellbore Deviation Have on Plunge Fall Velocity?***

# Horizontal Well Impacts Velocity

# Horizontal Well Impacts Velocity

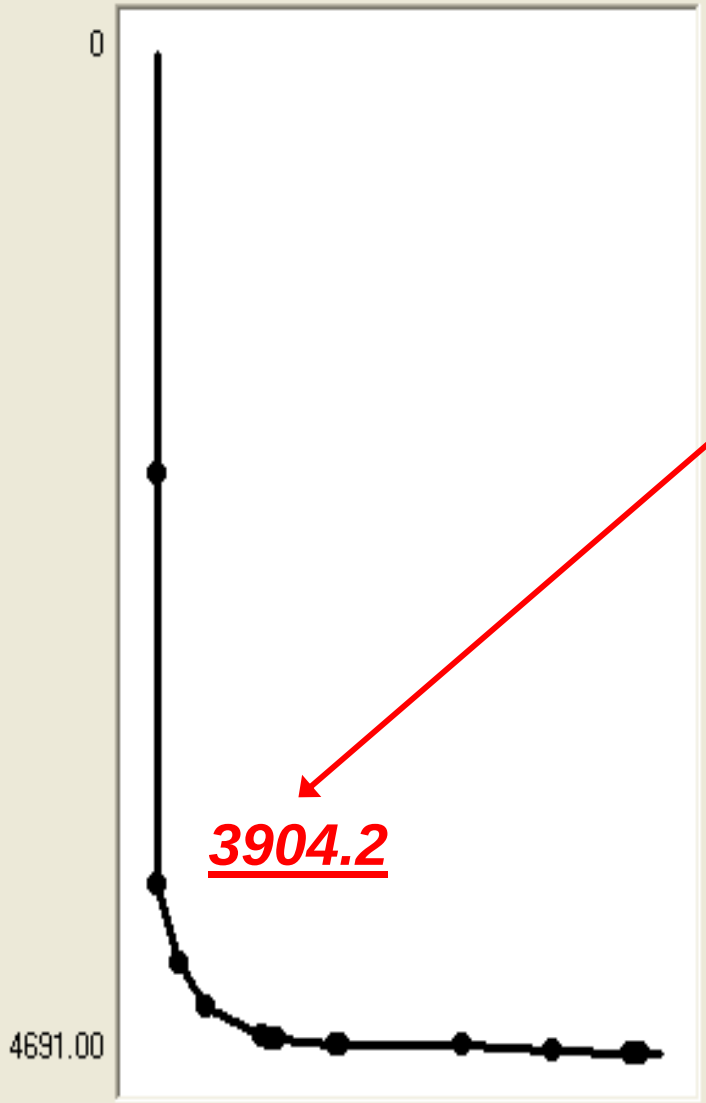
Echometer Online : PlungerTracking-Conv 2020_3 : Plunger_Deviation_Impact

Deviated Wellbore Profile

Wellbore Depths: ft

| | Measured | True Vertical |
|---|---|---|
| 1 | 1965.22 | 1965.22 |
| 2 | 3904.20 | 3904.20 |
| 3 | 4301.18 | 4268.37 |
| 4 | 4586.61 | 4481.63 |
| 5 | 5006.56 | 4616.14 |
| 6 | 5052.49 | 4622.70 |
| 7 | 5098.43 | 4625.98 |
| 8 | 5521.65 | 4652.23 |
| 9 | 5524.93 | 4652.23 |
| 10 | 5557.74 | 4655.51 |
| 11 | 6423.06 | 4656.99 |
| 12 | 7046.26 | 4675.89 |
| 13 | 7610.53 | 4694.46 |
| 14 | 7672.80 | 4692.42 |
| 15 | 7810.24 | 4689.63 |

<-- Entry Ignored (possibly incomplete)



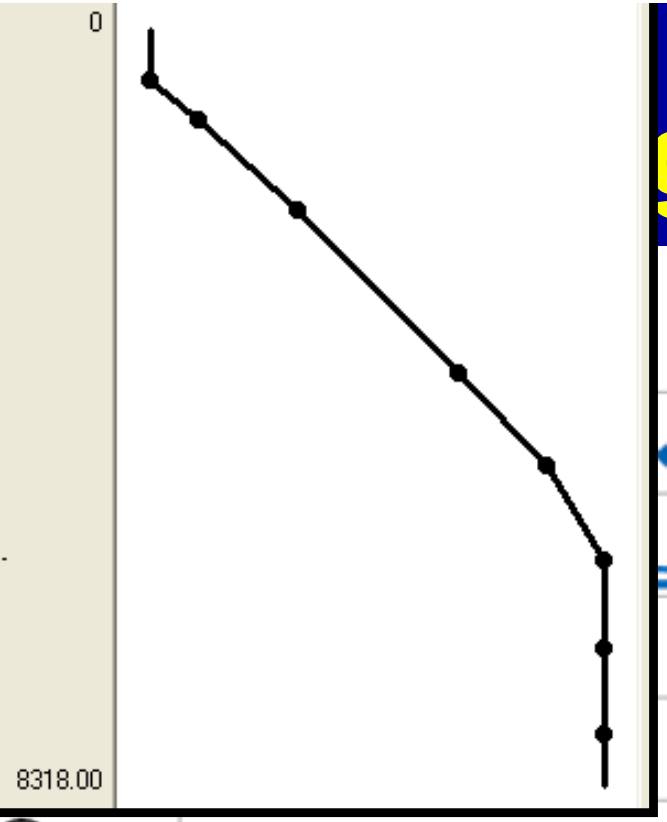

th Graph

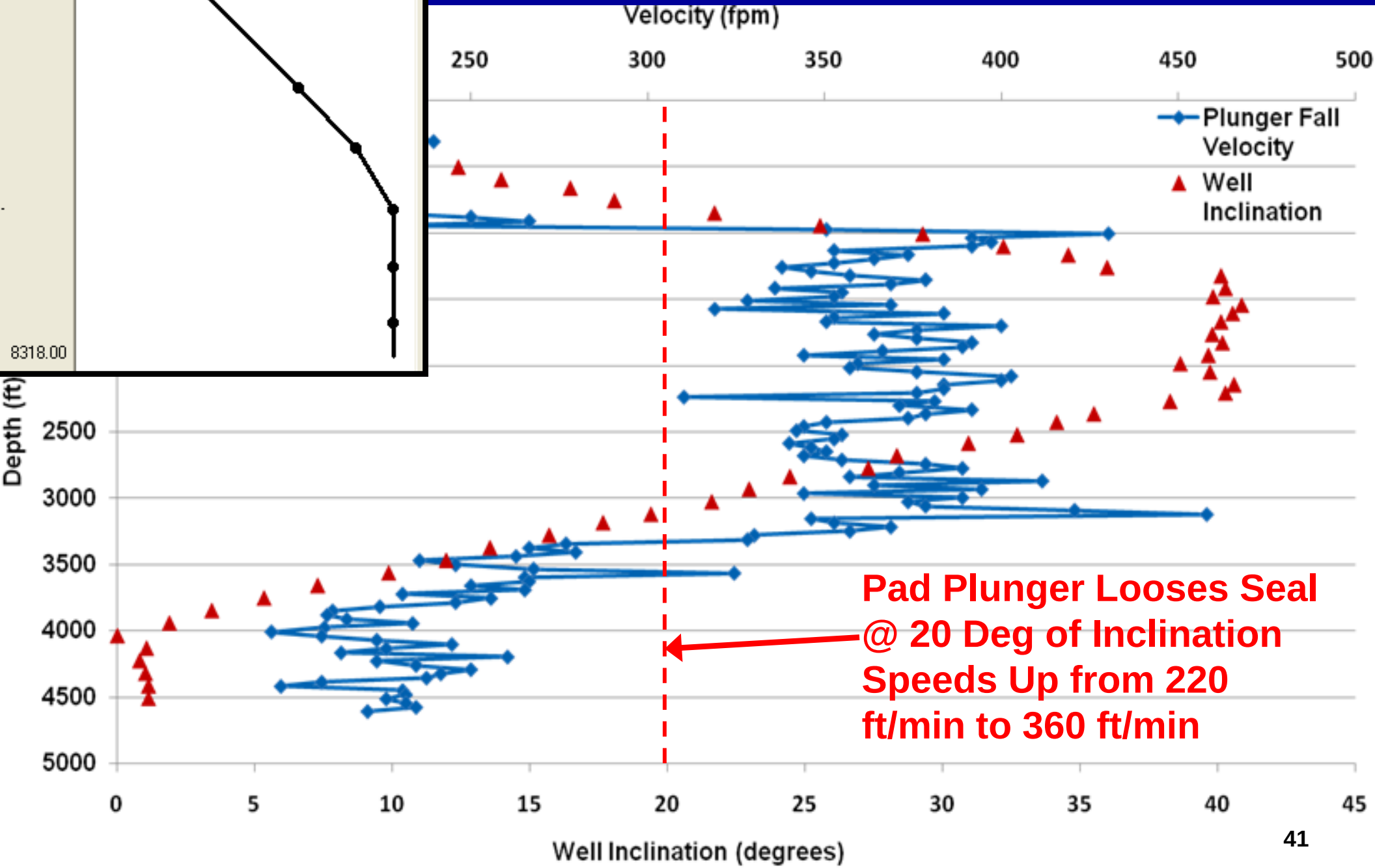
230.08 ft/min

**Dual Pad Plunger Increased Speed from 230 to 450 ft/min once Plunger Goes Past Kick Off Point**

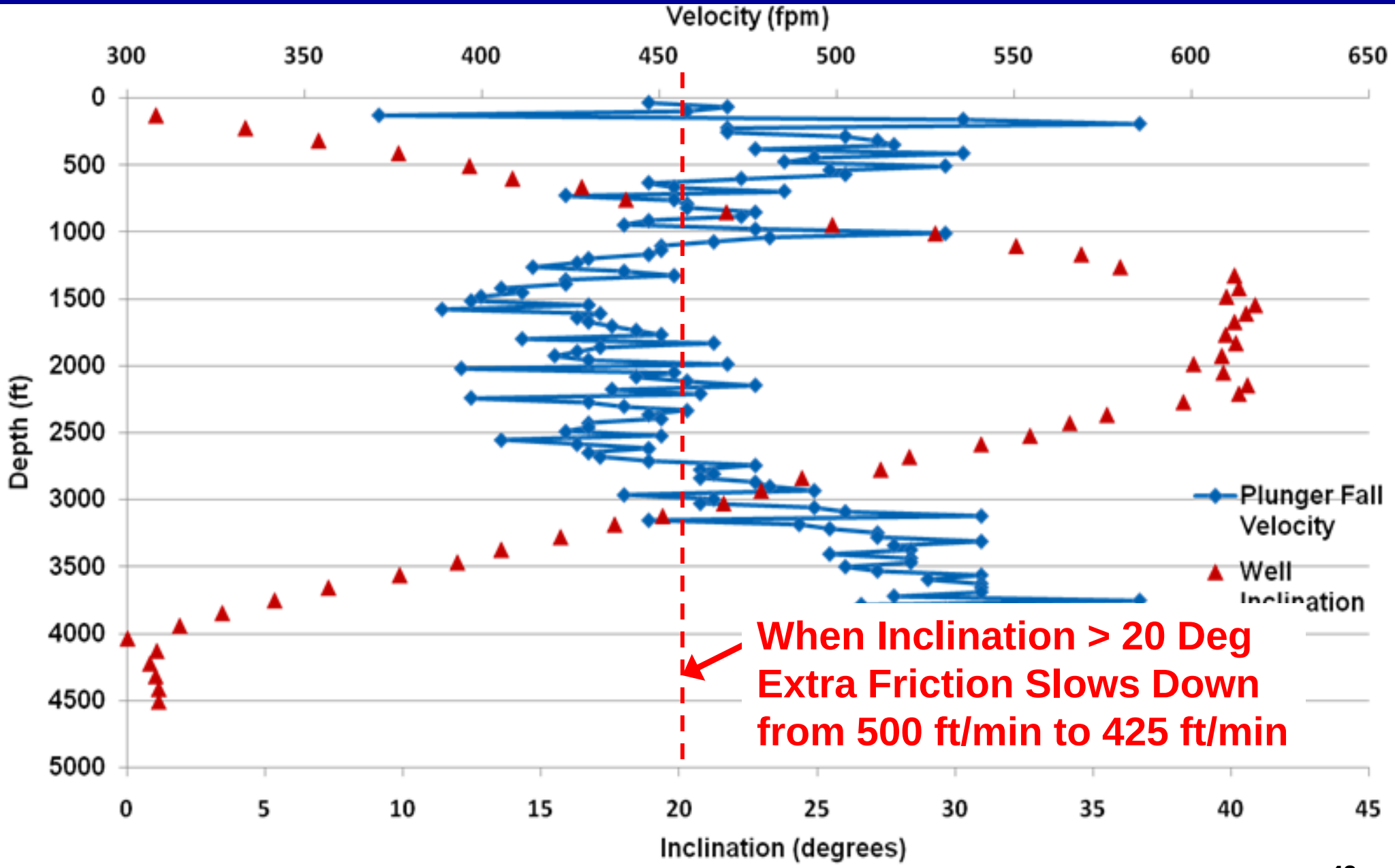
***added Plungers Increase Speed?***

# ger in Deviated S-Curve



# Solid Plunger in Deviated Well



# Turner Unloading Velocity (w/ hole angle adjustment)

$$v_c = 1.5934 \underbrace{\left[\frac{N_{we}}{30}\right]^{0.25}}_{\text{Turner Adjustment}} \left[\frac{\sigma\left(\rho_l - \rho_g\right)}{\rho_g^2}\right]^{0.25} \underbrace{\frac{\left[\sin\left(1.7\left(90-\theta\right)\right)\right]^{0.38}}{0.740767}}_{\text{TNO/Shell Angle Correction}}$$

where

$\rho_g$ = gas phase density, lbm/ft$^3$

$\rho_L$ = liquid phase density, lbm/ft$^3$

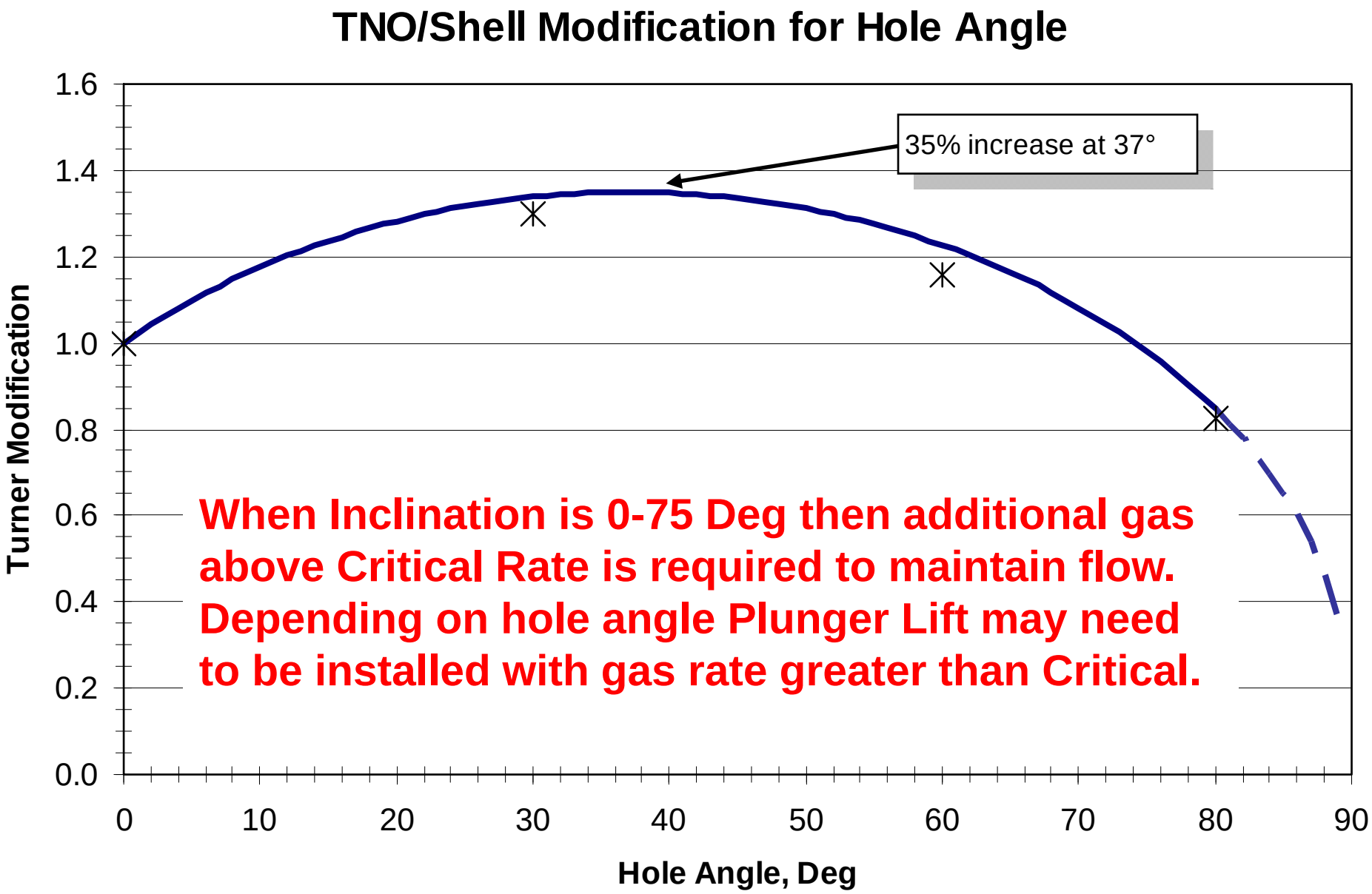
$\sigma$ = surface tension, dynes/cm

$N_{we}$ = Weber Number (use 60 for original Turner)

$\Theta$ = hole angle (Deg from vertical)

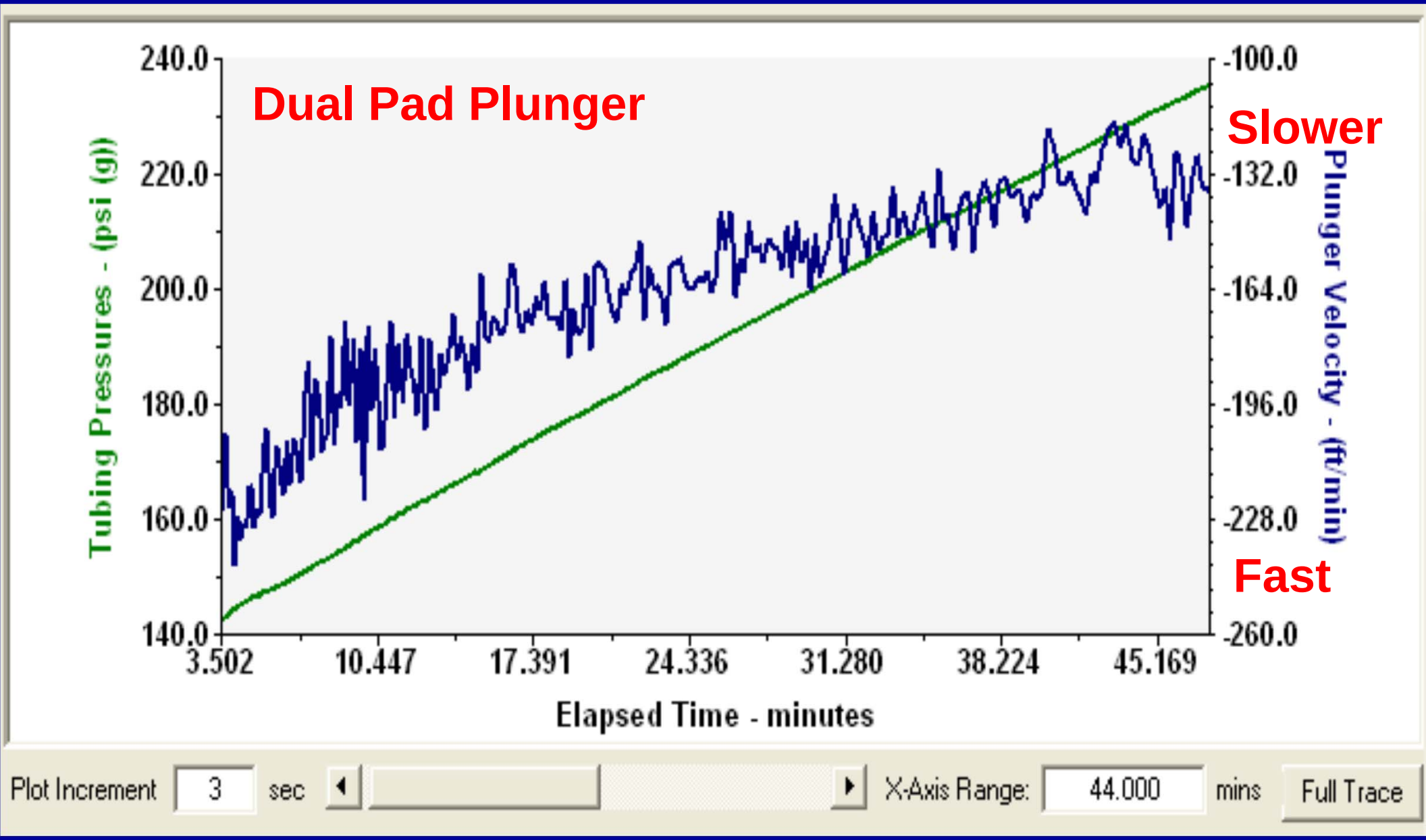
$v_c$ = critical velocity of liquid droplet, ft/sec

# Turner Angle Modification (TNO-Shell)

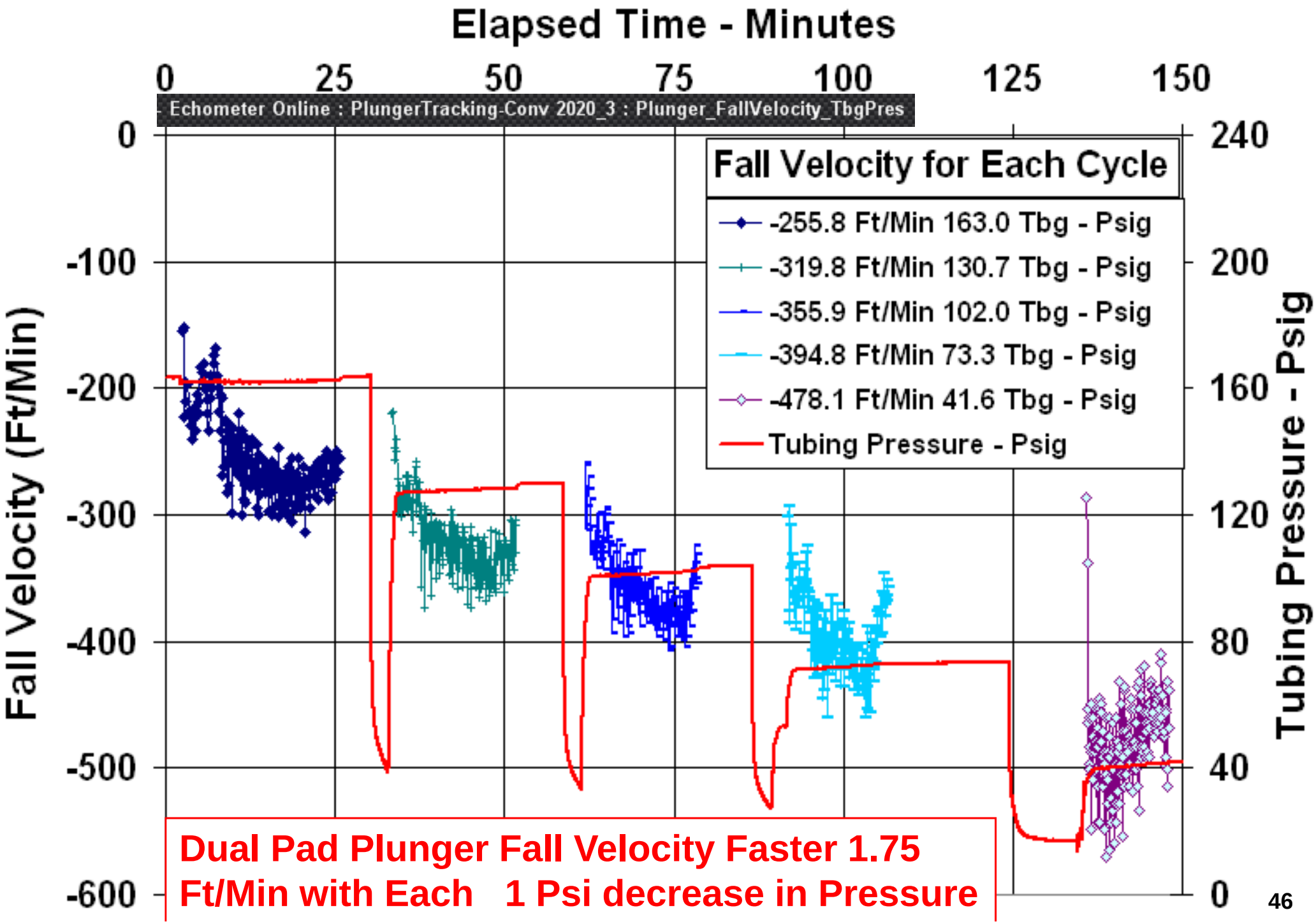



**When Inclination is 0-75 Deg then additional gas above Critical Rate is required to maintain flow. Depending on hole angle Plunger Lift may need to be installed with gas rate greater than Critical.**

# Fall Velocity is Faster at Low Pressures Slows as Pressure Increases



# Fall Velocity Increases as Pressure Decreases




**Dual Pad Plunger Fall Velocity Faster 1.75 Ft/Min with Each 1 Psi decrease in Pressure**

# Measured Fall Velocity in 40 Different Wells

| Average Fall Pressure | Measured Average Fall Velocity (Gas) | Model Average Fall Velocity (Gas) | Difference Measured - Model | Model's Absolute % Error |
|---|---|---|---|---|
| psi | ft/Min | ft/Min | ft/Min | % |
| 140 | 296 | 412.9 | -116.9 | 39.5 |
| 53 | 532 | 674.0 | -142.0 | 26.7 |
| 265 | 244 | 298.1 | -54.1 | 22.2 |
| 99 | 404 | 492.0 | -88.0 | 21.8 |
| 234 | 264 | 317.7 | -53.7 | 20.3 |
| 152 | 330 | 396.0 | -66.0 | 20.0 |
| 146 | 338 | 404.2 | -66.2 | 19.6 |
| 181 | 446 | 362.0 | 84.0 | 18.8 |
| 411 | 291 | 237.4 | 53.6 | 18.4 |
| 273 | 359 | 293.5 | 65.5 | 18.2 |
| 247 | 312 | 363.3 | -51.3 | 16.4 |
| 268 | 352 | 296.3 | 55.7 | 15.8 |
| 260 | 260 | 301.0 | -41.0 | 15.8 |
| 310 | 322 | 274.9 | 47.1 | 14.6 |
| 193 | 406 | 350.6 | 55.4 | 13.6 |
| 129 | 493 | 430.3 | 62.7 | 12.7 |
| 186 | 405 | 357.3 | 47.7 | 11.8 |
| 292 | 319 | 283.5 | 35.5 | 11.1 |
| 218 | 369 | 329.5 | 39.5 | 10.7 |
| 216 | 370 | 331.0 | 39.0 | 10.5 |

**All Same Type of Cleanout Plungers Installed in Wells**

**Avg Error = 0.7 Ft/Min**
**Avg Abs Error= 11.7%**
**Abs Avg Error = 40.1 Ft/Min**

| | | | | |
|---|---|---|---|---|
| 438 | 253 | 229.6 | 23.4 | 9.2 |
| 322 | 296 | 269.6 | 26.4 | 8.9 |
| 147 | 442 | 402.8 | 39.2 | 8.9 |
| 151 | 366 | 397.3 | -31.3 | 8.6 |
| 300 | 305 | 279.6 | 25.4 | 8.3 |
| 268 | 319 | 296.3 | 22.7 | 7.1 |
| 352 | 241 | 257.4 | -16.4 | 6.8 |
| 235 | 338 | 317.0 | 21.0 | 6.2 |
| 250 | 292 | 307.1 | -15.1 | 5.2 |
| 193 | 334 | 350.6 | -16.6 | 5.0 |
| 247 | 297 | 309.0 | -12.0 | 4.0 |
| 282 | 299 | 288.7 | 10.3 | 3.4 |
| 245 | 300 | 310.3 | -10.3 | 3.4 |
| 358 | 264 | 255.1 | 8.9 | 3.4 |
| 275 | 286 | 292.4 | -6.4 | 2.2 |
| 800 | 165 | 164.0 | 1.0 | 0.6 |
| 177 | 366 | 366.5 | -0.5 | 0.1 |
| 130 | 429 | 428.7 | 0.3 | 0.1 |

# *Plunger Fall Velocity Model Macro* EXCEL Spreadsheet

B4 | 300

| | A | B | C |
|---|---|---|---|
| 1 | James F. Lea & Lynn Rowlan Plunger Fall Velocity Model | | |
| 2 | Title/Identification: | Example | |
| 3 | Plunger Weight, lbf | 7.16 | |
| 4 | Measured Fall Velocity, ft/min | 300 | |
| 5 | Average Temperature @ Measured Vel, F | 135 | |
| 6 | Average Presssure @ Measured Vel, Psia | 261.7 | |
| 7 | Gas Specific Gravity (Air = 1) | 0.65 | |
| 8 | Mole Fraction H2S (Decimal Fraction) | 0 | |
| 9 | Mole Fraction CO2 (Decimal Fraction) | 0 | |
| 10 | | | |
| 11 | Fall Velocity Calculations: | | |
| 12 | Initial Pressure, Psia | 14.7 | |
| 13 | Final Pressure, Psia | 825 | |
| 14 | Pressure Step, Psi | 25 | |
| 15 | Temperature, Deg F | 135 | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | Calculate Fall Velocity | | |
| 20 | | | |

1. **Input Known Fall Velocity to Calibrate Model**
2. **For Fall Velocity Calculation Specify Pressure Range**
3. **Click Calculate Fall Velocity Button to Plot Calculated Fall Velocities**
4. **Go to Output Worksheet to see Plot**

# General Plunger Velocity Fall Model From the Drag Model

**Step 1** $$\mathrm{Cd} \times \mathrm{A} = \mathrm{Wt} \times 2\mathrm{gc}/(\boxed{\rho}\mathrm{V}^2)$$

**Step 2** $$V = \frac{\sqrt{2\mathrm{Wt\ gc}/(\mathrm{CdA})}}{\sqrt{\boxed{\rho}}}$$

## General Model

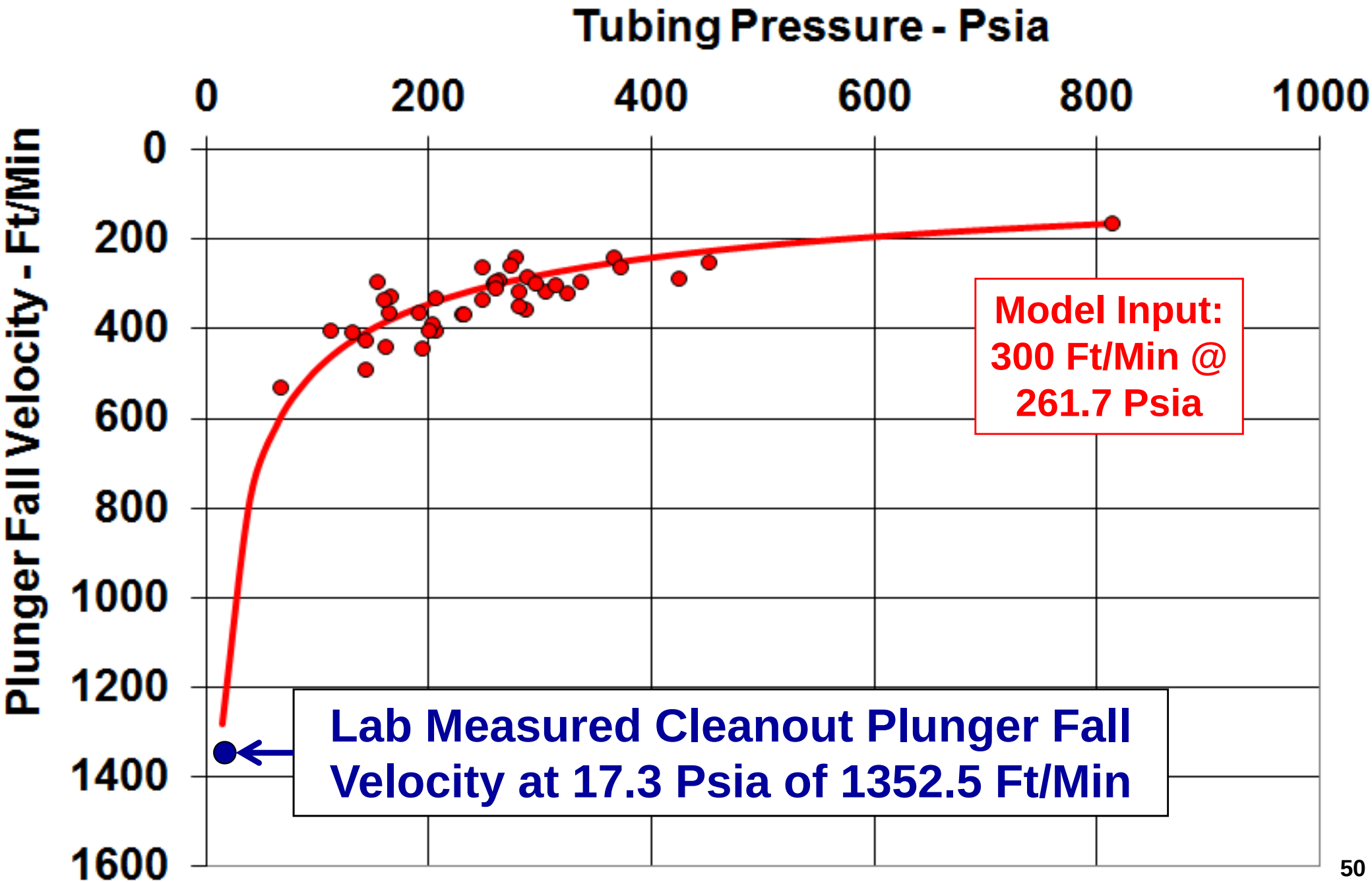
**Step 3** $$V = \mathrm{C}/\sqrt{\boxed{\rho}}$$

**Where**

$$\mathrm{C} = \sqrt{2\mathrm{Wt\ gc}/(\mathrm{CdA})}$$

**Echometer Plunger Fall Performance Coefficient: C**

# Dry Gas ~ Terminal Plunger Fall Velocity Measured in Laboratory: Specific Gas Rate to Float Plunger



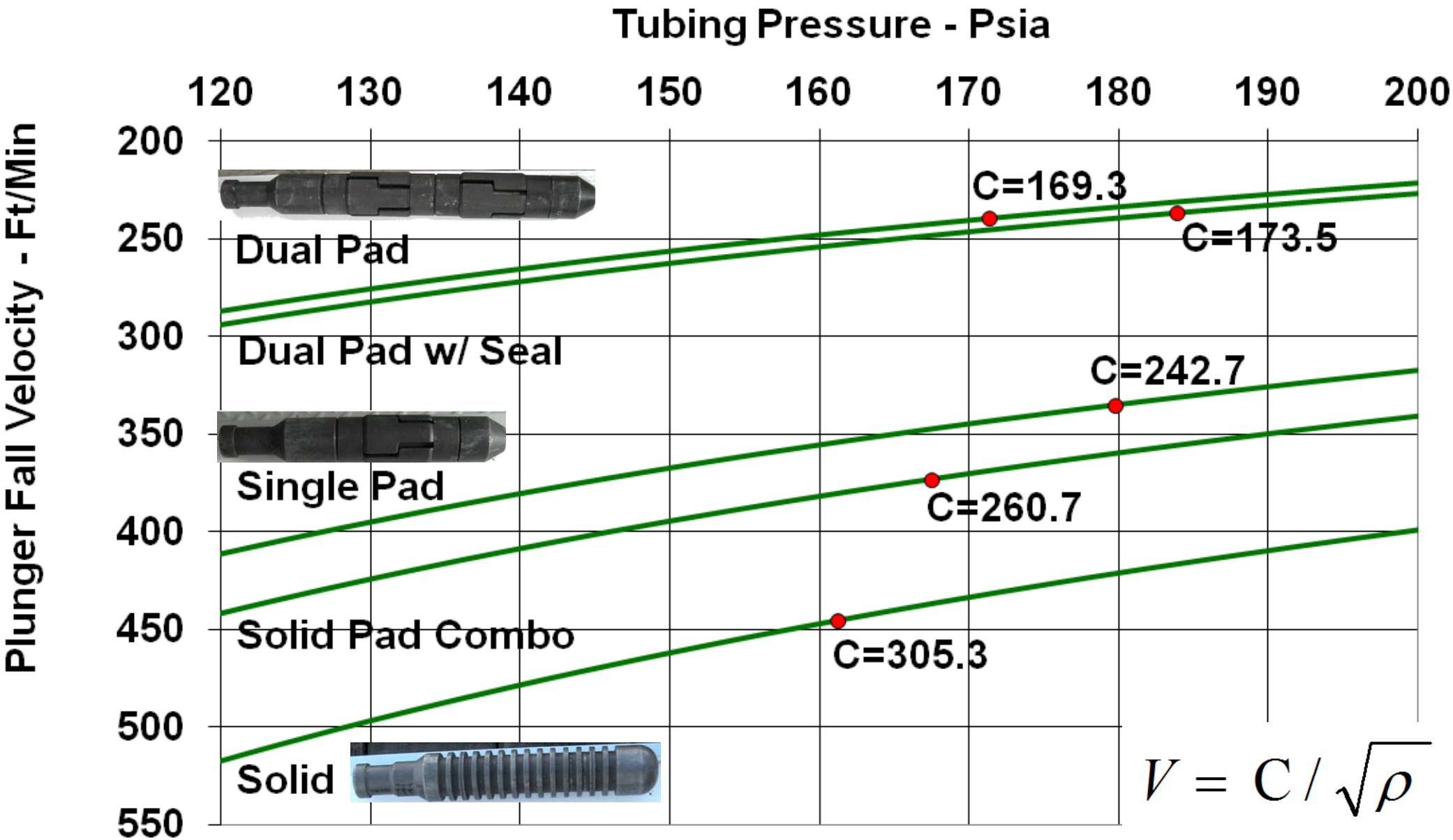
# Plunger Fall Performance Coefficient [C] for Different Plungers in Same Well

## C @ Average P, T, and Plunger Velocity

$$V = C / \sqrt{\rho}$$

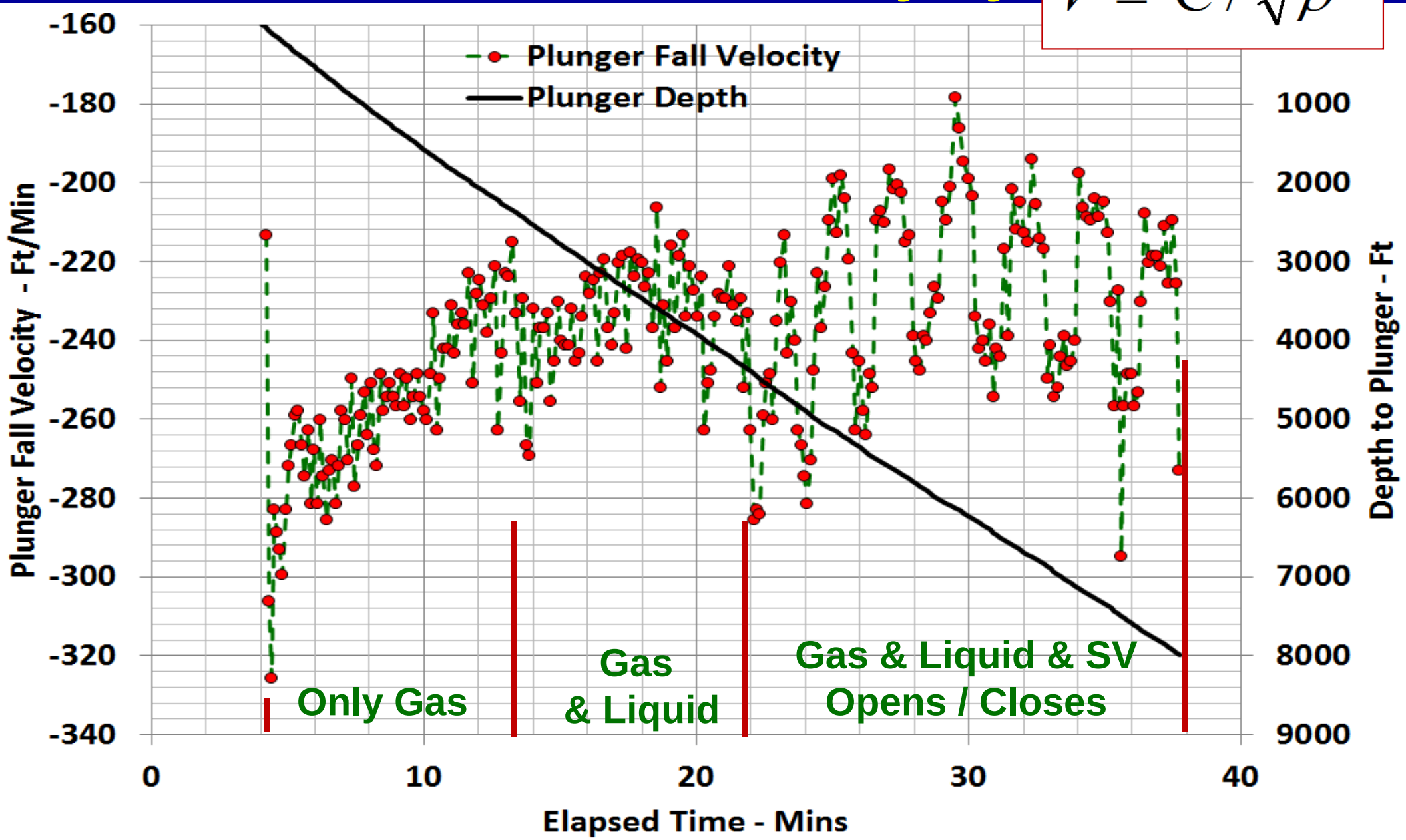
| Plunger Description | Picture | Avg Fall Velocity Ft/min | Avg Pressure Psia | C |
|---|---|---|---|---|
| Dual Pad w/ Seal | | -236.6 | 183.9 | 173.5 |
| Dual Pad | | -239.5 | 171.4 | 169.3 |
| Single Pad | | -335.0 | 179.7 | 242.7 |
| Solid Pad Combo | | -372.9 | 167.5 | 260.7 |
| Solid | | -445.3 | 161.2 | 305.3 |

# Predicted Plunger Fall Velocity at Different Pressure Using [C] for Different Plungers

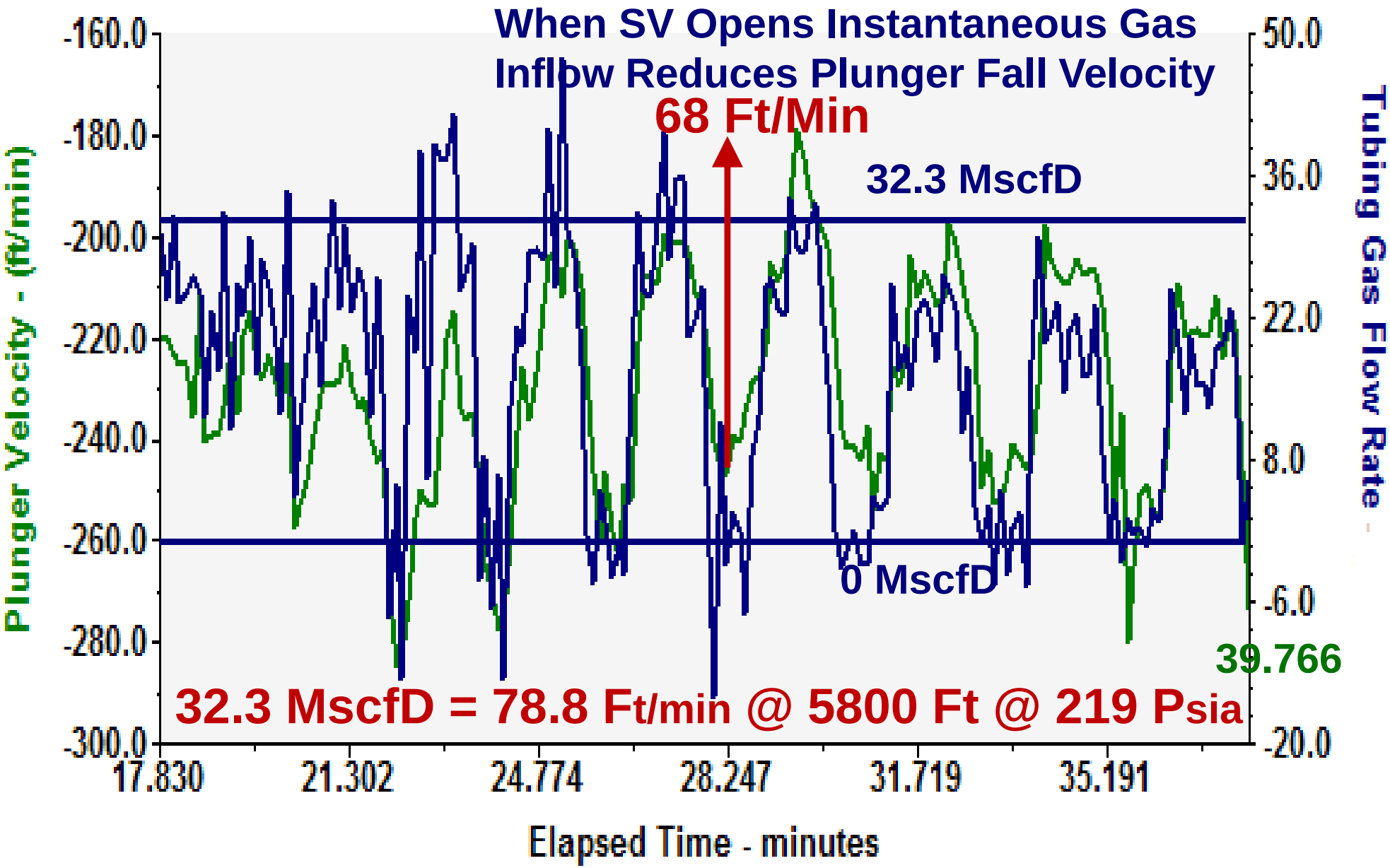



$$V = C / \sqrt{\rho}$$

# Measured Plunger Fall Velocities Compared to Predicted Fall Velocity by $V = C / \sqrt{\rho}$



# Change in Plunger Fall Velocity Directly Related to Change in Low Gas Flow Rate



# Plunger Fall Velocity Impacted By:

1. Diameter of Plunger – Larger Diameter Falls Slower
2. Effectiveness of Seal between Plunger and Tubing – Better Seal Plunger Falls Slower
3. Brush stiffness – If the Bristles do not provide a effective seal then the plunger falls faster
4. Increased friction due to contact with the tubing – Plunger Falls Slower
5. Old age/increased wear – as the plunger wears out the worn plunger falls faster
6. If Gas can pass through plunger (i.e. Bypass) – then a plunger falls faster
7. When the plunger becomes stuck and stops – usually indicated by a 3 psi increase in pressure
8. If the Tubing is Sticky – the plunger falls slower

O.L. Rowlan, J. McCoy, J. Lea,, R. Nadkrynechny, C. Cepuch, " Measured Plunger Fall Velocity Used to Calibrate New Fall Velocity Model", SPE 164495 presentation at the SPE Production and Operations Symposium held in OKC, OK, U.S.A., 23–26 March 2013

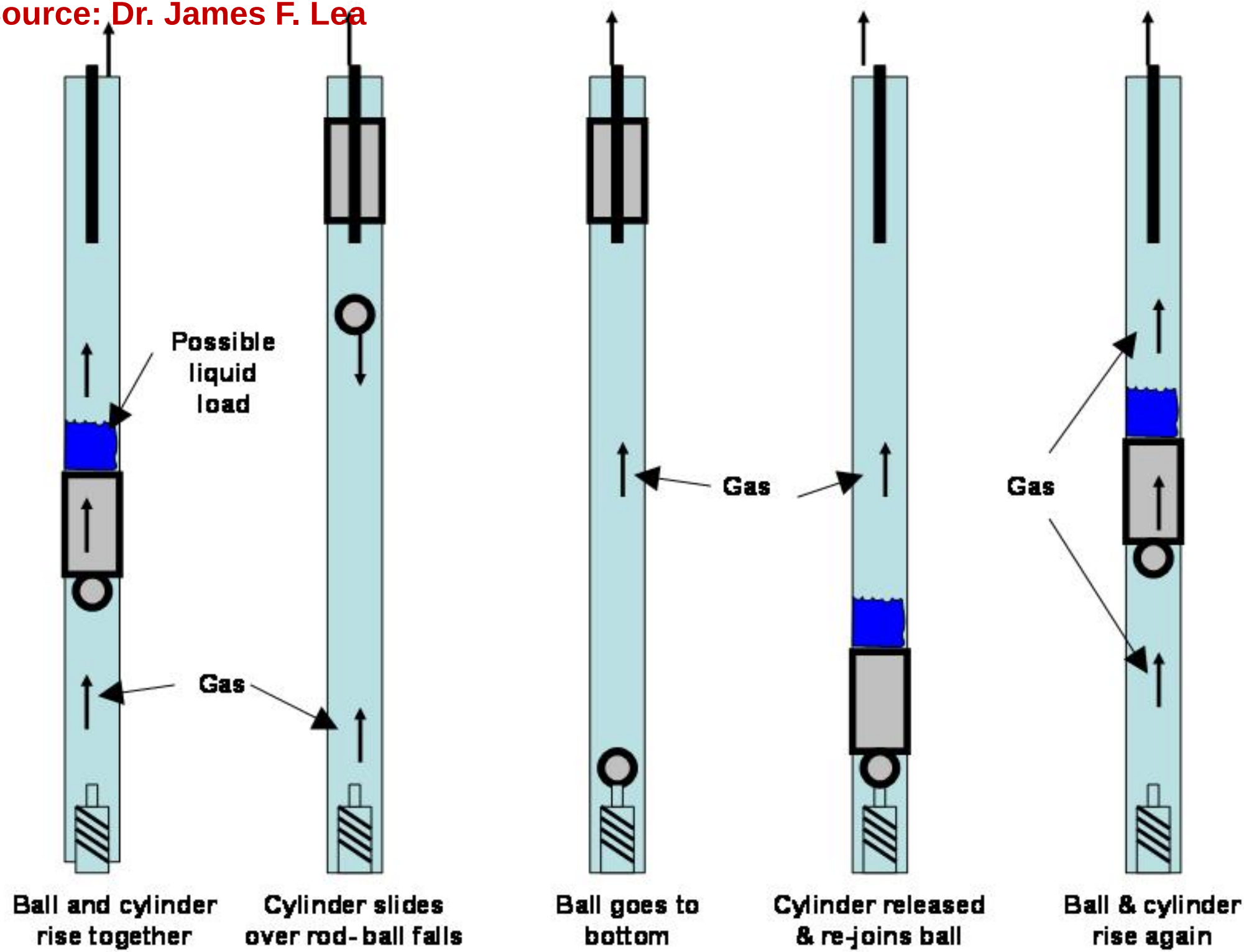
# Plunger Fall Velocity Impacted By:

9. Wellbore Deviation – more than 20 degrees of deviation impacts plunger fall velocity
   a. Padded Plungers Faster due to Loss of Seal
   b. Solid Plungers Slower due to Increased Friction
10. Gas Flow Rate Into The Tubing – gas flow into tubing reduces plunger fall velocity
11. Pressure or Density of Gas
   a. High Pressure and plunger fall is Slow
   b. Low Pressure and plunger fall is Fast
12. Liquids increase density – plunger falls slow
   a. Surfactant lightens gradient and plunger falls faster, but more time may be required
   b. High pressure also causes plunger to fall more slowly through liquid

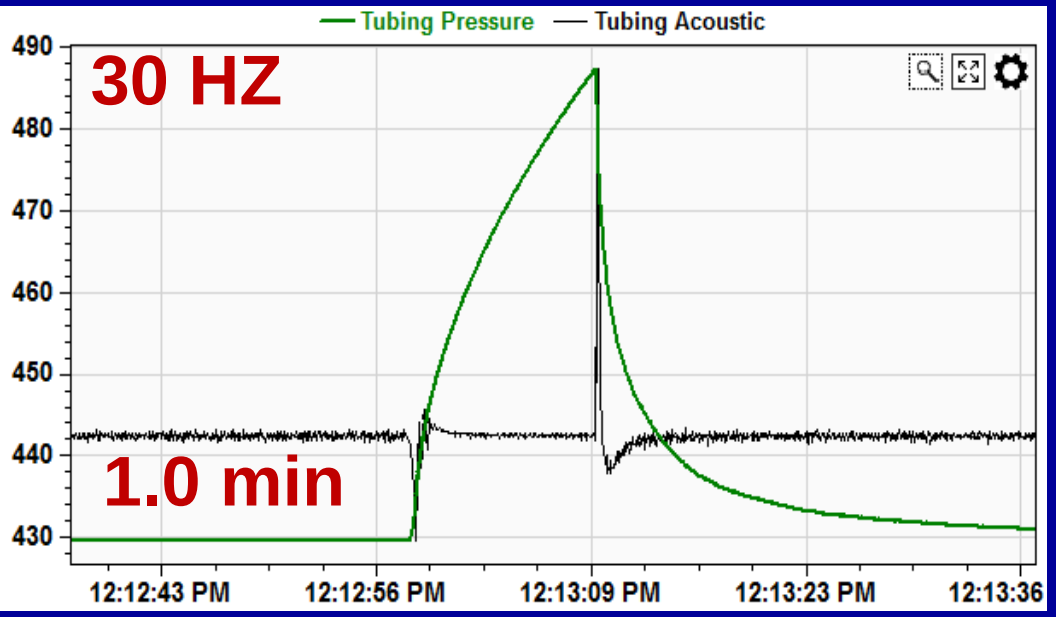
# By-pass and 2 Piece Plungers

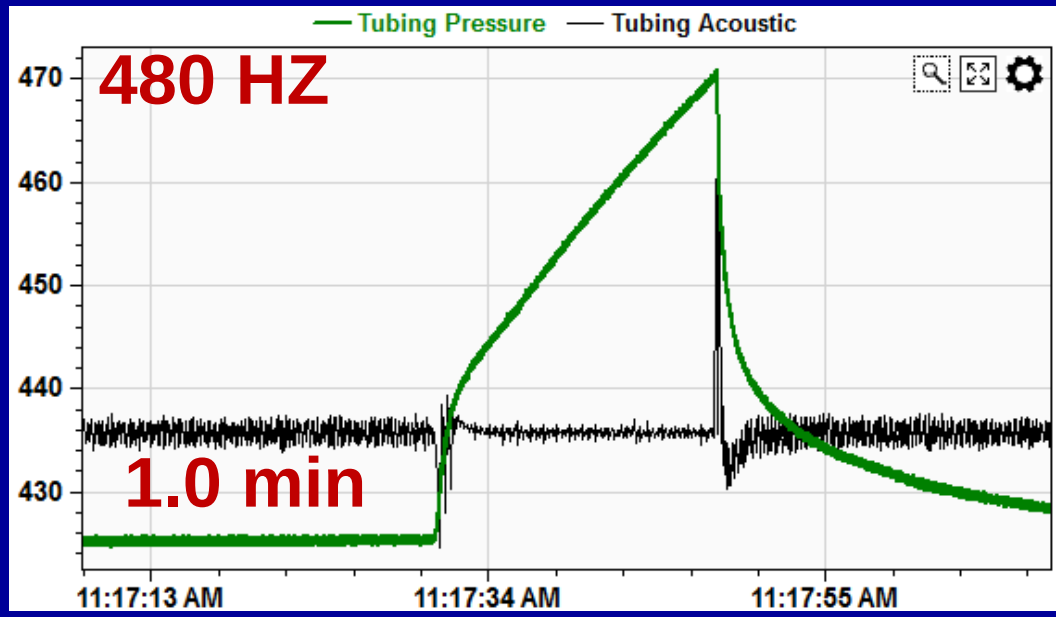
1. Plungers with gas bypass ~ fall very fast
   a) Bypass may close
   b) Cylinder may catch ball, before bottom
   c) Heavy Plungers can hit bottom hard and cause damage
   d) Impact of plunger at top/bottom require Liquid to cushion/absorb energy
2. Benefits of Fast Fall against flow
   a) Many cycles per day possible
   b) Able to lift high liquid rates
   c) Maintain Low FBHP (no shut-in required)

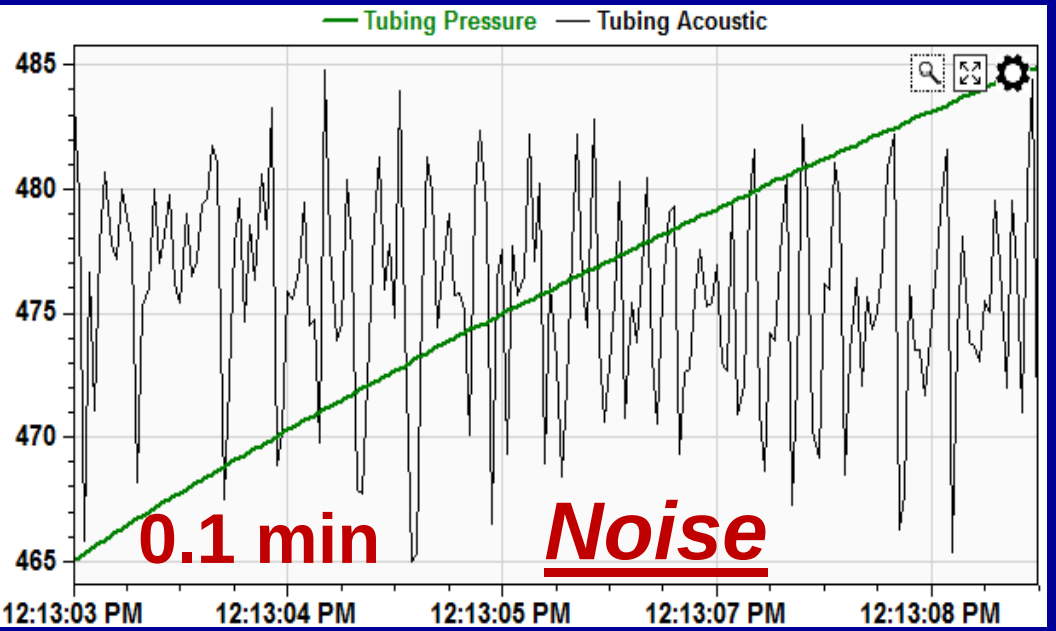
Source: Dr. James F. Lea

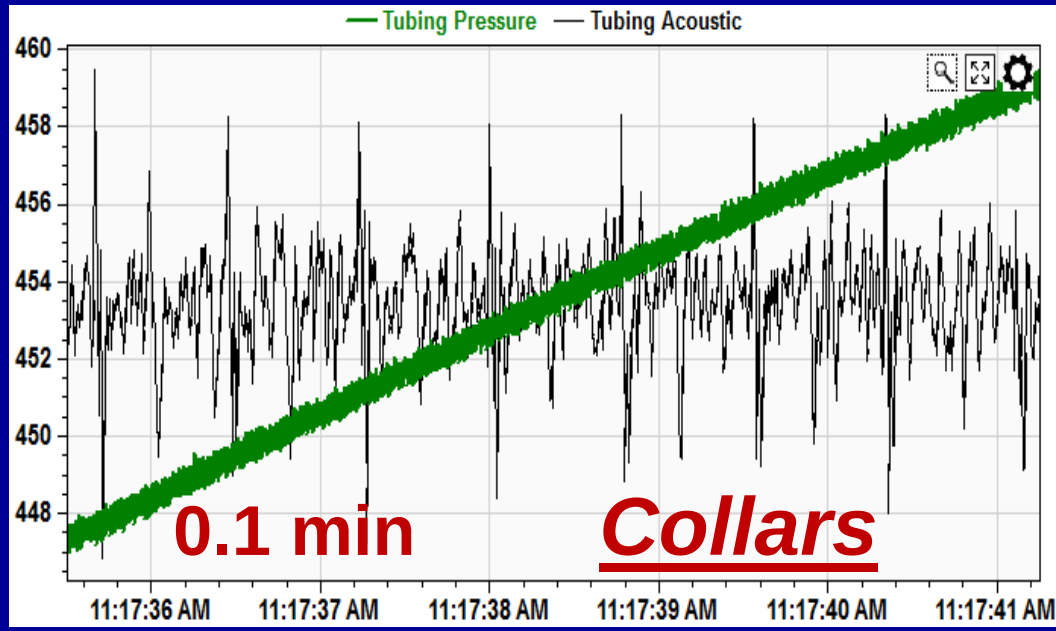


# Data Collection – for Fast Falling Plunger
# 30 HZ "Noise" @ 480 HZ Becomes Data



Define Cycle | Cycle Limits | Plunger Fall | Gas Properties

Selection: 0.983 min

— Tubing Pressure — Tubing Acoustic

Sleeve Only
3000 Ft/Min

Sleeve+Ball
400 Ft/Min

@ 50th Joint
Sleeve caught
the ball

288 286 284 282 280 278 276 274 272

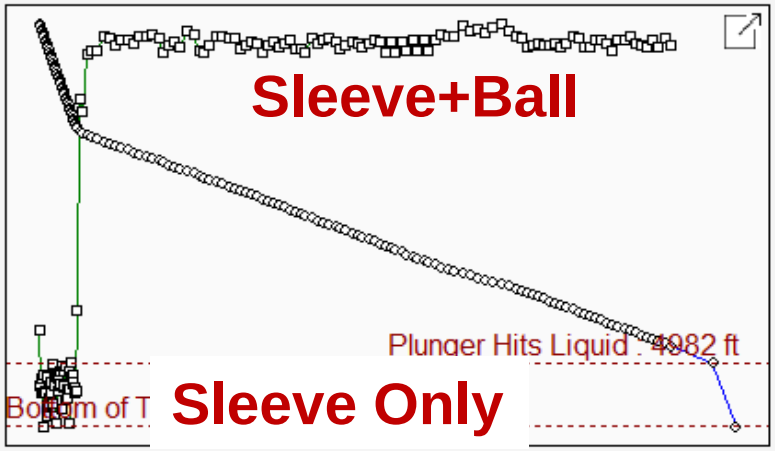
01:04:27 PM 01:04:37 PM 01:04:48 PM 01:04:58 PM 01:05:08 PM 01:05:19 P

Elapsed Time

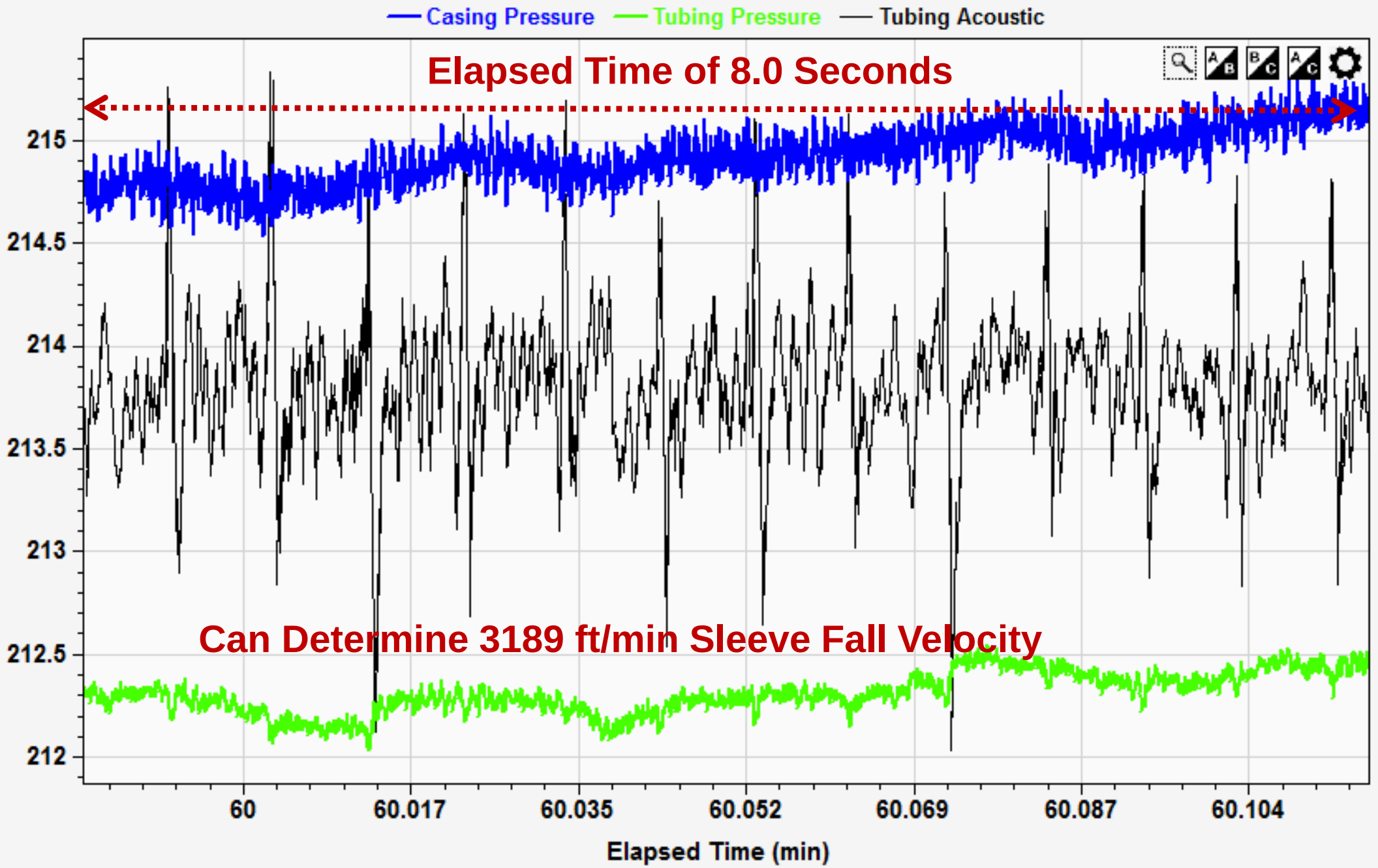
Cursor 27 min | Add Collar | Auto Select | Remove All

| # | Time (clock) | Velocity (ft/min) | Depth (ft) |
|---|---|---|---|
| C49 | 12:37:57 PM | -2931.52 | 1526.22 |
| C50 | 12:37:58 PM | -2342.15 | 1557.37 |
| C51 | 12:38:01 PM | -791.74 | 1588.52 |
| C52 | 12:38:03 PM | -888.16 | 1619.66 |

Average Plunger Vel. (gas): **-1215.49 ft/min** Average Jts/min (gas): **39.024**



# Zoom in to See Sleeve Fall Fast (480 HZ)



# 2-Piece Plunger Performance

- Field data shows 2-piece plunger fall velocity can be measured using acoustic plunger tracking techniques
- Need to use High Speed Data Acquisition (480 HZ)
- Software improved visualization displays 100 echoes per minute at reasonable scale to determine plunger velocity
- 2-piece plunger
  - Fell 2200 ft/min against flow,
  - Fell against 3600 ft/min no flow
  - Sleeve caught the ball prior to reaching the BSA
- Common problems are: 1) broken plungers, 2) damaged BSAs and 3) loaded wells due to sleeve falling off rod

# Optimize Plunger in Well

- Published fall velocity for a plunger type are NOT accurate, because fall velocity is significantly impacted by gas density.
- Using Measured Plunger Fall Velocity with the Model to Predict Plunger Fall Velocity at other P & T.
- Changing the Plunger Cycle Impacts Operating Pressure, Model Calculates Velocity at New P & T.
- Each plunger type has its own Performance Coefficient
- When changes to the well cycle impact the operating pressure, use model to determine the change in time required for the plunger to fall to bottom during shut-in.

# Conclusions

- All plungers have faster fall velocity at low pressure vs slower fall velocity at high pressure (Gas Density).
- Gas Density and $C$ are used to Predict Plunger Fall Velocity through Gas at any P & T in the Tubing
- BUT, Plunger Velocity Relative to the Tubing Changes as the Upward Velocity of the Gas Changes – When Gas Velocities are Slow
- Gas Flow Impact on Plunger Fall Velocity is Negligible when Gas Flow is Turbulent
- Plunger Fall Velocity Directly Impacted when Gas Flow is Laminar when Gas Flow Rates are Slow