Optimizing Industrial Productivity With Improved Metrology

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Outline:

- **Background**
- **Select "Flow" as a "Worst Case (Most Difficult)" Measurement Area**
- **Select Specific Type of Flow Meter – Liquid Turbines**
- **Describe and Sketch Conventional "Best Practice" for Liquid Turbine Meters**
- **Describe and Sketch a Sequence of "Improvements" on Best Practice now available via *"Modern Metrology"***
- **Conclusions**

Background:

Older Industrial *"Batch"* Process Technology has evolved into newer *"Continuous"* Process Technology because *"Continuous" is more productive.*

Continuous Productivity **is only *optimized* if it is properly *controlled*, and it is only properly controlled if it is properly (and accurately!!) *measured*.**

Currently available improvements in Modern Metrology **now offer *reduced measurement uncertainties and (very!) wide rangeabilities* for *optimizing continuous industrial productivity.***

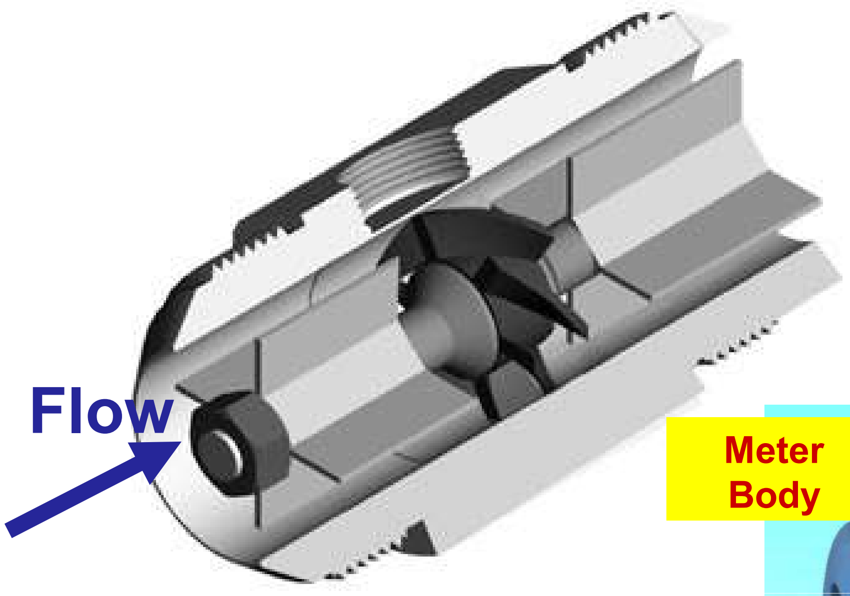
Choose Flow Measurement Example:

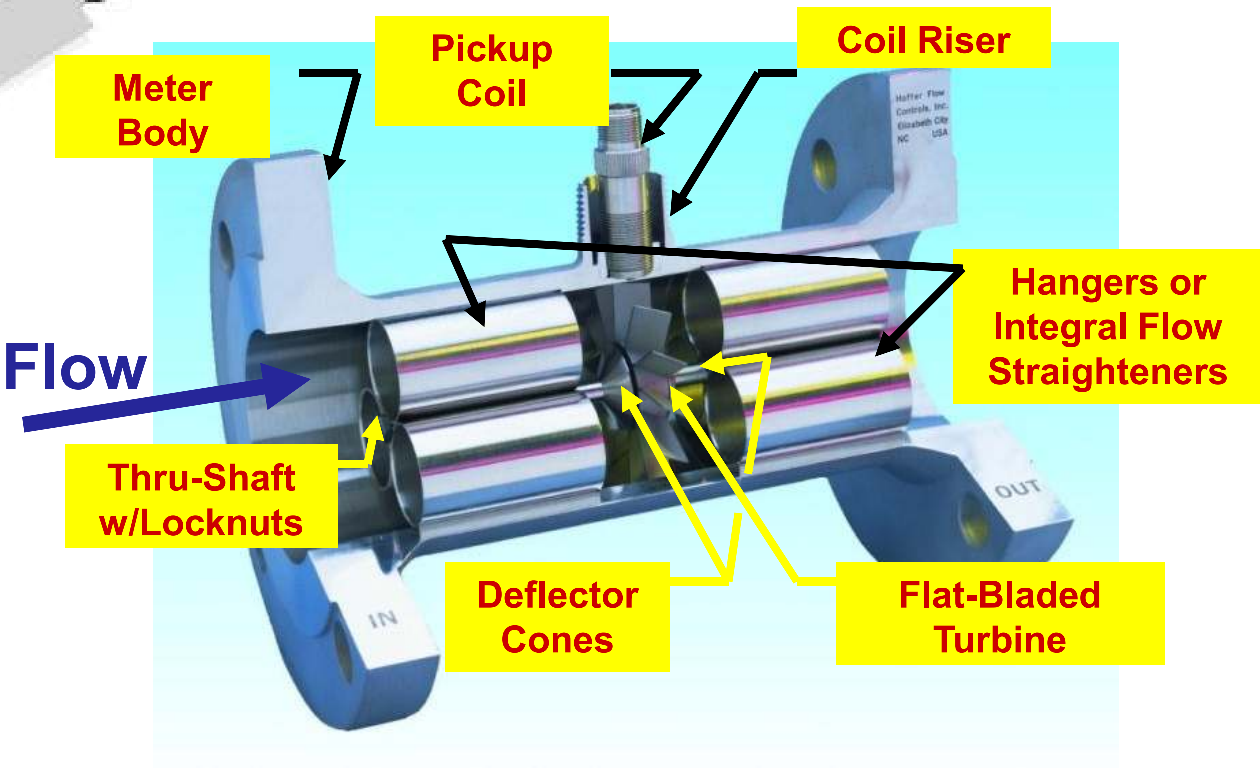
Fluid Flow Rate Measurement is a *"Worst Case"* because it is :

- **the most *difficult* of the 8 most prevalent industrial process measurements (length, time, temp, press, mass/weight, volts, frequency, flow….), and is**
- **a "rate" measurement (i.e., fluid volume or mass per time) that *has no "identity" standard!***

….both of which (I believe) make "flow" a good example as a "difficult", "worst case" measurement area to show the benefits of *"Modern Metrology"* to improve industrial "control" to, in turn, optimize industrial productivity.

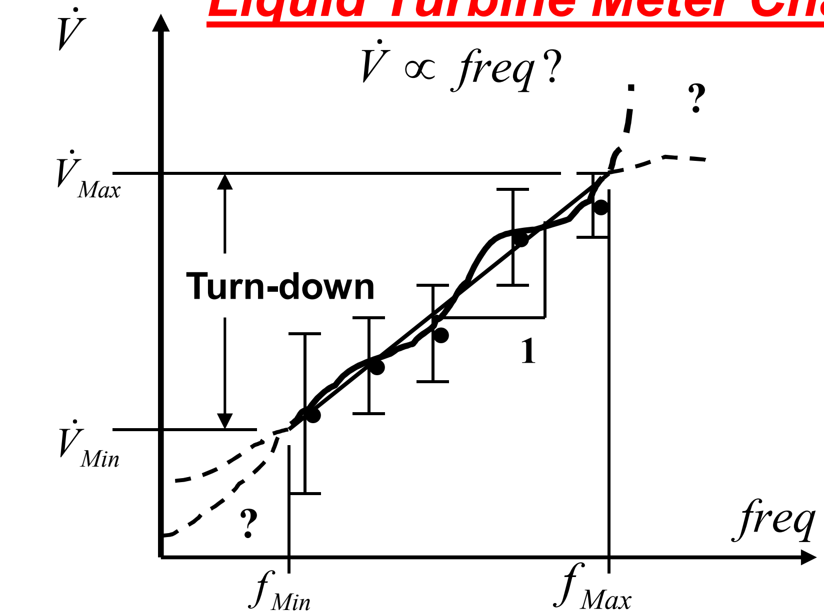
Select "Meter" Example: Liquid Flow Turbine Meters:



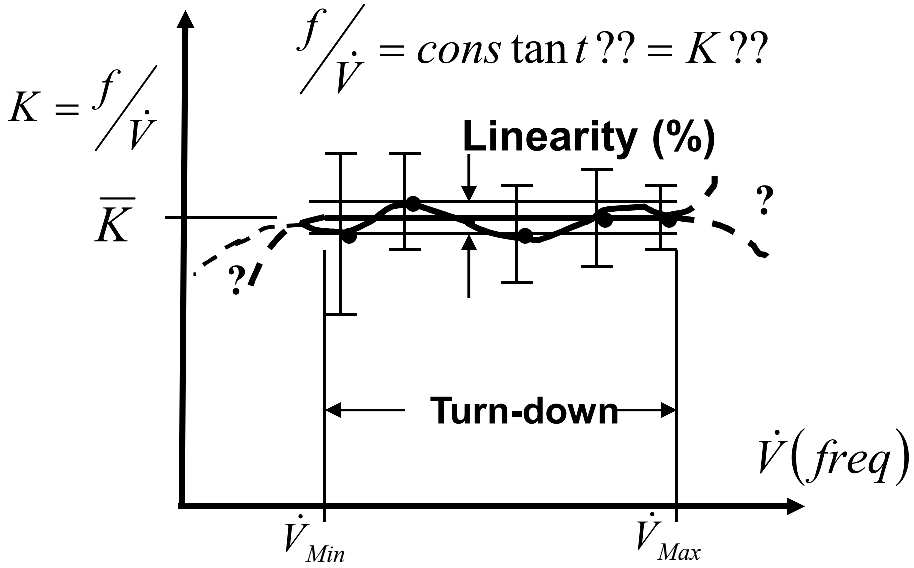


…uncertainties are 0.25-0.5% over 10-15:1 "Turndown"

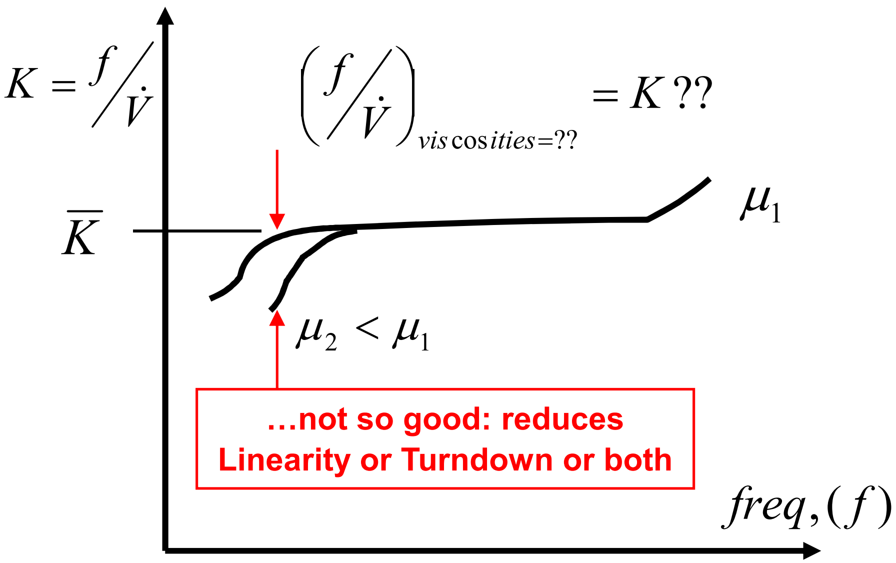
Liquid Turbine Meter Characterizations ~ 60 year evolution:



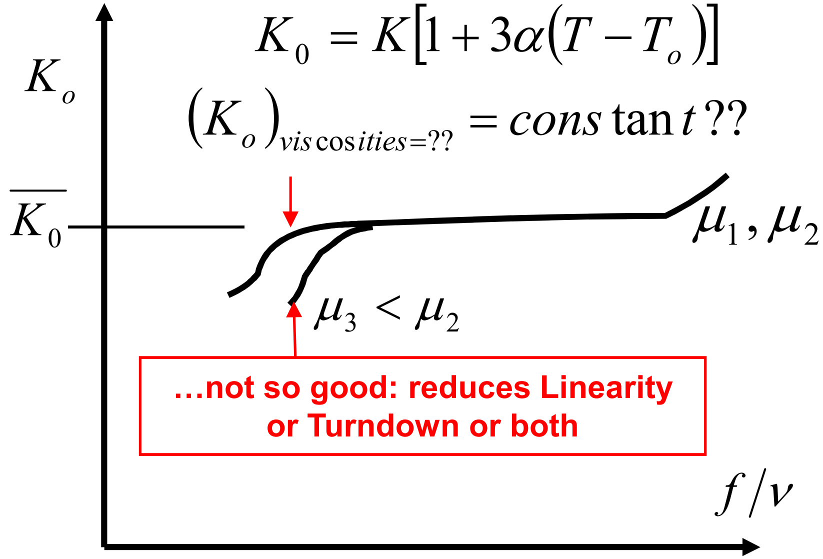
Initial Characterization



"Improved" Characterization



More "Improved"



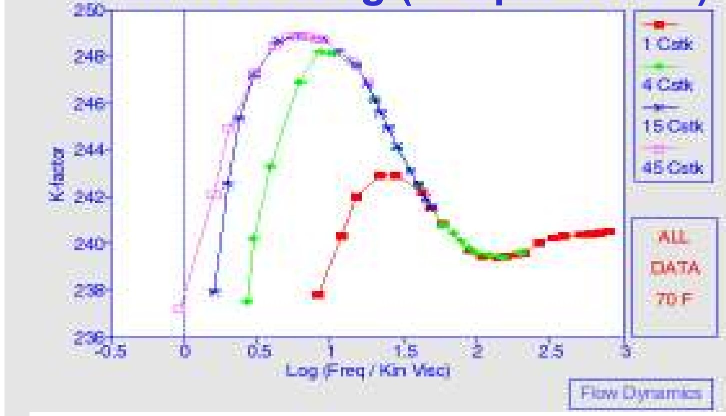
Yet "More Improved" - "UVC Curve"

Data →

Different Viscosities are handled “better” by plotting

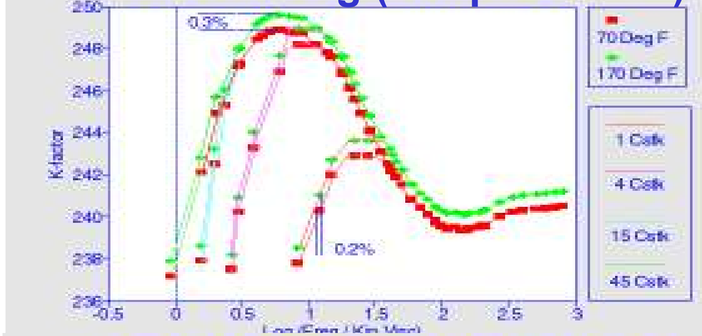
K versus Freq/Kin Visc

K-Factor vs. Log (Freq/ Kin Visc)



…but different temperatures give

K-Factor vs. Log (Freq/ Kin Visc)



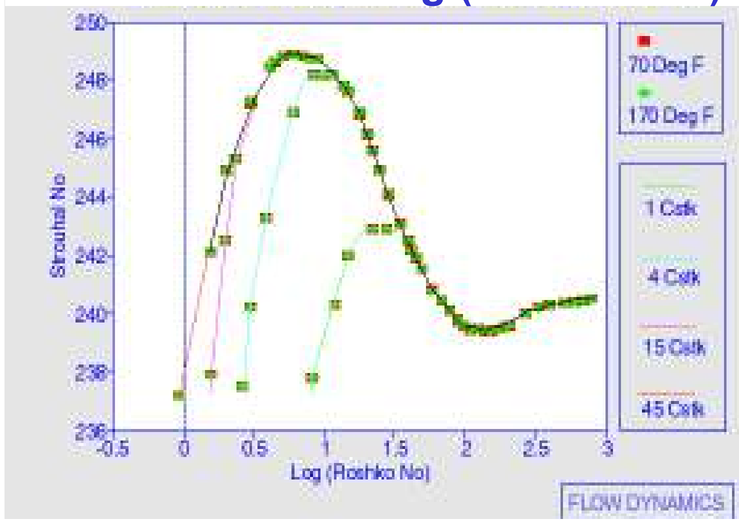
“Complete”

Non-Dimensionalization:

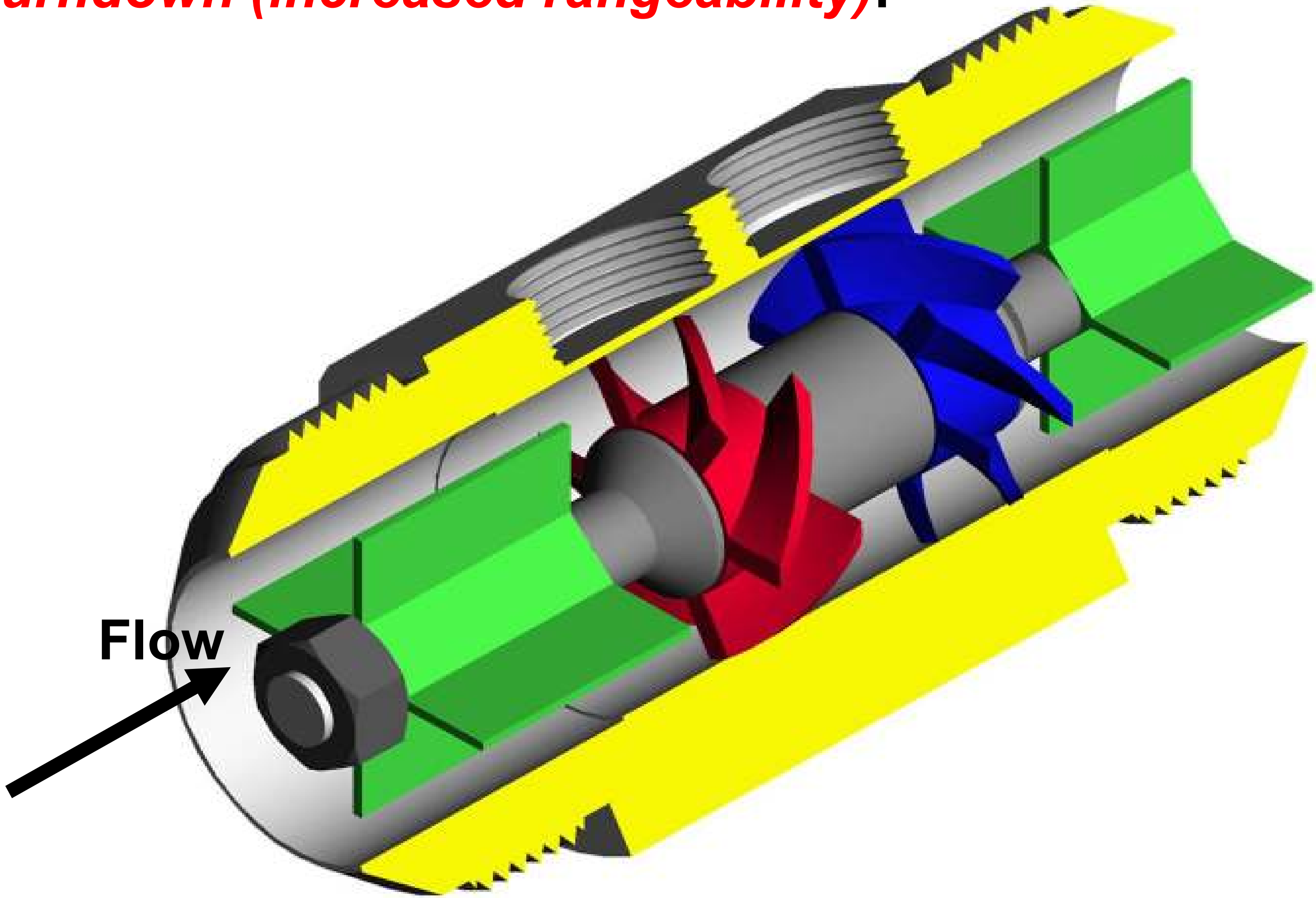
Strouhal – Roshko (St-Ro) Numbers

produces

Strouhal No. vs. Log (Roshko No.)

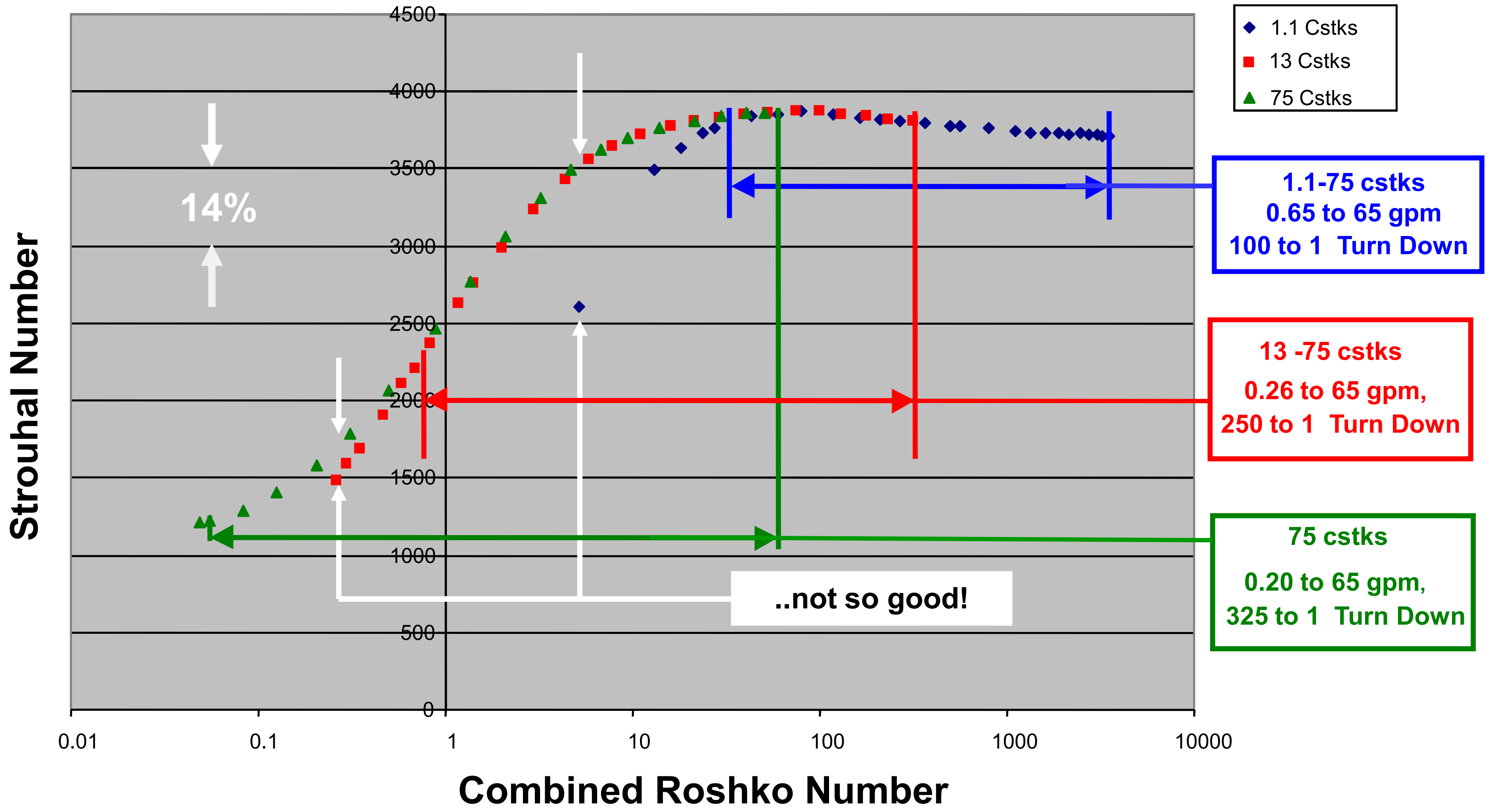


Improved "Dual Rotor" Liquid Flow Turbines have *wider Turndown (increased rangeability)*:



Data ⟶

Strouhal vs Combined Roshko Characterization
(“Combined” means Upstream and Downstream Rotor Frequencies are Added)
EFM16DR



While this characterization is considered “good” for these viscosities and turndowns, what happens for other viscosities between 1 & 75 cstks?

Improvements on “Best Practice” for Flow Measurements:

1. *Improved Dimensionless Characterization*,
2. Using “Correlation” Technique, and
3. Using “Slope – Correction” Technique.

Strouhal vs Combined Roshko Characterization
(“Combined” means Upstream and Downstream Rotor Frequencies are Added)
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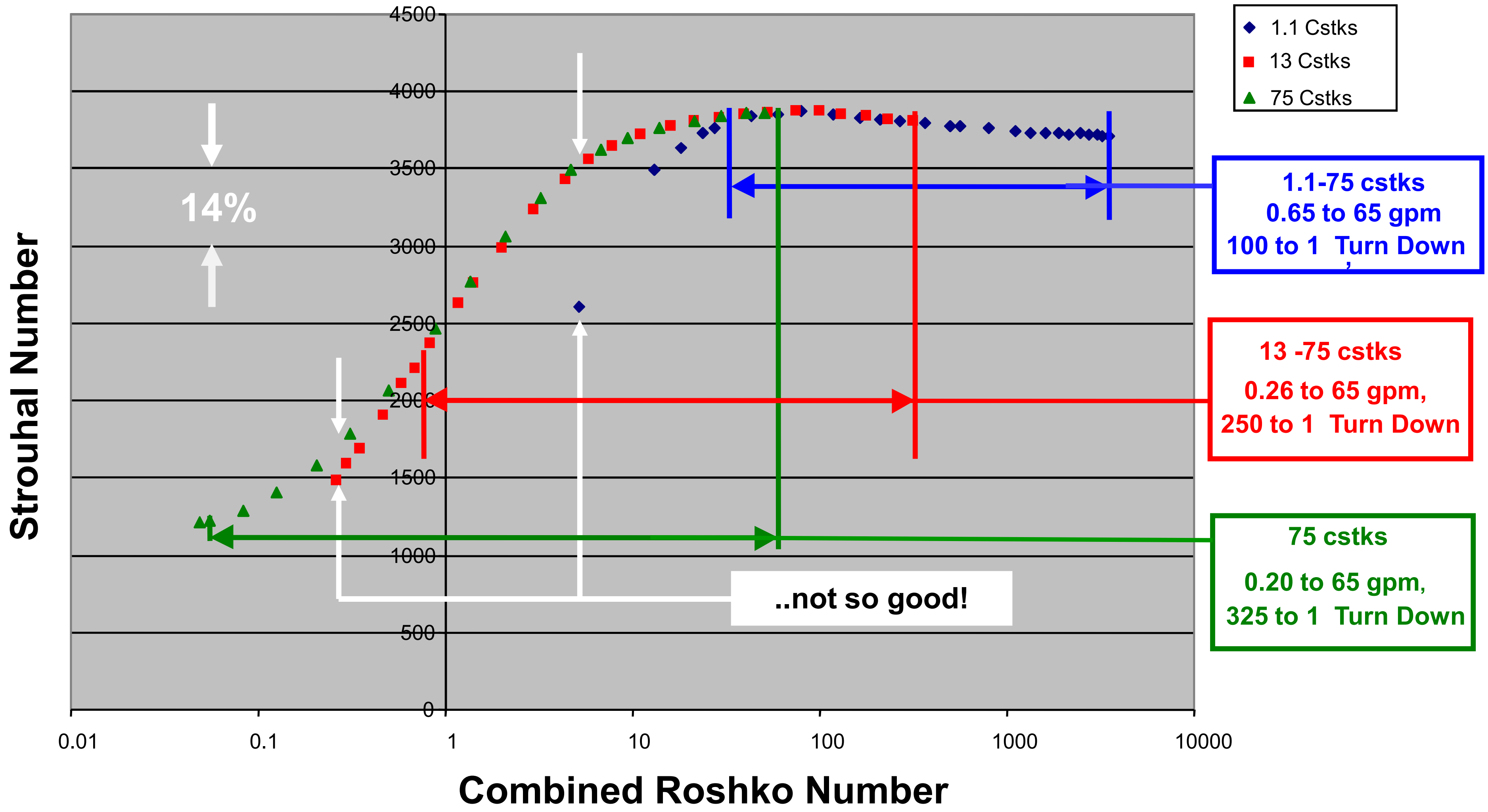
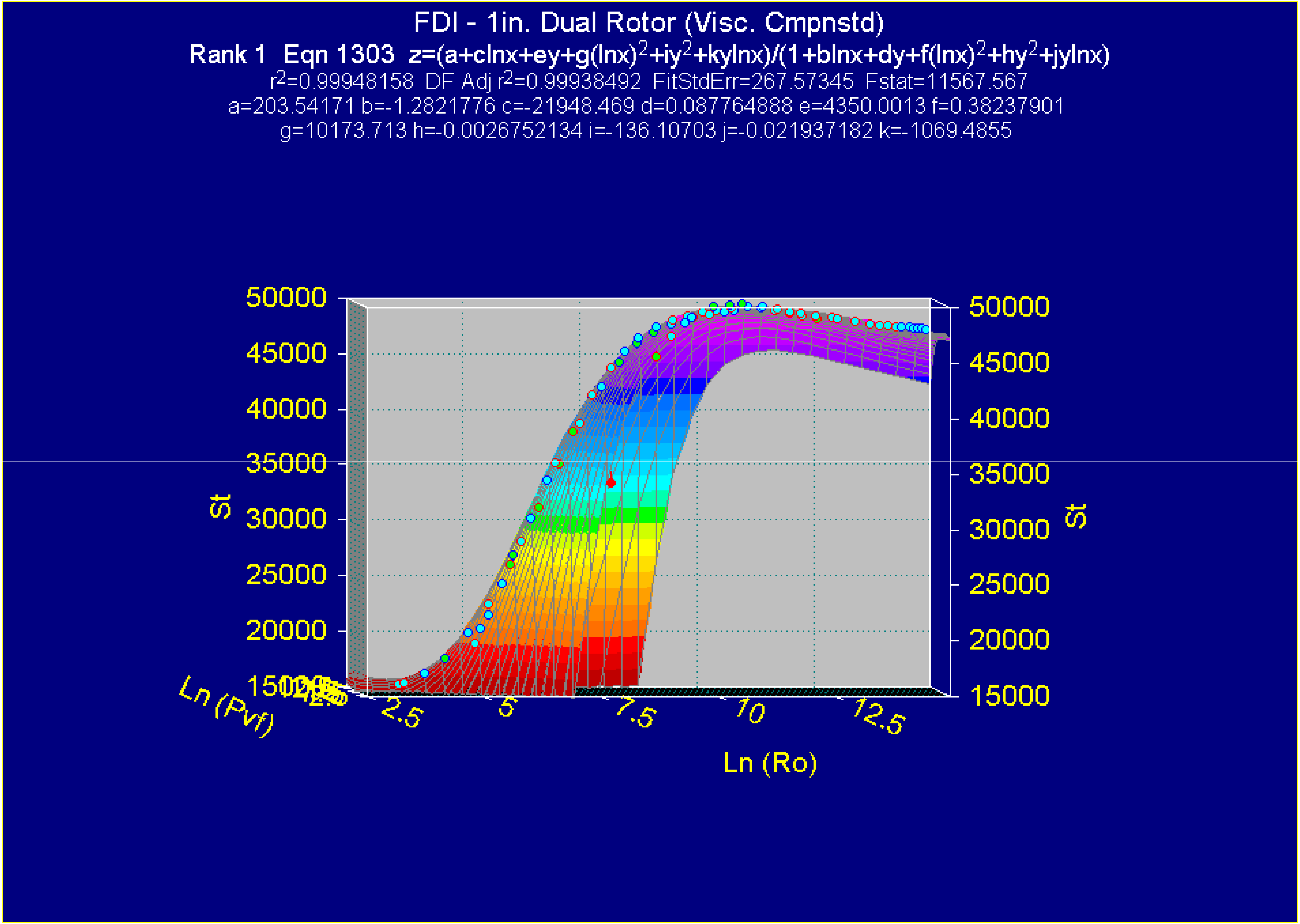
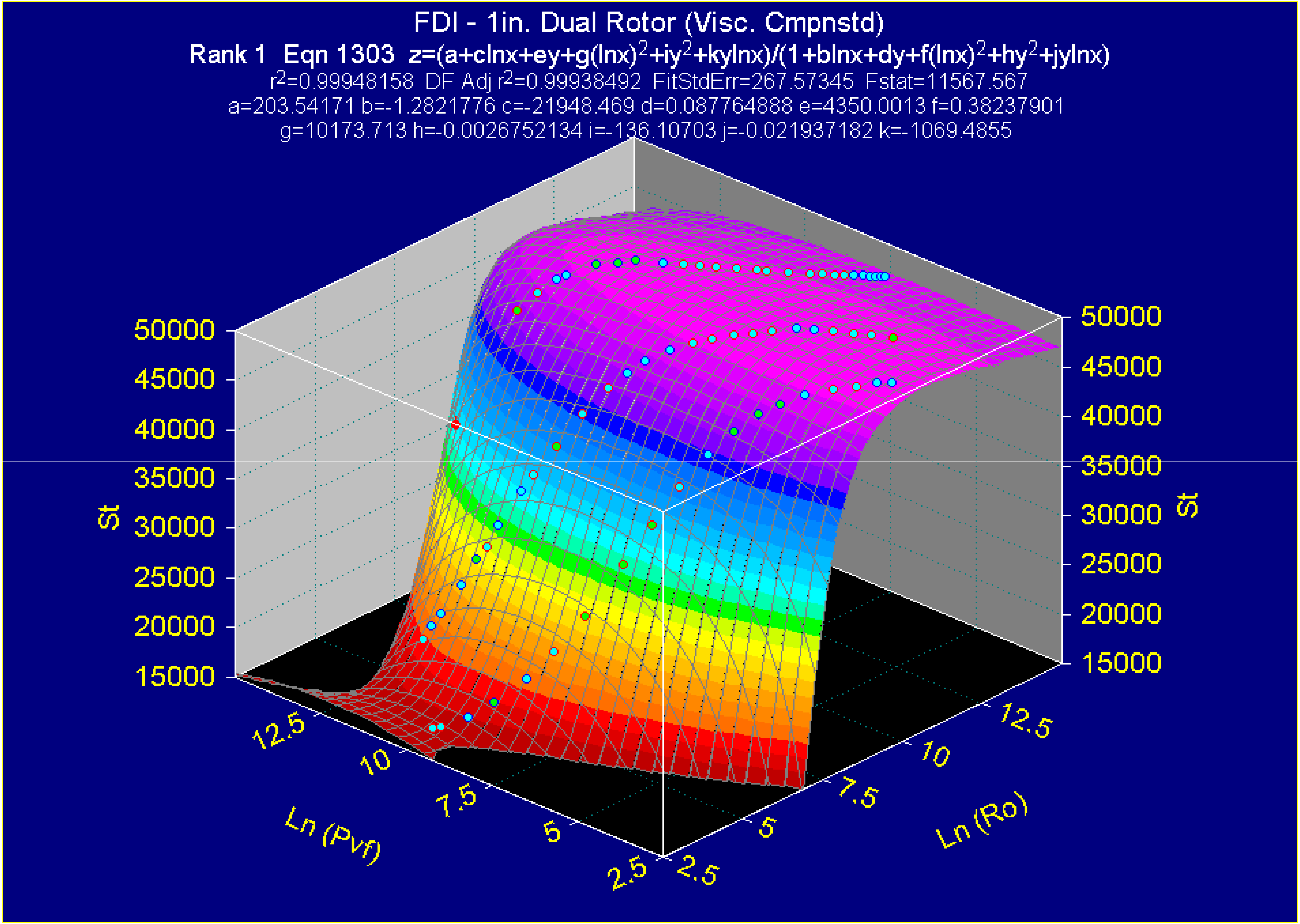


Improvement is to characterize this performance, using a 3rd Dimensionless Parameter; this changes above “Calibration Lines” into a “Calibration Surface”



FDI - 1in. Dual Rotor (Visc. Cmpnstd)
Rank 1 Eqn 1303 z=(a+clnx+ey+g(lnx)^2+iy^2+kylnx)/(1+blnx+dy+f(lnx)^2+hy^2+jylnx)
r^2=0.99948158 DF Adj r^2=0.99938492 FitStdErr=267.57345 Fstat=11567.567
a=203.54171 b=-1.2821776 c=-21948.469 d=0.087764888 e=4350.0013 f=0.38237901
g=10173.713 h=-0.0026752134 i=-136.10703 j=-0.021937182 k=-1069.4855
50000
45000
40000
35000
30000
25000
20000
15000
St
Ln (Pvf)
2.5
5
7.5
10
12.5
Ln (Ro)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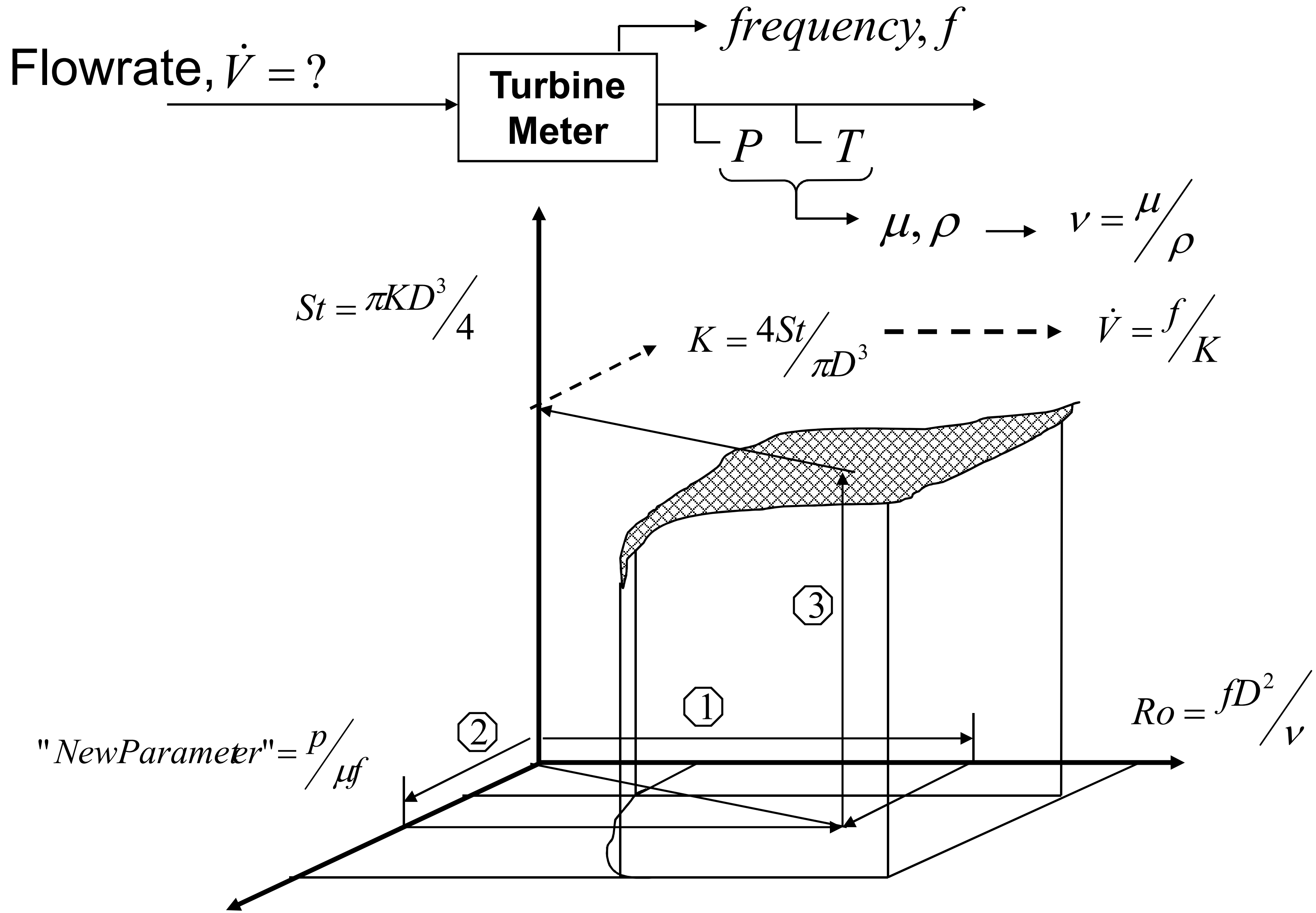
g=10173.713 h=-0.0026752134 i=-136.10703 j=-0.021937182 k=-1069.4855
St
50000
45000
40000
35000
30000
25000
20000
15000
Ln (Pvf)
12.5
10
7.5
5
2.5
Ln (Ro)
2.5
5
7.5
10
12.5

Using the "Calibration Surface":



Strouhal vs Combined Roshko Characterization
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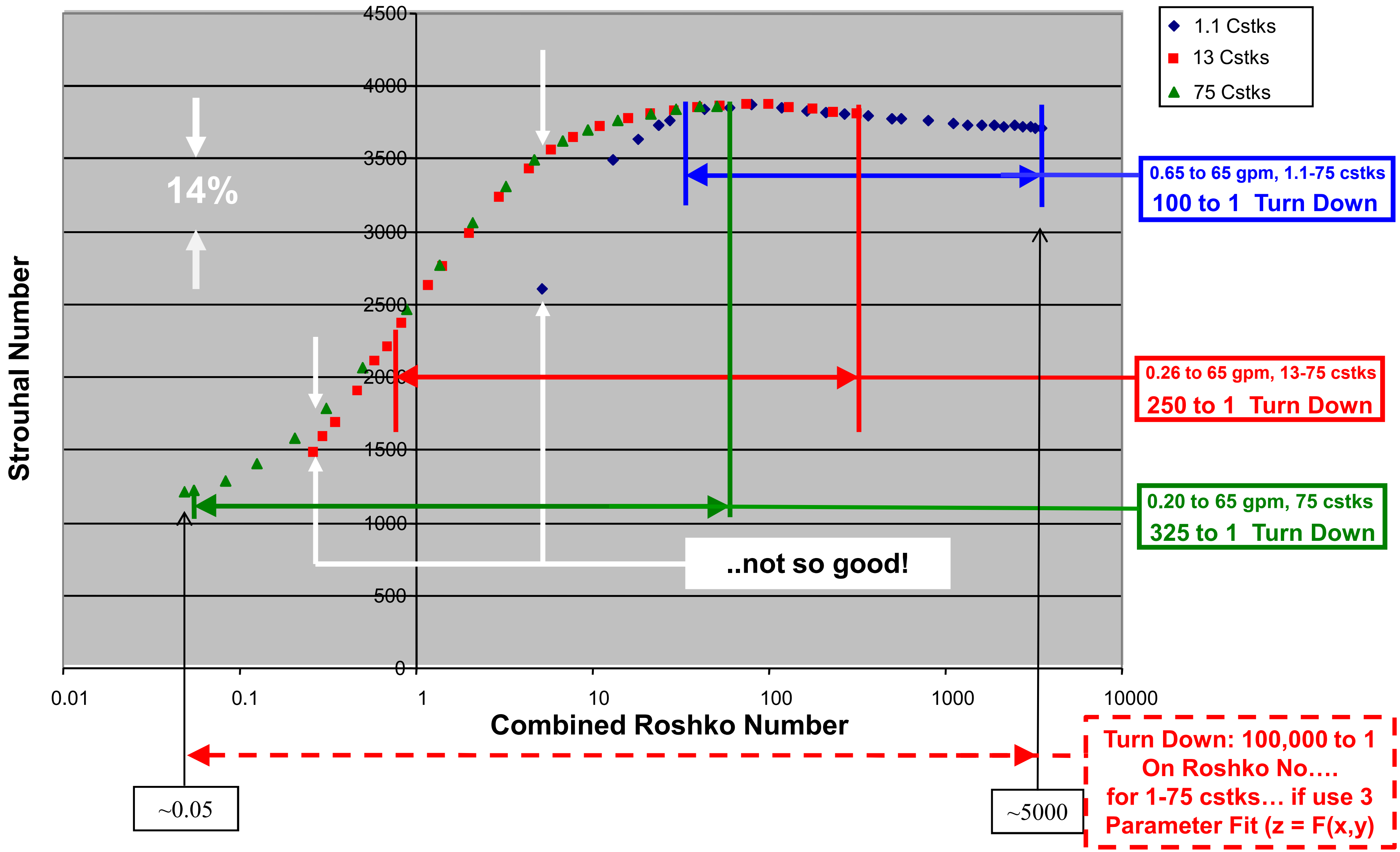


Improvements on "Best Practice" for Flow Measurements:

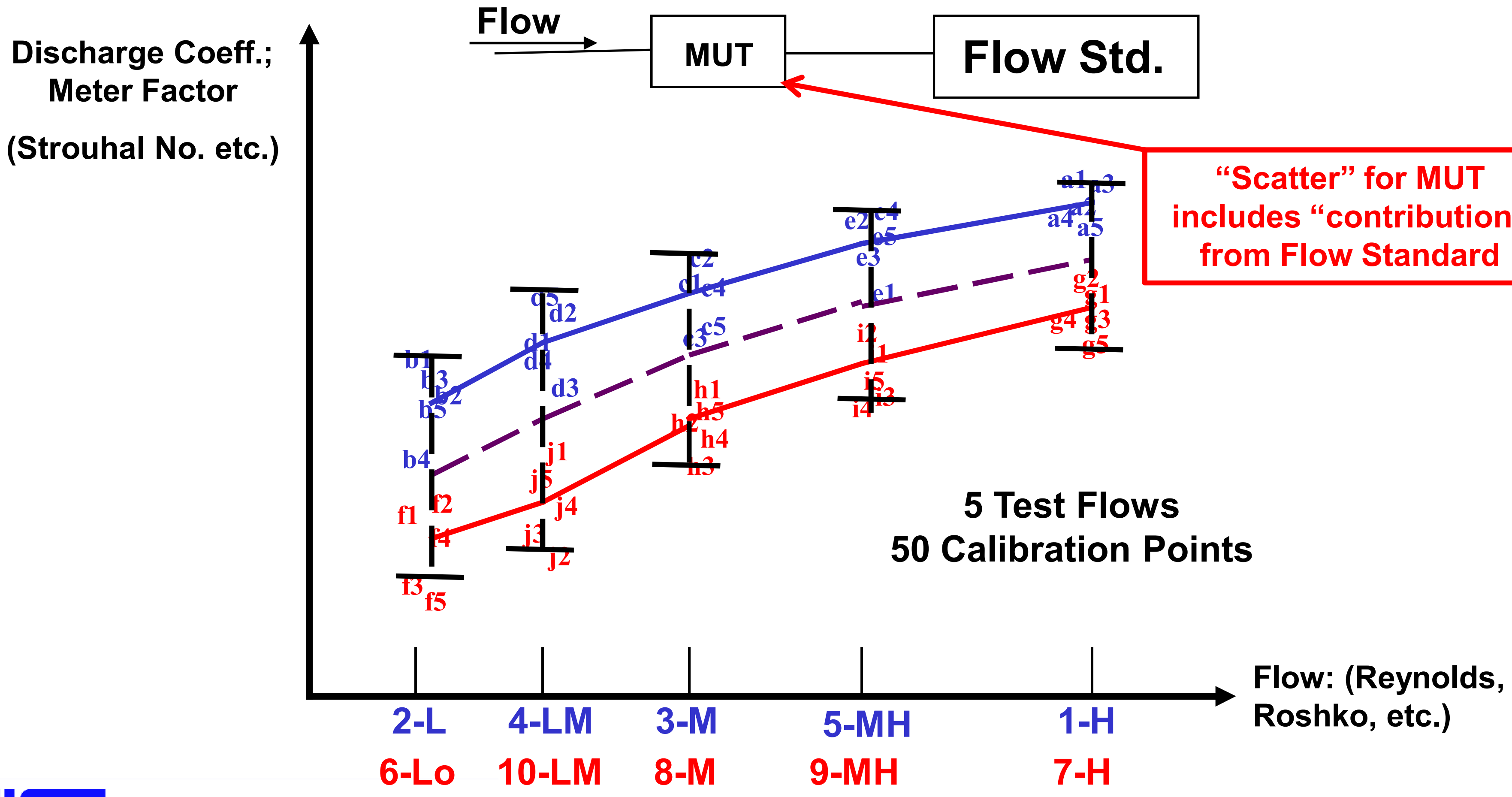
1. **Improved Dimensionless Characterization,**

2. ***Using "Correlation" Technique*, and**

3. **Using "Slope – Correction" Technique.**

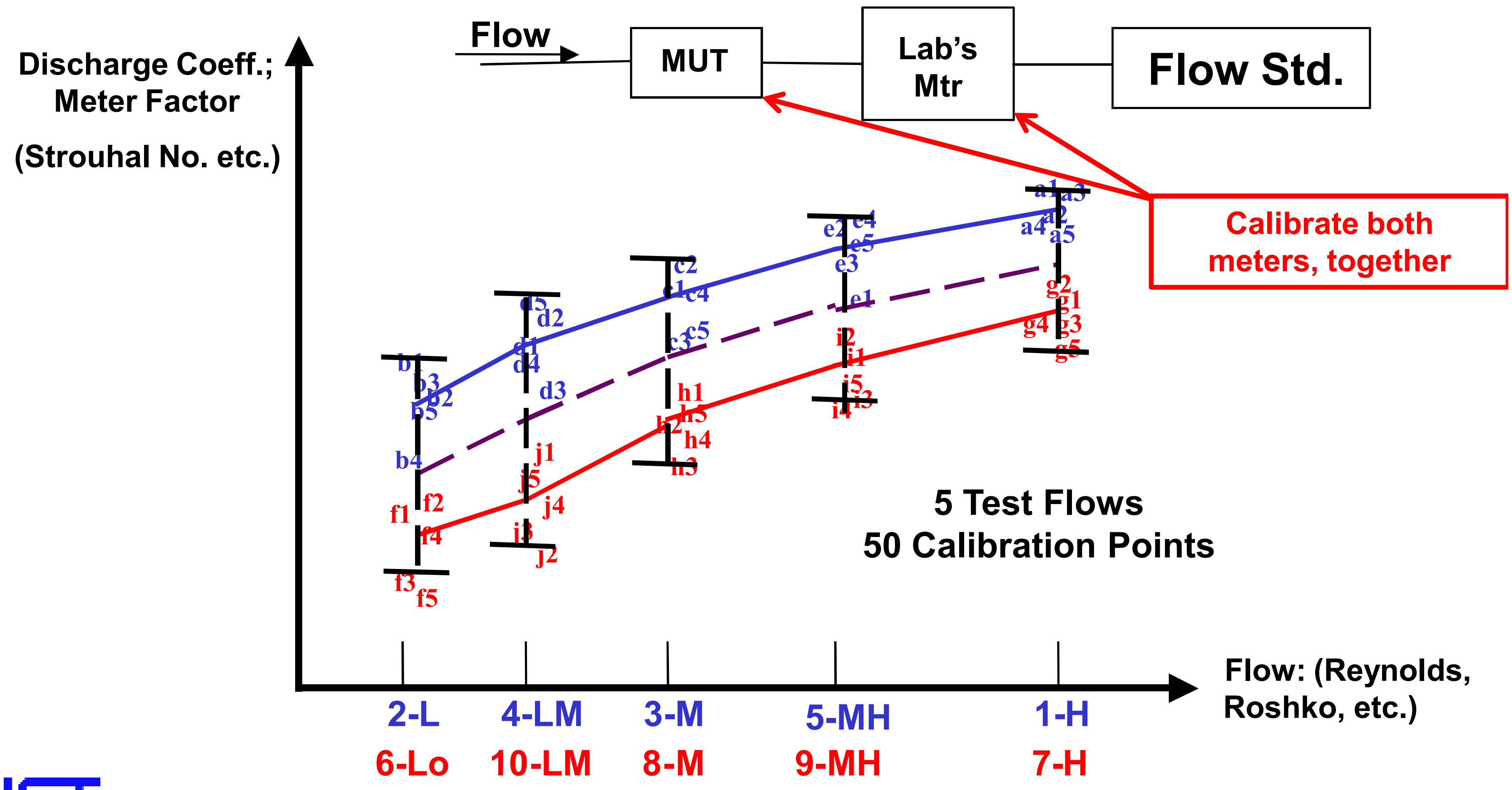
Meter Performance

Sketch of "Best" Practice Calibration Procedure:



Meter Performance

Sketch of Improvement on "Best Practice" Calibration



Data Analysis:

For each calibration test flow have results:

MUT: $\bar{k}_1 = \frac{1}{n}\sum_{i=1}^{n} k_{1i}$; **Lab's Meter:** $\bar{k}_2 = \frac{1}{n}\sum_{i=1}^{n} k_{2i}$

$$s_1 = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(k_{1i} - \bar{k}_1\right)^2\right]^{1/2} \quad ; \quad s_2 = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(k_{2i} - \bar{k}_2\right)^2\right]^{1/2}$$

However, since both meters are calibrated together, can now get *correlation coefficient, r_{12}* as:

$$r_{12} = \frac{\sum_{i=1}^{n}\left(k_{1i} - \bar{k}_1\right)\left(k_{2i} - \bar{k}_2\right)}{\left[\left[\sum_{i=1}^{n}\left(k_{1i} - \bar{k}_1\right)^2\right]\left[\sum_{i=1}^{n}\left(k_{2i} - \bar{k}_2\right)^2\right]\right]^{1/2}}$$

Decomposition of Variance:

Now take total variance for MUT to be sum of parts, as:

$$s^2_{MUT\ (Total)} = s^2_{MUT\ ("Itself")} + s^2_{FlowStd}$$

When "correlated" portion of total variance is taken to be due to the source common to both meters i.e., the "Flow Std", can write:

$$|r_{12}| = s^2_{FlowStdPart} \Big/ s^2_{MUT\ (Total)}$$

$$s_{FlowStdPart} = \pm\sqrt{\left(|r_{12}|\, s^2_{MUT(Total)}\right)}$$

$$s_{MUT(Itself)} = \pm\sqrt{\left(1-|r_{12}|\right) s^2_{MUT(Total)}}$$

This improvement extracts the "Flow Std" part of the MUT variance from the MUT Total, and thereby it enables *a "cleaner" assessment of the "MUT's" uncertainty.*

Improvements on “Best Practice” for Flow Measurements:

1. **Improved Dimensionless Characterization,**

2. **Using “Correlation” Technique, and**

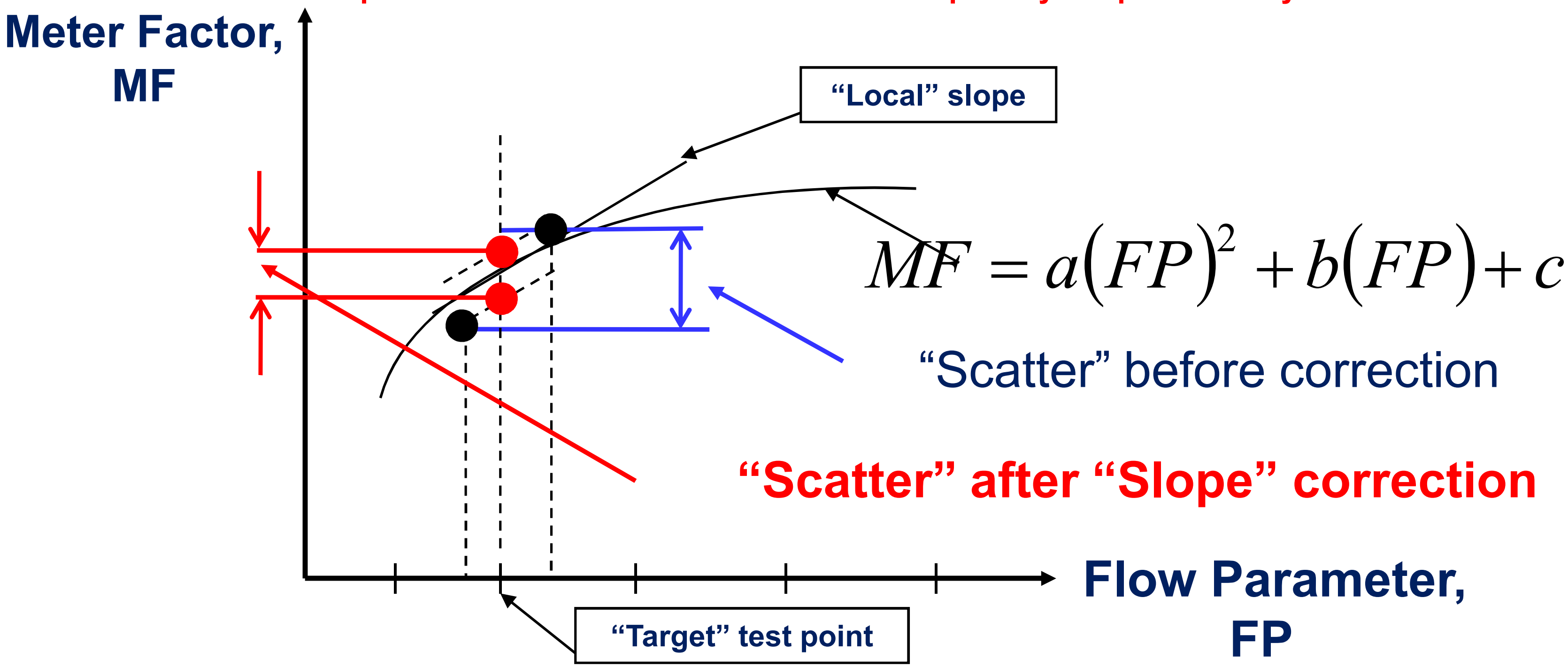
3. ***Using “Slope – Correction” Technique*.**

“Slope – Correction” Method:

Where replicated calibrations are done at “close” but not “exact” test flow conditions, possible corrections to “exact” conditions can be done.

The procedures sketched below can be applied to all data records for each “Target” testpoint in range.

Current potential here of Excel….where need to quantify “Reproducibility”..



This improvement reduces the scatter in calibrations due to “missing” the Target test point and gives: *a “cleaner” assessment of the “MUT’s” uncertainty.*

Conclusions:

1. For the "difficult" measurement area of liquid turbine meter flow, it now seems apparent that *"Modern Metrology"* offers significant improvements *over "Best Practice"* by:

   a. Using *"Improved Parameterization"* for extending turbine meter performance *to (100,000:1)!!,*

   b. Using the *"Correlation Technique"* to improve calibration results, and

   c. Using *"Slope Corrections"* to further improve calibration results…

….to, in turn, improve *"measurement",* for improved *"control",* to, in turn, *"better optimize"* industrial productivity.

2. It only remains now for enlightened industrialists to use this Modern Metrology to *"better measure"* and then to *"better control"* and then to *"better optimize"* their industrial productivity!!